

**A study of the relationship between habitual recreational sporting activity and bone health in adolescents and young adults**

by

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## Abstract

Osteoporosis is a major worldwide public health problem through its association with fragility fracture. Acquisition of peak bone mass (PBM) is an important contributor to later osteoporosis risk and may be modified by lifestyle factors, including habitual recreational sporting activity (HRSA). Previous studies that have considered the relationship between HRSA and bone health have focused on older people, elite sporting activity and used dual energy X-ray absorptiometry as a measure of bone density, rather than calcaneal quantitative ultrasound (cQUS), the outcome measure in this study. This research is important because it considers younger adults, to determine relationships between HRSA and bone health in adolescents and young adults, and the factors that affect their engagement with HRSA.

In this thesis we consider the relationship between HRSA and bone health in three separate studies, reported as four manuscripts: (1) a systematic literature review of studies that considered relationships between non-elite sporting activity and bone health in adolescents and young adults as assessed by calcaneal heel ultrasound; (2) a quantitative study of 452 adolescents and young adults aged 16 to 35 years, who completed a questionnaire detailing sporting activity and relevant lifestyle confounders and underwent heel ultrasound measurements; and (3) nine focus groups of young adults to better understand their knowledge of bone health, the factors that impact it, and the barriers and facilitators to increasing HRSA.

The results of the systematic literature review suggested that the available literature was scarce, with few studies focusing on relationships between HRSA and cQUS in adolescents and young adults. The studies available were too heterogeneous to perform a meta-analysis although, through a narrative synthesis, we reported that all six studies included in the systematic literature review reported significant benefits from weight-bearing HRSA on cQUS outcomes.

In the quantitative study, selected bone cQUS parameters were positively associated with: BMI (SI-stiffness index, BUA-broadband ultrasound attenuation, and T-score); physical activity (SI, SOS-speed of sound, BUA, and T-score); and past HRSA score (SOS only), with weight-bearing sporting activity such as running (SI and SOS), soccer (SI and BUA) and rugby (T-score and Z-score) associated with better bone health. This study also reported that lifetime sport participation typically declined after individuals' mid-teens.

The qualitative study suggested that knowledge of PBM and risk of osteoporotic fracture were limited in the young adult age group. There was a general awareness of the positive and negative impacts of many lifestyle behaviours such as physical activity, diet, tobacco smoking and alcohol consumption on health in general, but not specifically how these impact PBM and good bone health in later life. Furthermore three main barriers to sports participation that emerged were: a) structural (disorientation in a new living environment, facilities, access to healthcare); b) social (financial and time constraints); and c) personal (social pressures and lack of an understanding of why sporting activity matters for bone health). On the other hand, enablers of sports participation included: a) supportive environments; b) access to health checks including support to avoid injury; and c) education to better understand the benefits of HRSA.

In conclusion, HRSA that is of higher impact appears to be associated with more favourable bone health as assessed by heel ultrasound, but few studies have adequately considered these relationships. The quantitative study performed as part of this thesis provides further evidence that high impact HRSA is associated with more favourable bone health in adolescence and early adulthood, and while participation in sport in New Zealand is common until late teens, subsequently HRSA often decreases during the window of PBM acquisition. Knowledge of factors impacting bone health is poor, and barriers and facilitators to HRSA have been identified. Further work to consider how best to address these knowledge and evidence gaps is now warranted, including focus on young school to early adulthood populations to reduce their future fragility fracture risk.

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I would like to thank all those that helped with my journey to return to further study after a long interval spent raising a much loved family.

Understanding the stories behind young people's behaviours and bone health is of special interest to me because of a personal journey. The journey started with my loving parents (Bhikhabhai Lakhubhai Patel and Deviben Patel, both of Indian descent) who emigrated to England from rural India in the 1950's for a better life for their five healthy children. My older sister and I were born later in England. My sister, a winter baby, developed poor bone health and rickets as a toddler whereas I, on the other hand, through maternal education and lifestyle changes, did not develop rickets.

I could not have completed this thesis without the support, dedication and immeasurable knowledge and patience of so many people. Professor Elaine Dennison, your gentle inspiring encouragement has always helped me get through the many highs and lows and to keep me focused on the study. Your immense knowledge and ability to see through the vast amounts of data with clarity was truly amazing. How lucky I am to have had the best supervisor possible to guide me through my journey.

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## **Statement of authorship**

I hereby declare that this thesis is my own work and that all sources quoted, paraphrased or otherwise referred to, have been properly acknowledged in the bibliography.

Although my co-authors assisted and supported my thesis construction, the majority of the work is my own. I designed the studies under the guidance of my supervisors, I fully prepared the ethics applications to both the university and to Health and Disability Ethics Committee (HDEC), including the Māori consultation process for both the quantitative and qualitative studies, the peer-reviewed protocol, recruited the participants, collected the quantitative and qualitative data and performed all the heel ultrasound tests myself; I designed the questionnaire and distributed the online questionnaires through the Qualtrics platform; performed all of the data cleaning and statistical analyses under the supervision of Dr Lisa Woods.

I registered the systematic literature review protocol to Prospero (an international database of prospectively registered systematic reviews in health and social care) and I was the first reviewer for the systematic literature review (under guidance from Dr Hayley Denison) and collaborated internationally with the second reviewer Dr Luke Sammut in Southampton, United Kingdom; Professor Elaine Dennison was the third reviewer for the systematic literature review.

I also led all the focus groups and thematic analysis (under guidance from Dr Hayley Denison) with the focus group transcriptions undertaken by volunteer students at university.

I prepared the manuscripts for publication and fully acknowledge co-authors for assisting and supporting the editing. These manuscripts have been written as individual research papers for Chapters 4, 5, 6 and 7 and have been presented in the individual journals' publishable format in the thesis. The published papers are used in this thesis with permission under the terms of the Creative Commons Attribution License (CC BY).

For Chapters 4, 5, 6 and 7, the manuscripts have been submitted to international journals, therefore there is some repetition throughout the thesis and the table legend numbering applied to the papers. In this thesis, only the necessary minor edits and formatting changes have been applied to those chapters. As the format style submitted is specific to the particular journals (including the referencing style, line

spacing and layout within the individual papers themselves), consistent formatting throughout the thesis was not possible.

In addition, during the time of submission the university has been re-named “*Victoria University of Wellington, Te Herenga Waka*,” therefore in part the original formal name and logo have been presented in this thesis.

## **Publications**

***The following paper publications are part of the thesis (and presented in Chapters 4, 5, 6 and 7):***

- 1. Patel, H., Sammut, L., Denison, H., Teesdale-Spittle, P., & Dennison, E. (2020). The relationship between non-elite sporting activity and calcaneal bone density in adolescents and young adults: A narrative systematic review. Frontiers in Physiology, 11(167). <https://doi.org/10.3389/fphys.2020.00167>*
- 2. Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2020). A cross-sectional study of the relationship between recreational sporting activity and calcaneal bone density in adolescents and young adults. The Physician and Sportsmedicine [under review].*
- 3. Patel, H., Denison, H., Zafar, S., Teesdale-Spittle, P., & Dennison, E. (2020). Knowledge of osteoporosis and lifestyle behaviours impacting peak bone mass: Might we be able to modify behaviour in young adulthood to prevent osteoporosis in later life? OBM Geriatrics, 4(1) [under review]*
- 4. Patel, H., Denison, H., Teesdale-Spittle, P., & Dennison, E. (2020). Understanding the barriers and enablers to sporting activity in relation to bone health: A qualitative narrative study among adolescents and young adults in New Zealand. Journal of Osteoporosis and Physical Activity, 8(220). <https://doi.org/10.35248/2329-9509.20.8.220>*

***The following abstract publications arising from this thesis were presented at International Osteoporosis Foundation meetings (see Appendix):***

- 1. Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2018). Alcohol intake and bone health in New Zealand young adults: Reason for concern? Osteoporosis International, Krakow.*
- 2. Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2019). Bone health in New Zealand young adults: Cause for concern? Osteoporosis International, Sydney.*

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## List of abbreviations

Abbreviation	Definition
aBMD	areal bone mineral density
APHV	age of peak height velocity
BH	bone health
BMC	bone mineral content
BMD	bone mineral density
BMI	body mass index
BONZ	burden of osteoporosis in New Zealand report
BPAQ	bone physical activity questionnaire
BUA	broadband ultrasound attenuation
cQUS	calcaneal quantitative ultrasound
CV	coefficient of variation
DEXA	dual energy x-ray absorptiometry
DXA	dual energy x-ray absorptiometry
ELS	effective load stimulus
ER	oestrogen receptor gene
FRAX	Fracture Risk Assessment Tool
GRF	ground reaction force
HDEC	Health and Disability Ethics Committee
HI	high impact
HR-pQCT	high resolution peripheral quantitative computed tomography
HRSA	habitual recreational sporting activity
HSA	hip structural analysis
ISCD	International Society for Clinical Densitometry
MET	metabolic equivalent of task
MRI	magnetic resonance imaging
MVPA	moderate vigorous physical activity
NOS	Newcastle-Ottawa Scale
NWB	non-weight-bearing

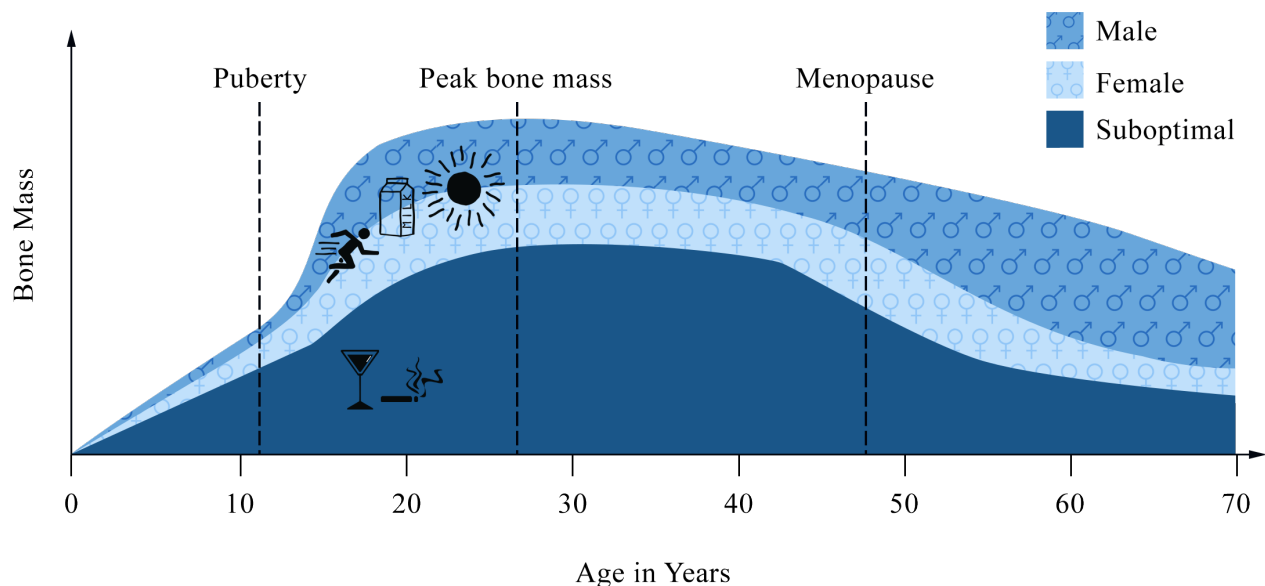
OCP	oral contraceptive pill
OI	osteogenic index
PA	physical activity
PBM	peak bone mass
pBPAQ	past bone physical activity questionnaire (HRSA history)
pQCT	peripheral quantitative computed tomography
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO	International Prospective Register of Systematic Reviews
RED-S	relative energy deficient-syndrome
RSA	recreational sporting activity
QCT	quantitative computed tomography
QUI	quantitative ultrasound index
QUS	quantitative ultrasound
SD	standard deviation
SI	stiffness index calculated from the SOS and BUA
SOS	speed of sound
SPSS	Statistical Package for the Social Sciences
STROBE	Strengthening the Reporting of Observational studies in Epidemiology
T-score	standardised BMD as compared to sex-matched young adults
TBS	trabecular bone score
TGF	transforming growth factor
VDR	vitamin D receptor
VOS	velocity of sound
VPA	vigorous physical activity
VUW	Victoria University of Wellington
WB	weight-bearing
WBV	whole body vibration
WBPA	weight-bearing physical activity
WHO	World Health Organization
Z-score	standardised BMD as compared to age and sex-matched individuals

## 1 Chapter 1: Introduction, rationale, aims and methods

### 1.1 Introduction: why the topic is important

Osteoporosis is a major international public health problem through its association with fragility fracture (Cole et al., 2008). Fragility fractures not only carry a huge societal and financial burden, but at an individual level they reduce quality of life, increases morbidity and mortality. World-wide, osteoporosis affects approximately one third of women and one fifth of men aged over 50 (Cooper & Ferrari, 2019). The Burden of Osteoporosis in New Zealand 2007-2020 report indicates that in New Zealand, there is an osteoporotic fracture rate of one fracture in every four and half minutes (Brown et al., 2007).

Osteoporosis is often described as a disease that occurs in later life, more often in females, and preventative methods thus often focus on older people (Hui et al., 1990; Tan et al., 2014). However, peak bone mass (PBM) is a major contributor to osteoporosis risk later in life (Rizzoli et al., 2010). Bone mass increases up to and during late adolescence, peaks in an individual's twenties and thirties, and decreases from around the age of 45 in both men and women, as shown in Figure 1 (Cooper & Ferrari, 2019; Lindgren et al., 2019; Weaver et al., 2016). During adolescence, growth of 25% of the final PBM occurs: the exact timing appears to vary with skeletal site and with sex (Heaney et al., 2000; Kovacs, 2013). A greater PBM is very important for later in life and can be an important way to reduce the risk of osteoporotic fracture (Hernandez et al., 2003).



**Figure 1:** Bone mass across the lifespan with optimal and suboptimal lifestyle choices. Adapted from Cooper and Ferrari (2019); Weaver et al. (2016)

Genetic and environmental factors affect PBM acquisition; lifestyle factors are important contributors to the acquisition of optimal PBM and to an individual's risk of osteoporosis (Hernandez et al., 2003).

In a systematic review, modifiable lifestyle factors potentially affecting PBM were graded; factors considered were the effect of dietary factors, alcohol, smoking, contraceptive intake and physical activity (PA) on bone mass and strength development (Weaver et al., 2016). This systematic review assigned PA, along with calcium intake, as the most beneficial to bone mass and density, especially during the growing years (Weaver et al., 2016).

## **1.2 Why this study topic was selected**

This topic was chosen as there is little existing literature regarding the relationship between habitual recreational sporting activity (HRSA) bone health, as assessed through calcaneal quantitative ultrasound (cQUS) amongst existing literature in young people. How HRSA relates to PA is discussed below. Available studies in young people often focused on the effect of elite sports on bone health assessed at different skeletal sites using dual energy x-ray absorptiometry (DXA), peripheral computed quantitative tomography (pQCT) or hip structural analysis (HSA) (Deere et al., 2012a; McVeigh et al., 2019).

### **1.2.1 Defining the levels of activity**

In this thesis, the term “HRSA” has been defined by the author to mean a form of PA that young people define as a sport or exercise that is incorporated in their daily lives, and performed regularly for a sustained period of their lives. HRSA includes team sports involving competition but not at a professional elite level. There are a multitude of terms used interchangeably to describe the many forms of PA and exercise, leading to confusion and ambiguity; therefore the term HRSA has been used in this thesis as a collective term for sports and exercise (Caspersen et al., 1985). HRSA does not include passive recreation such as gardening and housework (Sport New Zealand, 2009). This is consistent with other definitions in the literature; recently a “recreational athlete” was defined as a physically active participant in sport at an amateur, masters or club level who wants to remain physically fit (Wilson-Barnes et al., 2020). HRSA is used throughout the thesis, but when reporting previous studies that have used other terms such as PA, this is reported where appropriate (and for clarity includes the terms “sporting activity”, “sporting physical activity”, “recreational sporting activity”, “habitual sport” and “exercise”).



However, in the systematic literature review, the term “non-elite sports” is defined as participation in “non-elite sporting activity” performed at school or leisure time as an organised or regular activity which is either self-reported or measured objectively, excluding that performed at an international or professional level. For the purpose of the systematic literature review, only specific non-elite sports were assessed, therefore any participation in competition(s) at an elite or national level of sport were considered an exclusion to the systematic literature review undertaken in this thesis (Bellver et al., 2019; Lorenz et al., 2013).

“PA” is a generalised term used throughout the thesis and is defined as any bodily skeletal muscle movement that results in energy expenditure that is measured in kilocalories (World Health Organization, 2018). PA is categorised into occupational, sports and other activities; exercise is a sub-set of PA that is planned, structured, repetitive to improve or maintain physical fitness for health or skill (Caspersen et al., 1985). Work-based or occupational PA has the duration of an eight-hour work day whereas leisure-time PA, such as aerobic activities, structured endurance exercise programs, resistance-training programmes and sports, vary in type, duration, level, intensity and frequency for the individual. Comparative analysis PA requires standardisation of both energy expenditure and the relative effort required for specific PA on an individual level; therefore objectively measuring PA is challenging (Howley, 2001).

In the thesis, typically PA is referred to by using the same terminology as referenced in the supporting or corresponding literature. The term “recreational sporting activity” is used in both qualitative papers in Chapters 6 and 7 as the participants referred to the various recreational pursuits and the different types and levels of sports activity collectively, as we did not want to stop the flow of their discussions to identify clearly what level of engagement that they were discussing.

Sedentary activity is described as waking behaviours that involve sitting, reclining or lying positions characterised by an energy expenditure of  $\leq 1.5$  METs; this differs from inactivity which is described as not achieving the recommended levels of PA (Thivel et al., 2018). Sedentary activities are often associated with work; work-based activities and sedentary activity in general were not considered in this thesis and this particular limitation is discussed in the final chapter of this thesis.

### **1.2.2 The study participants' ages**

The age group of the study of 16 to 35 year old participants was selected as, whilst the relationship between PA and bone health in older adults has been well studied (Hernandez et al., 2003), there are fewer data available regarding young adults at the important period of PBM accrual (Tan et al., 2014). HRSA is one of the main factors that can impact that PBM. Previous studies have highlighted the requirement for further research to investigate the effects of sports loading on bone health over all stages of maturation in young people using a variety of methods, including quantitative ultrasound sound (QUS) (MacKelvie et al., 2002). To date, there are a limited number of studies that have looked at the impact of participation in individual HRSA on bone health at the calcaneus using QUS in young people.

### **1.3 The rationale**

We know from seminal literature that acquisition of PBM during the late teens and 20's is a critical period for determining an individual's later osteoporosis risk (Bonjour et al., 2009; Hernandez et al., 2003; Weaver et al., 2016). Most of the literature focuses on the relationship between PA and bone health in older adults. This study helps to fill the significant knowledge gap regarding the bone health and specific HRSA of adolescents and young adults.

One of the few studies that has considered PA in relation to bone health in a large population of adolescents was based in Tromsø, Norway: the Fit Futures Study (Christoffersen et al., 2015; Winther et al., 2015; Winther et al., 2014). In that study, 1,000 Norwegian teenagers aged 15 to 18 years participated in a questionnaire that assessed sport related to DXA to assess bone mass. The study reported that increased frequency and high intensive impact, sporting activities were related to better bone health and strength (Christoffersen et al., 2015). Improved bone health and bone strength in adolescence, leading to higher PBM acquisition, can help reduce the risk of fragility fracture later in life (Bass et al., 1998; Rizzoli et al., 2010).

The National Osteoporosis Foundation's scientific statement considered lifestyle factors that impact bone accretion during the critical years and found that the best evidence was available for the positive effects of calcium intake and PA (Weaver et al., 2016). During the growing years when bone is apparently most responsive to PA, the level of PA and its frequency declines with increasing age: this is most profound in females (Dumith et al., 2011). A meta-analysis indicated that weight-bearing PA and high calcium intake in childhood has the potential to act synergistically to reduce later osteoporosis risk (Behringer et al., 2014). The form of PA is believed to be important; the Avon Longitudinal Study of Parents and

Children suggested that high impact activity such as running and jumping are more beneficial in improving hip BMD and strength than lower impact activities. Furthermore, the same study in a large longitudinal study of 724 adolescents found that moderate impact activity such as jogging was not as beneficial as high impact activity (Deere et al., 2012a). That study used a combination of methods including accelerometers to assess and categorise the level of impact of different PA on bone health measures using HSA and DXA.

There is a need to study the evidence (through a systematic literature review) that non-elite sporting activity in adolescents and young adults may impact bone accrual to support evidence-based bone health policies and thereby reduce the risk of osteoporosis in older age. Currently, there are key gaps in the knowledge of how bone health of young people is related to specific HRSA as assessed by non-invasive methods such as cQUS that can measure important aspects of bone quality and density.

This study used a combination of quantitative and qualitative methods to understand the long-term non-elite sporting activity behaviours and experiences of adolescents and young adults in New Zealand and the impact this had on their bone health. We aimed to elicit evidence for the specific types and levels of HRSA that may be effective in improving bone health outcomes, as the available literature has found some sporting activities to be more beneficial than others. For example, systematic literature reviews have shown the bone health benefits of gymnastics early in life (Burt et al., 2013), whereas swimming, although associated with some health benefits, has not been specifically recognised as improving BMD (Gomez-Bruton et al., 2016). A finding of higher bone density and more favourable bone parameters as assessed by QUS in adolescents and young adults engaging in HRSA would help make the case for the promotion of national and international HRSA policies to improve the quality of later life (Winther et al., 2014).

#### **1.4 Purpose of the study, hypothesis, research questions, aims and objectives**

The purpose of this study was twofold: firstly to consider the relationship between specific HRSA and bone health using cQUS in adolescents and young adults (as a systematic literature review, and original quantitative study) and secondly to explore knowledge of factors affecting bone health, and specifically what affects engagement with HRSA in the same age group through qualitative focus groups.

### **1.4.1 Hypothesis**

The hypothesis of this doctorate is that certain modifiable lifestyles such as specific long-term HRSA are associated with increased bone density (as measured by heel ultrasound) and may be used as a means of improving PBM acquisition and reducing osteoporotic fracture later in life in young people.

### **1.4.2 Research questions**

The research questions for the thesis were as follows:

1. What relationship does HRSA have with bone health in adolescents and young adults as assessed through heel ultrasound?
2. *What do young adults understand about PBM, the lifestyle factors that impact PBM and what affects their engagement with HRSA?*

### **1.4.3 Aims and objectives**

The aims and objectives of the thesis were as follows:

1. To perform a narrative systematic literature review of the relationship between individual sports (performed non-competitively or at a local level) and bone mass as measured by cQUS in young people (Paper I).
2. To undertake a quantitative, mixed-centred Wellington-based study (at a local university, girls' schools and sport complexes) of the association between bone mass as measured by cQUS and HRSA as assessed by an online, self-completed questionnaire to collect lifestyle and demographic information (Paper II).
3. To undertake a qualitative study in the young adult population to assess the knowledge of osteoporosis, PBM, understanding of the risk factors for poor bone health influencing their participation in HRSA (Paper III & IV).

## **1.5 Research methodology**

The quantitative and qualitative studies involved human studies, for which ethical approval was obtained from both the VUW ethics committee (#23752) and subsequently the New Zealand Health and Disability Ethics Committee (reference #HDEC 18/CEN/18). Ethical approval was sought at the different stages of

the study, with amendments sought concurrently to progress to the next stage of the study or carry on the studies in parallel.

This study adopted a mixed methods approach, combining quantitative and qualitative methodologies to provide an improved understanding of the research topic (Schoonenboom & Johnson, 2017). The mixed study method approach permitted data to be collected and analysed using a mixture of qualitative and quantitative data in order to assess relationships from a variety of perspectives. The qualitative focus groups study permitted a deeper understanding of participants' knowledge and experiences of osteoporosis, PBM and the lifestyles factors that may impact bone health. The results of the data were analysed and synthesised to draw overall overarching conclusions for the thesis. Therefore, by integrating quantitative and qualitative perspectives of the research, it was possible to gain a better understanding of the research objectives (Creswell, 2014; Creswell et al., 2004).

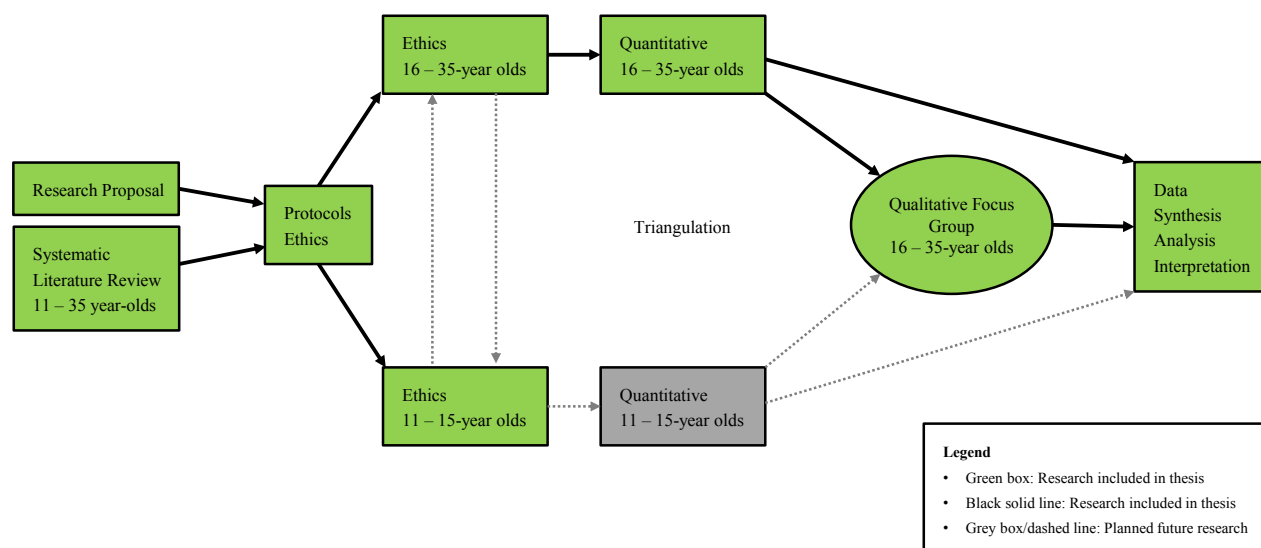
The review of the literature (Chapter 2) provided a background to the current knowledge of osteoporosis and PBM acquisition, the determinants of PBM, the context for the diagnosis and prevention of osteoporosis, current strategies for public health awareness and the future implications of the impact of osteoporosis, with particular reference to New Zealand.

Much of the available literature focuses on PA or sporting PA for those at an elite or competitive level of the sport or a group of sports, both at national or international level. In the majority of these studies, the comparative level of measure for bone health is through DXA or pQCT, or some other form of ionising and/or radiating method. The systematic literature review gives insight into the literature specifically of non-elite sporting activity at a recreational level (which is the standard much of the general adolescent population is at), rather than the exclusive level of competitive sport, and how it relates to bone health as represented by cQUS. In the quantitative study to assess bone health, we used a portable cQUS heel ultrasound machine and a questionnaire. The machine was used to assess bone structure and strength and is used worldwide for osteoporotic fracture risk assessment. The machine's portability allowed the testing procedure to be easily moved to different locations around the university, schools and sport complexes. Details of the use of the heel ultrasound machine are reported in Chapter 3.

The qualitative focus group study held discussions with the young adults that helped to assess the knowledge of osteoporosis, bone health and the lifestyle factors influencing their participation in HRSA. A list of the guide questions to prompt participants used may be found in the Appendix (note: initially as

the qualitative study was a part of a wider larger study, the prompt questions had a broader scope to assess the relationship between lifestyle factors and bone health such as alcohol consumption and dietary influences). We used an iterative process of data collection from the focus group discussions to understand the depth of the knowledge adolescents and young adults had about their bone health, in particular, in respect to HRSA. A debriefing session with the study facilitators after each focus group addressed any potential areas of clarification required. In addition, field notes and a reflective diary of each discussion recorded any emergent themes or ideas. This method of layering each focus group discussion through inductive thematic analysis added to the information gained, as previous emergent themes could be followed up with open-ended probes to obtain theoretical data saturation.

In this thesis, the information gathered from the systematic literature review and the results of both the quantitative and qualitative studies provide an overall synthesis and conclusion of the thesis (see Figure 2). This method is best described as a between-method of triangulation where qualitative and quantitative data collection methods within the same study complement each other to investigate the same element (Graham, 2005). In this case the influence of lifestyle factors (in particular, HRSA) on PBM acquisition and young people's knowledge of bone health. In addition, triangulation in the context of a qualitative research strategy adds robustness to the research study through the merging of data from different sources, the different voices in different focus groups, field notes, reflexive diary, quantitative information obtained from the questionnaire about their lifestyles and any other factors participants wished to consider (Carter et al., 2014; Heale & Forbes, 2013).



*Figure 2: Thesis conceptual framework*

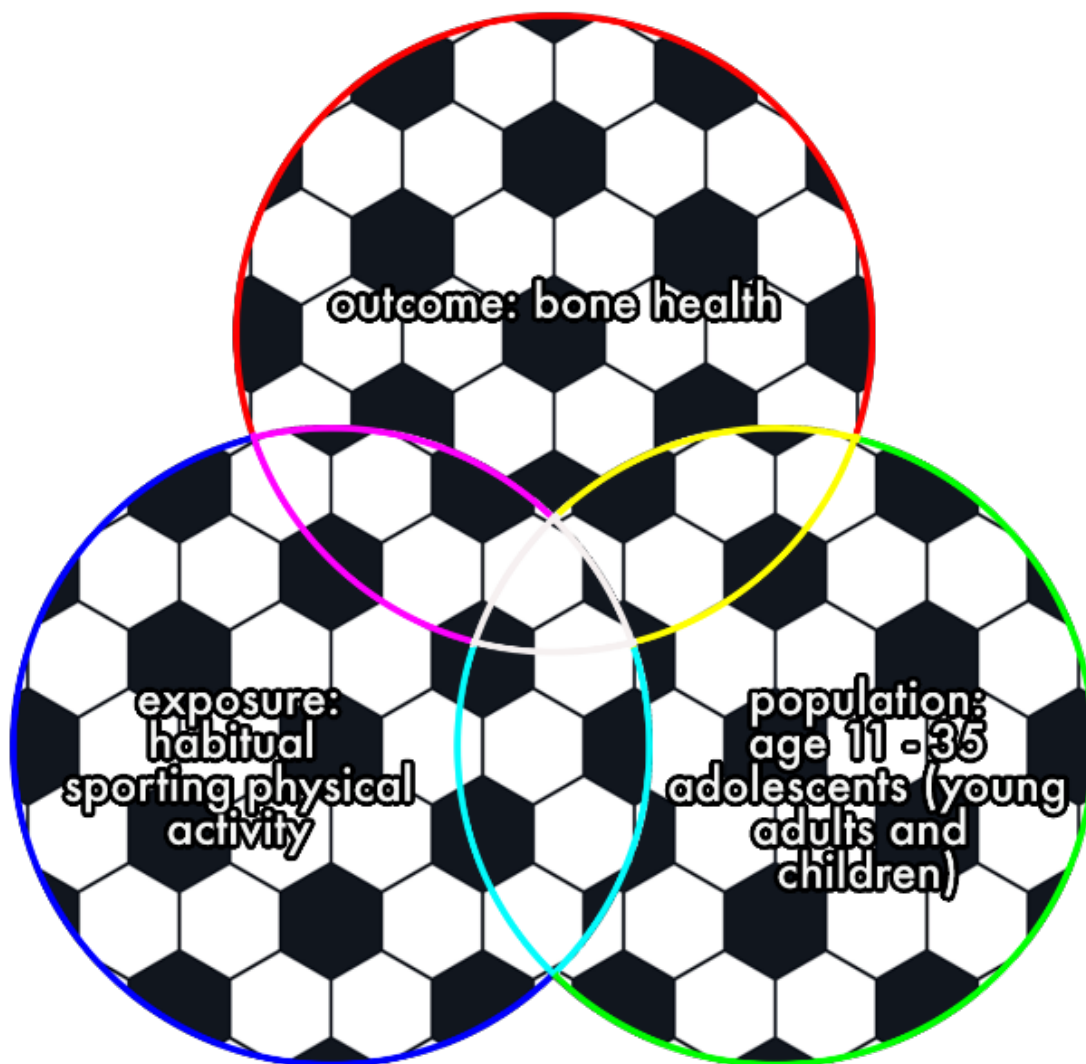
Determinants of PBM are complex, some which positively affect PBM and other risk factors that may negatively impact bone health. Figure 3 demonstrates the interacting influence of predictor variables (including non-specific and/or unknown factors) on the outcome variable (bone health), with the study (independent and dependent) variables influencing the results of the study.



*Figure 3: Outcomes and exposures of interest*

Figure 4 indicates the search terms used for the systematic literature review to broadly capture the literature available for the study topic of the thesis:

- (1) Exposure: Non-elite participation in sporting activity performed at school or leisure time as an organised or regular activity – either self-reported or measured objectively. Participation in any type of sporting physical activity (quantitative studies).
- (2) Outcome: Any bone heel ultrasound measures such as speed of sound (SOS)/velocity of sound (VOS), broadband ultrasonic attenuation (BUA), stiffness index (SI)/quantitative ultrasound index (QUI).
- (3) Population: Inclusions: The age of study participants was a mean age between 11 to 35 years inclusive. Both sexes were included. Participation in a named sporting activity at a local or regional level.



*Figure 4: Exposure outcome model of the search terms 11 to 35*



## **1.6 Thesis structure**

This first chapter provides an introduction to the thesis to understand the reasoning behind the study and its aims. The second chapter sets out the background to the current knowledge of osteoporosis, specifically its definition and risk factors, with particular reference to adolescents and young adults and HRSA, and the context for its diagnosis and prevention. The third chapter describes the mixed methodology and tools used to assess bone health in the quantitative and qualitative studies in the thesis. The fourth chapter provides an overview of the relationships between non-elite sporting activity with bone density in adolescents and young adults as a systematic literature review. The fifth chapter aims to understand the association between HRSA and bone health through a quantitative, mixed-centred adolescent study in the 16 to 35 year group (based at a university, sports complexes and secondary schools in the Wellington region) using the heel ultrasound scan as a measure of bone health and an online questionnaire in the 16 to 35 year age group. The sixth chapter describes the methodology and results of the qualitative focus group work with 44 participants to understand the knowledge of obtaining a better bone health later in life. Barriers and enablers specifically in relation to HRSA are reported in Chapter 7. The final chapter, Chapter 8, is a summary of the main findings of the literature review and the quantitative and qualitative studies, with a discussion on the strengths and limitations of the methodology and overall synthesis of the findings and future implications of the research undertaken. The References identify all the supporting literature used. The Appendix includes the study documentation, posters, abstract presentations, questionnaire, focus group questions and prompts for the discussions held and any additional results.

### **1.6.1 Reporting of the study manuscripts**

In this thesis, we consider the relationship between HRSA and bone health in three separate studies, reported as four manuscripts: (1) a systematic literature review of studies that considered relationships between non-elite sporting activity and bone health in adolescents and young adults as assessed by calcaneal heel ultrasound; (2) a quantitative study of 920 Wellington-based adolescents and young adults aged 16 to 35 years of age, only those who fully completed a questionnaire detailing sporting activity and relevant lifestyle confounders and underwent heel ultrasound measurements ( $n=452$ ) are reported; and (3) a qualitative study involving nine focus groups of young adults to better understand their knowledge of bone health, the factors that impact it, and the barriers and facilitators to increasing HRSA was reported as two separate manuscripts to give more breadth to the analysis.

## **2 Chapter 2: Background**

### **2.1 Chapter 2 overview**

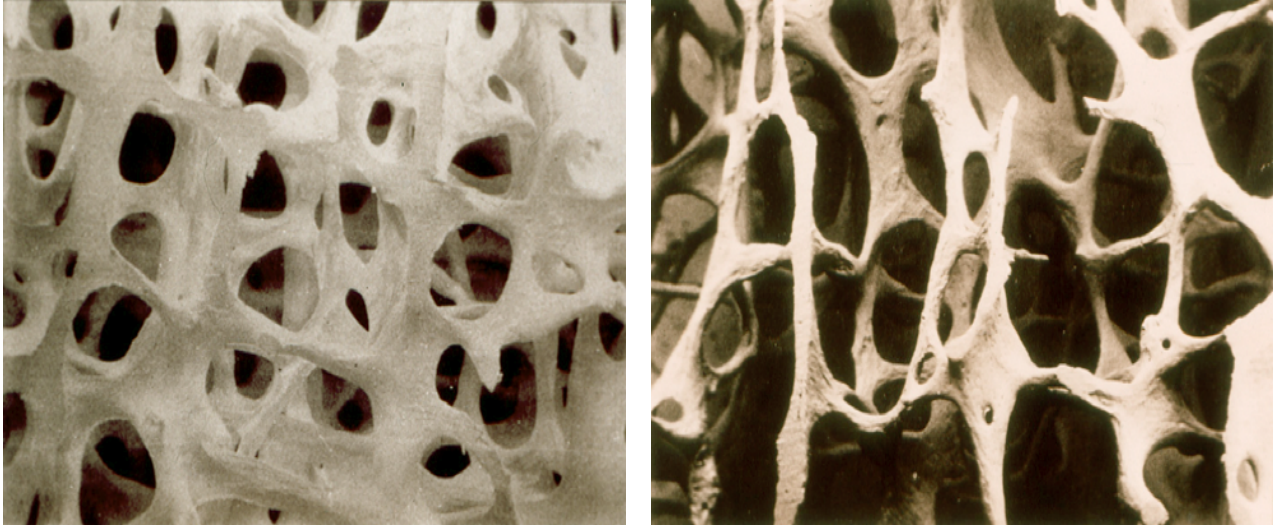
This chapter provides an overview of the importance of peak bone mass (PBM). This approach helps explain the consequences of failing to attain a good PBM in youth; namely an increased risk of osteoporosis, a summary of which is described in this chapter. This chapter also sets out the determinants of PBM, the lifestyle factors that affect PBM (in particular, the relationship between PBM and habitual recreational sporting activity (HRSA)), how the risk of osteoporotic fracture is measured currently and the use of heel ultrasound as a measure of bone health.

### **2.2 Definition of osteoporosis**

Osteoporosis is a disease where bones become porous, thin and fragile: this disease is a major global public health problem through its association with fragility fracture (Cole et al., 2008; Glaser & Kaplan, 1997). Osteoporosis is typified by deterioration in bone mass and micro-architectural deterioration of bone tissue undermining the integrity of the skeletal structure. More often, osteoporosis remains undetected until it is expressed as a skeletal fracture. Commonly recognised sites of osteoporotic fractures are at the hip, vertebrae and appendicular bones (Brown et al., 2011).

The World Health Organization's (WHO) definition of osteoporosis is set out below (see Figure 5) (Kanis & Kanis, 1994):

*“Osteoporosis is a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture.”*



**Figure 5:** Normal bone (left) and osteoporotic bone (right) structure. Personal communication from Professor Cyrus Cooper

Health data needs to be collected in a standardised manner. The gold standard method for diagnosis of osteoporosis is bone mineral density (BMD) using dual energy X-ray absorptiometry (DXA) at the non-dominant hip and vertebrae (International Society for Clinical Densitometry, 2019). Typically bone health measures are reported as BMD scores which are compared to established standards, as shown in Table 1 below (National Institutes of Health, 2018).

WHO defines standards that categorise BMD by T-score for those people aged 20 years or more as: within the normal range; low bone mass; osteoporosis; and those with confirmed osteoporosis (Kanis, 2008; Kanis et al., 2010) (see Table 1).

**Table 1:** T-score values. BMD is the areal BMD by DXA

Categories	T-score values by DXA
Normal range	Greater than or equal to -1.0 [Bone density is within 1 SD (+1 or -1) of the young adult mean]
Low bone mass	-1.0 or less than -2.5 [Bone density is between 1 and 2.5 SD below the young adult mean (-1 to -2.5 SD)]
Osteoporosis	Equal to or less than -2.5 [Bone density is 2.5 SD or more below the young adult mean (-2.5 SD or lower)]
Confirmed osteoporosis	-2.5 and one or more osteoporotic fracture

T-score is the number of standard deviations (SD) below the average of a young adult at peak bone density as compared to a reference population. Z-score is the number of standard deviations below the average of same age group of people. T-score is often used in conjunction with the Fracture Risk Assessment Tool (FRAX) to improve the estimation of future risk of fracture. The FRAX tool is an algorithm that helps to calculate the 10-year risk of osteoporotic fracture using information provided based on clinical risk factors and BMD as discussed above (Binkley et al., 2014; Kanis et al., 2010; Osteoporosis New Zealand, 2017b).

### **2.3 The public health importance of osteoporotic fracture and acquiring optimal PBM**

Osteoporosis is regarded as a “*Paediatric disease with geriatric consequences*” (Hightower, 2000). A recent report in the International Osteoporosis Foundation’s Compendium of Osteoporosis reported that osteoporosis and the risk of fragility fracture presents a huge economic, public, social and personal health burden: on average, nine million osteoporotic fractures occur each year globally (Cooper & Ferrari, 2019; Sözen et al., 2017). For those aged 50 years or above, one third of women and one fifth of men will have an osteoporotic fracture (Osteoporosis New Zealand, 2017c). Those younger than 50 may develop osteoporosis through specific medical conditions, taking certain types of medication or drugs or certain lifestyle behaviours (Kok & Sambrook, 2009). Bone fractures commonly occur at the wrist, shoulder, hip and spine. Internationally, there is a gender difference in fracture rates, with over 60% of hip fractures occurring in women and one third occurring in men (Cooper & Ferrari, 2019). In addition, with an increasing aging population with longer life-spans than previous generations, the consequences of osteoporosis are increasing exponentially (Sözen et al., 2017).

In New Zealand, a country with a population of approximately five million, 1.6 million people are aged over 50 years and it has been estimated that 180,000 individuals aged over 50 have broken a bone, with fragility fractures costing society over \$300 million annually (Brown et al., 2011; Osteoporosis New Zealand, 2017c). The Burden of Osteoporosis in New Zealand report (BONZ) estimated that 80,000 osteoporotic fractures occurred in 2007 and over 60% of these fractures occurred in women. This report found that of the total osteoporotic fractures, 5% were of the hip and were associated with the highest health cost, mortality and morbidity. In addition, the report estimated 4,000 people a year suffer a fracture of the hip in New Zealand. The BONZ report also predicted the number of osteoporotic fractures occurring by 2020 to be around 120,000 (Brown et al., 2007) with an expected annual loss of over 15,000 quality-adjusted life years (QALY) by 2020 due to osteoporotic fractures (Brown et al., 2011). QALY is a measure of health outcomes that includes quantity of life lived in relation to the amount of life

remaining and the quality of life in terms of health: pain, mobility, self-care, usual abilities and depression and/or anxiety (Howren, 2013).

Individuals who have an initial osteoporotic fracture often have a subsequent fracture (Balasubramanian et al., 2019; Kanis, Johnell, et al., 2004). Those with a hip fracture often have had a previous fragility fracture elsewhere, require long-term care, more hospital treatment care over a longer period of time and have overall greater mortality and morbidity risks (Borgström et al., 2020). The personal and socio-economic impact of those affected by osteoporosis is immense, affecting an individual's quality of life, that of their families and their wider community (Brown et al., 2011).

In addition, personal costs of diagnostic treatment (for scans and testing) may hinder early diagnosis and treatment (Fox et al., 2015). The pain that fractures inflict may acutely impair independence, with reduced mobility and the ability to care for one's self or family. The reduction in physical abilities can lead to various levels of depression along with individuals becoming fearful of suffering subsequent falls that may lead to inactivity, which may lead to poor functional status (Coelho et al., 1999; Dennison et al., 2005; Rizzoli et al., 2012). This increases the risk of fracture, which further compounds the problems of osteoporosis management (Fox et al., 2015). The lack of self-reliance and increasing dependence may lead to a fear of being a burden to family and friends. Other personal issues that may arise include fear of premature aging and physical disfigurement through reduced stature and curvature of the spine that affect physical and mental well-being (Cooper & Ferrari, 2019; Kanis, 2008).

## **2.4 Current strategies for public health awareness of PBM in New Zealand**

One aspect of this thesis considers the knowledge young people have of bone health. As long ago as 1997, the New Zealand government had a target to increase calcium intake in young people in order to achieve high PBM and prevent osteoporotic fractures (Ministry of Health, 1997). Health strategies through education and counselling include nutritional advice, encouraging PA in younger adults, and the use of vitamin D supplements for at risk groups from health professionals, but these do not target young people to effectively improve PBM acquisition (Ebeling et al., 2013; Rockell et al., 2008).

In 2012, the BoneCare report stated that New Zealand had no coordinated strategy to manage the increasing number of older New Zealanders at risk of fragility fractures (Osteoporosis New Zealand, 2012). BoneCare 2020 disseminates public health messages for PBM accrual through diet and regular exercise for bone development in young people and "*The Live Stronger for Longer*" promotion which

encompasses health and community agencies to prevent falls and fractures (Osteoporosis New Zealand, 2017c). New Zealand's first national Community Sport Strategy was launched in 2009, a national support strategy to increase sports participation in young people and adults. The strategy notes that "*Playing sport can help improve posture and balance, and can build stronger muscles and bones*" (Sport New Zealand, 2009, 2018a).

## **2.5 Bone biology**

### **2.5.1 Bone growth**

Bones are living tissue that support the structure of the body. They are both light and strong with some flexibility to sustain daily activities and are in a constant state of change, requiring essential nutrients to grow and be maintained throughout life. From preconception, bones are susceptible to maternal health. While genetics play a role, *in utero* maternal lifestyle behaviours (such as nutrition and medications) affect the foetal skeleton (Heaney et al., 2000). The rate of bone growth is rapid from the foetal stage to late adolescence and beyond. Childhood, adolescence and young adulthood are the most beneficial periods for long-term bone density accrual, where up to 90% of PBM is gained. Although the main determinant of PBM is genetics, which accounts for 60 to 80% of variance in PBM (Bonjour et al., 2009), there are important modifiable environmental factors which affect PBM. Osteogenesis is at its optimum during skeletal growth provided there is optimal nutrition with adequate intake of calcium and vitamin D, along with PA (Weaver et al., 2016).

During childhood, height is dependent on the appendicular (long bones) growth rate, which is double that of the axial (head and trunk bones) growth rate. During pubertal hormonal changes, bone growth remains similar for the first two years (Alswat, 2017). In boys, the long bones continue to grow at a faster rate for a longer period of time, as the onset of puberty in boys usually occurs later than girls (Baxter-Jones et al., 2011).

The bone is not inert but is continually regenerating to replace older bone tissue. There is continual cycle of repair of bone tissue, ensuring deteriorating bone tissue is replaced by new bone tissue (Raisz, 2005). The balance between bone replacement with new bone formation and, bone being broken down (resorption) is generally normal up to and around the state of PBM, usually around an individual's thirties (International Osteoporosis Foundation, 2015). Generally, bone density begins to decrease in men and women after the age of 35 years (Baxter-Jones et al., 2011; International Osteoporosis Foundation, 2015; Lindgren et al., 2019).

### **2.5.2 Bone composition**

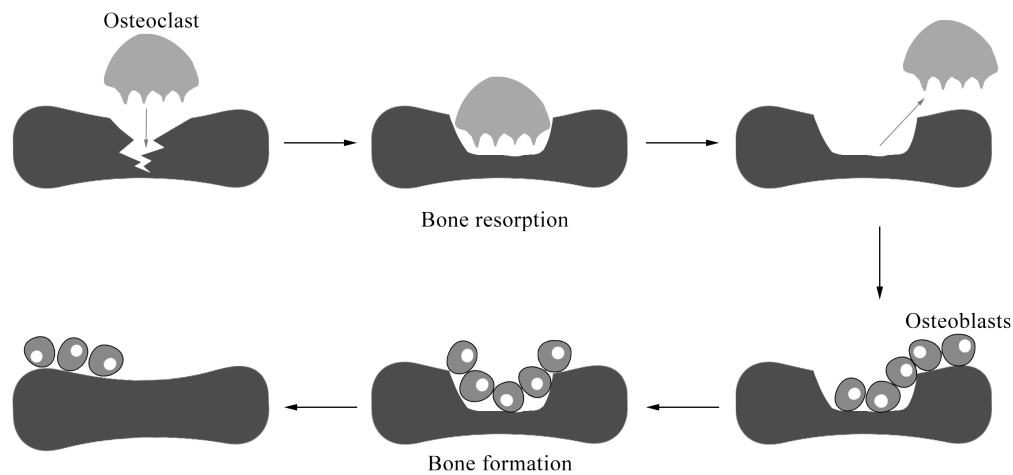
There are over three hundred bones in the human skeleton, with 80% comprised of cortical bone and 20% trabecular (cancellous) bone (Goolsby & Boniquit, 2017; International Osteoporosis Foundation, 2015). Cortical bone is the compact protective outer surface of the bone and, being resistant to bending and torsion, forms the weight-bearing component of the body and provides structural integrity (Tresguerres et al., 2020). Trabecular bone is found at the ends of long bones and comprise a porous, spongy network of trabecular plates and rods that add strength and flexibility. Trabecular bones also produce red blood cells in the bone marrow. Calcified bone forms the matrix with interconnected fluid and fatty marrow within the pores; weakening of the bone structure increases bone resorption and decreases bone production (Dallas et al., 2013). Thinning or reduction in the trabecular pattern reduces rigidity in the bony matrix and a loss of elasticity, reducing overall bone quality and strength. QUS has a particular advantage when providing an assessment of bone health, as it may detect some of the changes in the bone architecture, quality and density which are not detected by DXA (McKelvie, 1991).

### **2.5.3 Bone turnover**

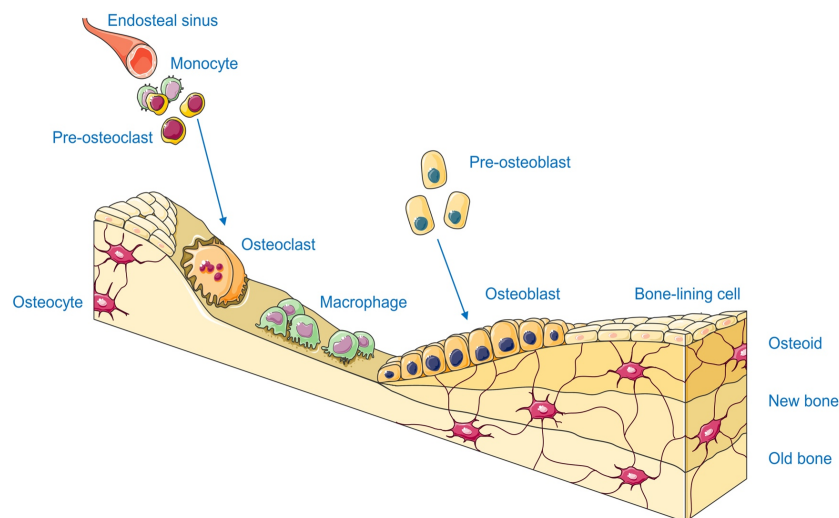
Bone tissue is a constantly evolving living tissue that remodels to maintain structural integrity through the bone cycle of resorption where bone is removed by osteoclasts and formed by osteoblasts through five stages of degeneration and regeneration (activation, resorption, reversal, formation and termination) (Raisz, 2005). The changes in the rate of resorption and reversal phases (which are relatively short processes) and formation process (which is a relatively longer process) affect bone mass production. The quality and quantity of the bone reduces when there is an imbalance in bone replacement with new bone tissue and bone resorption. Osteoporosis occurs when there is an imbalance in the bone remodelling process. Biochemical bone markers of bone formation and turnover markers can be used to determine the rate of bone metabolic activity by blood and urine laboratory testing (Raisz, 2005).

In the bone remodelling process there is a complex mix of interactions and a host of processes involved with various cells, lymphocytes, proteins, receptors, activators and regulators that affect and control the process (International Osteoporosis Foundation, 2015; Katsimbri, 2017). The bone remodelling process is a dynamic state of bone metabolism where osteoclasts are activated and mononuclear osteoclast precursors meet on the bone surface and undergo a fusion process.

After the resorption phase, there is a reversal phase whereby osteoclast and mononucleated resorbing cells die: these osteoblasts replace the osteoclasts and start the formation cycle. Osteoblasts cross the bone surface via the cortex and refill the cortex by depositing osteon a lamellar bone. During this formation phase in the bone matrix (osteoid) the osteoblasts are buried and formed into osteocytes. Osteocytes respond to mechanical stress and communicate with cells on the bone surface to regulate the bone remodelling process as required (see Figure 6) and forming layers of newly formed bone over older bone (see Figure 7) (Bonewald, 2011; Cooper, 2012).



**Figure 6:** Osteoclasts repair fractures by removing the damaged area, then osteoblasts form a matrix (osteoid) that is mineralised. Adapted from Cooper (2012)



**Figure 7:** Bone remodelling cycle. From Servier (2019)



#### **2.5.4 Bone and muscle interaction**

A focus of this thesis is the relationship between HRSA and bone health. Bones and muscles are interconnected by anatomy, metabolic and chemical components. Mechanical stress and loading is required for bone mineral accrual through impact (gravitational or ground force reaction or through skeletal muscle contraction) and/or non-impact muscle forces (such as different types of PA, including resistance exercise where a variety of different mechanical loads are applied and bone metabolism adapts to the load applied) (Lombardi et al., 2019). The bone adapts to the mechanical load depending on a host of interconnecting elements such as the magnitude, intensity, rate, frequency, distribution, number of loading cycles and rest-recovery periods presented on the bone (Hart et al., 2017; Robling et al., 2001). These mechanical stresses influence the bone mass and the bone architecture which determine bone strength. The musculoskeletal properties the normal body to function well (without fracturing or harming itself) balancing function with strength efficiently as defined in the Utah paradigm and the mechanostat theory (Frost, 1998; Hart et al., 2017; Schoenau & Frost, 2002). As per Wolff's Law, bone is able to self-organise in size, shape and structure in response to mechanical load, such that PA requiring muscle stress will promote bone resistance and strength (Schoenau & Frost, 2002).

The bone recognises mechanical loading stimulus through a process of mechano-transduction (Robling & Turner, 2009) where cellular and molecular action occurs through various mechanisms such as hormones, vitamins, proteins, genes, cytokines and mechano-receptors (osteocytes which are multifunctional bone cells) that respond to the internal fluid movement in the lacunar-canalicular network (Tresguerres et al., 2020). As the osteocytes in the bone tissue are connected to each other and to the bone-lining cells and the osteoblasts on the bone surfaces, this movement evokes a response of bone remodelling, translating the mechanical strain into chemical signals to osteoblasts and osteoclasts. Only mechanical stresses with sufficient intermittent stress intensity and with varying load patterns are osteogenic, such as jumping with discrete sessions of loading and resting for recovery help to preserve bone integrity and muscle mass (Goolsby & Boniquit, 2017).

It is generally accepted that the intensity, frequency and mechanical load induced by exercise training enhances osteoblastic activity (Fleg, 2012; Palombaro et al., 2013; Raisz, 2005). However, not all types of exercise are equally osteogenic (Hong & Kim, 2018). The osteogenic effect refers to bone accretion occurring when the mechanical load on bone tissue is greater than what typically occurs in everyday living (Hong & Kim, 2018). Additionally, the load required to stimulate bone building varies with the type, level, frequency and duration of the loading. Weight-bearing impact exercise such as hopping and

jumping has been shown to have the greatest benefits (Behringer et al., 2014; Clissold et al., 2020). Bone formation is increased in regions of high strain, with the skeletal effect of mechanical loading being site-specific, with greater responses at skeletal sites where loading impacts are greater (Morel et al., 2001; Tan et al., 2014; Weaver et al., 2016). The majority of weight-bearing exercise elicits physical loading to the lower limbs. To generate the adaptive response of bone to mechanical loading, sufficient magnitude, intensity, rate and frequency of loading are necessary if adequate intensity of loading is to be achieved: relatively few loading repetitions are sufficient to generate an adaptive skeletal response (Rubin & Lanyon, 1984). Further, as osteocytes are desensitised by repetitive loading, short bouts with intervals of rest are more beneficial than the same number of loads performed continuously (Robling et al., 2001). The bone has a greater capacity to adapt to mechanical loading during periods of bone growth than when the bone is mature. HRSA is particularly important as it has been suggested that adaptations to mechanical loading in adolescence and young adulthood may be translated into greater bone strength over a lifetime (Warden et al., 2014). Bones may become less sensitive to mechanical loading after skeletal maturity is reached at 18 to 25 years of age (Kontulainen et al., 2003). Therefore, it seems prudent to maximise efforts to increase PBM efforts before and during the third decade in life to reduce the impact of osteoporosis later in life. As such early and long term continued osteogenic and weight-bearing HRSA participation is an important determinant of bone health (Daly & Bass, 2006).

## **2.6 Peak bone mass and its determinants**

### **2.6.1 The importance of PBM to risk of later fragility fracture**

Typically PBM occurs when bones have accrued the maximum amount of bone density and are at their strongest (Heaney et al., 2000). Growth in early life is allied with bone size and strength (Oliver et al., 2007). Bone mass typically increases during late adolescence, peaking in an individual's twenties and thirties, and decreases from around the age of 45 years in both men and women (Baxter-Jones et al., 2011; Gordon et al., 2017). During adolescence, growth of 25% of the final PBM occurs: the exact timing appears to vary with skeletal site and with sex (Kovacs, 2013). There is an accelerated period of bone loss at perimenopause in women (Hernandez et al., 2003).

It is widely agreed that high PBM in adolescence has a protective influence later in life (Heaney et al., 2000); the National Osteoporosis Foundation's position statement on PBM development suggested that peak bone strength is characterised by mass, density, microarchitecture, micro-repair mechanisms and the geometric properties to achieve bone structural strength potential, which varies depending on the skeletal site (Weaver et al., 2016). Bone strength is determined by non-modifiable (such as genetics) and

modifiable factors (such as activity, nutrition and hormones) (Bachrach, 2007). Before and after puberty appears to be an opportune time to modify environmental factors that affect BMD acquisition (Bonjour et al., 2009).

The optimum PBM acquired during adolescence and during early adulthood is of strategic importance to reduce the burden of osteoporosis and fracture, as an increase of PBM by one standard deviation may reduce the osteoporotic fracture risk by 50% as individuals age (Hernandez et al., 2003). The magnitude of this effect highlights PBM optimisation as a strategy to reduce risk of fragility fracture and represents the key reason why it is explored in this thesis.

By using a computer generated model, Hernandez et al. (2003) were able to predict and quantify the delay in the development of osteoporosis by PBM or age-related bone loss and the onset of menopause. They found that a 10% increase in peak BMD could potentially delay the onset of osteoporosis by 13 years. By comparison, a 10% change in the age of menopause or bone loss may delay the onset of osteoporosis by two years (Hernandez et al., 2003). Therefore, any factor or combination of factors that helps to increase peak BMD may be effective at averting the development of poor bone health. By recognising the determinants of bone acquisition and the role they play from conception to early adulthood it may be possible to optimise PBM acquisition.

Therefore, achieving maximum PBM during the first three decades of life is a major factor in off-setting the onset of osteoporosis and poor bone health later in life (Hernandez et al., 2003). It may be possible to achieve the full genetic potential of PBM by ensuring adequate environmental factors such as good nutrition (with sufficient calcium, vitamin D intake and sun exposure) and loading exercise in combination with minimising detrimental modifiable lifestyles may reduce the personal and economic costs of osteoporosis (Heaney et al., 2000; Hernandez et al., 2003). There is a general consensus in the literature that supports the model of achieving higher PBM from infancy to adolescence and young adulthood as a “*bone bank*” to provide a protective influence to reduce the impact of osteoporosis later in life by using modifiable environmental lifestyle factors to improve bone mass acquisition (Bonjour et al., 2009; Harvey et al., 2008; Javaid et al., 2011; Min et al., 2019; Ramot et al., 2019; Weaver et al., 2016).

### 2.6.2 Determinants of PBM

Determinants of PBM are complex, some which positively affect PBM and other risk factors that may negatively impact bone health (see Table 2).

**Table 2:** Lifestyle determinants

<b>Lifestyle determinants that may influence achieving the full genetic potential for skeletal mass assessed by a review by Weaver et al. (2016).</b> <b>Graded lifestyle factors determinants potential influencing PBM development</b>							
A	Calcium	PA & exercise effect on bone mass and density					
B	Vitamin D	Dairy	Detriment of DMPA injections	PA & exercise effect on bone structural outcomes			
C	Protein	Fibre	Fruit & vegetables	Detriment of cola and caffeinated beverages	Detriment of smoking		
D	Fat	Micronutrients other than calcium & vitamin D	Duration of breastfeeding	Breastfeeding versus formula feeding	Enriched formula feeding	Detriment of oral contraceptives	Detriment of alcohol

#### 2.6.2.1 Gender

Childhood and adolescence are critical periods to optimise bone growth and PBM accrual processes which are dependent on gender and skeletal site of the bone (Heaney et al., 2000; Kovacs, 2013). Around puberty, the lumbar spine and proximal femur develop faster than other long bone, gender differences become noticeable and follow a sex-specific pattern. Bone mass accrual rate is similar to height rate growth but occurs approximately to six to twelve months later. During this phase of rapid growth, bones may have not attained maximum mineralisation and are therefore susceptible to fracture (Maggioli & Stagi, 2017). During puberty, bone size increases, with volumetric BMD being similar across both males and females. During pubertal maturation, males have a greater bone size as there is greater bone deposition on the outer surfaces of the bone (periosteal bone) due to sex hormones and growth hormone [insulin-like growth factor-1 (GH-IGF-1) system], resulting in greater resistance to mechanical force in males (Bonjour et al., 2009).

#### 2.6.2.2 Age

The quality and strength of bones present in the body are affected by a multitude of factors including age (Hernandez et al., 2003; Woolford et al., 2019), such that the bone's vulnerability to fracture varies with age. The incidence of fracture increases during the rapid growing stage of young bones and later in life in the elderly (Dennison et al., 2005).

During adolescence and young adulthood, along with a rapid increase in height, bones become stronger, larger, heavier and denser until PBM is attained in individuals' late twenties or early thirties (Bailey et al., 1999; Baxter-Jones et al., 2011). After this point, bones reduce in mass as the balance between bone formation and resorption shifts direction, causing a decrease in bone mass and thinning of bone tissue. These changes increase the risk of developing osteoporosis and fragility fracture (Heaney et al., 2000). For women, age-related bone loss often becomes particularly pronounced after menopause and associated hormonal induced changes (Hernandez et al., 2003).

Although chronological age is a useful measure, it does not always reflect the bone maturity of young people (Malina et al., 2015). The chronological age and maturational or development status (the physical and sexual maturity) of children and adolescents are complex, varying person to person and within genders. The same variety between individuals also applies to bone growth, including changes in bone mass and volume during maturation processes (Heaney, 2016).

An Australian study by Weeks & Beck (2010) suggested that during adolescence there are sex-specific associations between PA, maturity and bone mass. Therefore, to achieve optimum PBM through modifiable lifestyle, PA interventions should reflect maturation and gender (Weeks & Beck, 2010). Similarly, a longitudinal study with nearly 400 children aged between 9 to 20 years found maturity-specific associations using the age of peak height velocity (APHV) and with objectively measured moderate vigorous PA (MVPA) and sedentary time (accelerators) and bone using HR-pQCT (Gabel et al., 2017).

#### **2.6.2.3 Sports**

Previous studies have considered the effect of participation in individual sports on bone health, but most of these have focused on individuals playing competitively and training for extended periods each week. Those studies include: a systematic literature review of soccer practice on bone health that suggested soccer improves bone health during development (Lozano-Berges et al., 2018); a systematic literature review that found beneficial site-specific osteogenic outcomes in pre-professional female ballet dancers who practised at least 10 hours weekly compared to healthy age-matched controls (Wewege & Ward, 2018); and a systematic literature review of bone health in children up to the age of 18 years participating in gymnastics, rhythmic gymnastics, tennis, soccer, capoeira, swimming, cycling and/or jumping activities suggested that weight-bearing activities practised intensively and habitually are beneficial to bone geometry (Krahenbühl et al., 2018).

Most studies performed to date examined the impact of long-term participation in endurance sports on bone health. For example, a Finnish study reported findings in competitive female athletes competing in 11 different sports that were grouped depending on loading impact (high impact, odd impact and repetitive low impact loading exercises) and compared to physically active, non-athletic participants suggesting that pQCT bone measures of the tibia were associated with the magnitude of the strain placed by the sport (Nikander, Kannus, et al., 2010). The same authors completed a systematic literature review and metanalysis (using pQCT, MRI, DXA and HSA as outcome measures) with exercise (that was weight-bearing impact, resistance, endurance training singularly or in combination) as the exposure variable and found bone strength improved at loaded sites in children, adolescents and young adults but not in older adults (Nikander, Sievänen, et al., 2010). The individual characteristics of specific HRSA volume, intensity distribution of the activity on the bone determines the optimal bone outcome (Rowlands et al., 2020). Many other studies focused on adolescents who participated in sports competitively at higher intensity, frequency and duration than is reported in this thesis (Behringer et al., 2014; Marin-Puyalto et al., 2019; Tenforde & Fredericson, 2011). Hence, an evidence gap exists regarding the benefit of HRSA, but repetitive loading seems most beneficial for bone health.

Studies have considered the impact of playing a sport for a long duration. A Belgian longitudinal, 27-year follow-up study of 13 year old males found a positive association between bone health and continued impact sport participation (Van Langendonck et al., 2003). A Japanese study found higher BMD in Japanese women aged 20 to 39 years who had participated in HRSA from school age onwards (Hara et al., 2001). Findings from a Norwegian 12-year longitudinal study that performed serial BMD measurements in 17 year old males reported long-term beneficial effects of badminton playing, which were superior to participation in long-term ice hockey (Tervo et al., 2010). The Raine longitudinal adolescents study involved researchers collecting organised sport participation data as recorded by the parents of 984 offspring at ages 5, 8, 10, 14 and 17 years and DXA bone density being assessed at age 20 years. The Raine study reported higher bone density in young people using DXA bone measures in those who had participated in organised sports over this time (McVeigh et al., 2019). Together, these studies suggest that long term participation in sport is beneficial to bone health, and that engagement with HRSA should be sustained.

There are far fewer bone studies that have researched the effects of specific HRSA on bone health in the general young population. An Australian longitudinal study using DXA found that the mechanical effects

of dance training in non-elite female ballet dancers aged 11-14 years showed site-specific and maturity-specific positive bone mineral accrual at the femoral neck areal BMD over the pubertal years (Matthews et al., 2006). It has been shown that young female rowers competing at school or state level accrue greater lumbar spine BMD than age, height and weight matched controls (Morris et al., 2000). The PROBONE study showed that bone acquisition at the femoral neck and lumbar is higher in adolescent male footballers than in swimmers and cyclists (Vlachopoulos, Barker, Williams, et al., 2017). A Brazilian study found that lengthy basketball practice positively enhanced BMD in adolescent boys as measured by DXA (Júnior et al., 2017). Another Brazilian study of 60 adolescents indicated that judo practice significantly improved bone accrual in males relative to controls (Ito et al., 2017).

Most available studies have assessed bone health through DXA. These studies have typically focused on specific sports performed at high levels. For example, researchers have demonstrated that high impact sports (such as volleyball and hurdling) and odd-impact loading sports (squash-playing, soccer, speed-skating and step aerobics) were beneficial for BMD, as assessed by DXA (Nikander et al., 2005; Tenforde & Fredericson, 2011). Other studies have suggested the beneficial effects of professional soccer (Wittich et al., 1998), volley ball (Alfredson et al., 1998), tennis (Haapasalo et al., 1998), tennis and squash (Kannus et al., 1995), and aerobic dancing, squash and speed-skating (Heinonen et al., 1995).

Other cross-sectional studies have considered the benefits of a range of sporting activities in a single study. A study of amateur sporting activity in 704 sporting adolescents aged 11 to 18 years found in over the 14 sports identified (that included sports such as rugby, soccer, running, swimming and rowing), using DXA to assess BMD, benefits to be site-specific and related to the unusual strains during the sport training produced by muscle stress and gravitational forces (Morel et al., 2001). Another study found college-level dancers to have higher BMD (assessed by DXA) in the lumbar spine than non-dancers, but lower BMD or no difference in other areas (Farnell et al., 2018). An English study of young female rugby league footballers, netballers and runners, who were mostly eumenorrhic found that sports participation had osteogenic, site-specific effects with particular benefits associated with playing rugby league football (Egan et al., 2006).

Some previous researchers have used QUS as their outcome measure of bone health. One such study indicated sport site-specific effects on bone strength in adolescent male hockey and soccer players, with increased respective QUS quantitative radial and tibial speed of sound (SOS) measures compared to controls (Falk et al., 2010). The osteogenic benefits of different types of sports within their fields such

as martial arts require further investigation, as a Malay study of adolescent male boxing, Muay Thai and Silat athletes indicated (Abidin et al., 2018; Norsuriani & Ooi, 2018). Another QUS study of the phalanges (hands) study of karate players found high QUS measurements (Norsuriani & Ooi, 2018). Finally a recent cross-sectional study of Malaysian adolescents aged 15-17 years found that regular PA was positively associated with all three cQUS indices (SI, BUA and SOS) in both girls and boys (Zulfarina et al., 2018).

#### **2.6.2.4 Genetics, family history and ethnicity**

There is an association between osteoporosis and the number of immediate family members suffering from osteoporosis (Kanis, Johansson, et al., 2004). Studies have indicated that some genes are associated with osteoporosis such as the vitamin D receptor gene (VDR), oestrogen receptor gene (ER), interleukin (IL-6), transforming growth factor (TGF) and calcitonin receptor gene, with many more genetic associations becoming apparent (Raisz, 2005). There are also ethnic differences in bone parameters (Horlick et al., 2000; Micklesfield et al., 2004). Many studies have reported that African Americans and non-African Americans have greater BMD than Caucasians, who in turn have greater values than Asians and Latin-Americans (Weaver et al., 2016).

#### **2.6.2.5 Calcium and other key nutrients**

As living tissue, bone requires nourishment from conception *in utero* to achieve optimum bone health. In particular, sufficient calcium and vitamin D are essential (Cooper et al., 2015; Dawodu et al., 2015). Adequate intake of calcium helps to prevent bone resorption, reducing the rate of bone loss (Heaney et al., 2000; Rozenberg et al., 2020). Insufficient calcium intake leads to low serum calcium levels (Tai et al., 2015). This triggers the release of parathyroid hormone, initiating the bone resorption process and the release of calcium from the bones needed to maintain calcium homeostasis (Tresguerres et al., 2020). A New Zealand study indicated that 20-25% of females had low calcium intake (Fuggle et al., 2018; Horwath et al., 2001; Ministry of Health, 2012). Increasing calcium intake has been shown not only to increase PBM in the early years, but also to reduce decline in bone mass in the years after attaining peak PBM acquisition (Horwath et al., 1995).

The New Zealand Food and Nutrition Guidelines for Healthy Children and Young People aged 2 to 18 years report suggest that one third of young people have inadequate dietary calcium intake. Two or three daily servings of milk and other calcium rich dairy products (such as cheese and yoghurt) are



recommended in order to meet the calcium requirements. Calcium-fortified milk alternatives are available for non-dairy consumers such as soy and rice milks. Other sources of plant-based calcium include green leafy vegetables, legumes (beans and peas), nuts and seeds (such as quinoa, chia, amaranth and sesame seeds), and products fortified with calcium such as fruit juice, breakfast cereals, oils and tofu. Non-plant based sources of calcium include a variety of protein foods, including seafood, lean meats and poultry, eggs and, in particular, canned fish with bones (tuna and salmon) (Ministry of Health, 2012). The recommended daily intake for young people ranges from 1000 to 1300 mg; the main sources of calcium in New Zealand are milk (23%); bread-based dishes (13%); bread (10%); non-alcoholic beverages (8%); and cheese (7%) (Ministry of Health, 2012).

Although it is well known that calcium intake (along with vitamin D which supports calcium absorption) has an important beneficial effect on bone mass and strength, other dietary nutrients and micro-nutrients such as protein (amino-acids), nutrient related hormones, vitamin C, zinc, magnesium, potassium, phosphates, dietary fibres and trace minerals (such as boron found in dried fruits) also have a role (Carlos & Hamrick, 2015). Table 3 lists commonly served foods in New Zealand along with calcium levels (Department of Health and Ageing & Ministry of Health, 2006; U.S. Department of Agriculture, 2015).

Increasing numbers of adolescents and young adults are reducing their milk intake for a number of reasons, including lactose intolerance, which is associated with low bone health (Obermayer-Pietsch et al., 2004).

**Table 3:** Common foods with calcium (U.S. Department of Health and Human Services & U.S. Department of Agriculture, 2015)

<b>Selected food sources of calcium</b>	<b>Calcium (mg/per serving)</b>	<b>Food groups</b>
Almond milk, unsweetened, shelf stable, 1 cup	516	Milk & milk products
Amaranth grain, cooked 1 cup	116	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Apples, raw, golden delicious, with skin, 1 cup sliced	7	Vegetables & Fruit
Apricots, 1 cup sliced	20	Vegetables & Fruit
Asparagus, raw, 1 cup	32	Vegetables & Fruit
Avocado 1 cup cubed	18	Vegetables & Fruit
Beef, ground, 70% lean meat cooked, ½ cup	30	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)

Beetroots, raw 1 cup	22	Vegetables & Fruit
Bread, white, 1 slice	73	Grain foods
Bread, whole-wheat, 1 slice	30	Grain foods
Breakfast cereals, calcium fortified, 1 serving	130	Grain foods
Broccoli, flower clusters, raw 1 cup	43	Vegetables & Fruit
Broccoli, raw, ½ cup	21	Vegetables & Fruit
Cabbage, raw, 1 cup	36	Vegetables & Fruit
Carrots, raw, 1 cup	42	Vegetables & Fruit
Cauliflower, raw 1 cup	24	Vegetables & Fruit
Chapatti or roti, plain, commercially prepared	63	Grain foods
Cheddar cheese, 1 cup diced	937	Milk & milk products
Cheese, parmesan, grated 1 cup	853	Milk & milk products
Chia seeds, 1 tablespoon	76	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Chicken, drumstick meat and skin	16	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Chickpeas, 1 can drained	114	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Chinese cabbage (bok-choi), raw, shredded, 1 cup	74	Vegetables & Fruit
Cottage cheese, 1% milk fat, 1 cup	138	Milk & milk products
Cream cheese, regular, 1 tablespoon	14	Milk & milk products
Fish, canned tuna, 1 cup	19	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Fish, salmon, canned, drained solids with bone	212	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Ice cream, vanilla, ½ cup	84	Milk & milk products
Kale, fresh, cooked, 1 cup	94	Vegetables & Fruit
Kale, raw, chopped, 1 cup	24	Vegetables & Fruit
Lamb, New Zealand, ground lamb, cooked ½ cup	3	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Milk, buttermilk, low-fat, 1 cup	284	Milk & milk products
Milk, non-fat, 1 cup	299	Milk & milk products
Milk, reduced fat (2% milk fat), 1 cup	293	Milk & milk products
Milk, whole (3.25% milk fat), 1 cup	276	Milk & milk products
Mozzarella, part skim, ½ cup	333	Milk & milk products

Nuts, almonds, 1 cup	385	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Orange juice, calcium fortified, 1 cup	349	Vegetables & Fruit
Peas, green, frozen, cooked, ½ cup	19	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Rice milk, unsweetened, 1 cup	283	Milk & milk products
Rice, white, long-grain, regular, unenriched, cooked without salt, 1 cup	16	Grain foods
Salmon, pink, canned, solids with bone, ⅓ cup	181	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Sardines, canned in oil, with bones, ⅓ cup	325	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Sesame seeds, whole, dried 1 cup	1404	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Sour cream, reduced fat, 2 tablespoons	31	Milk & milk products
Soymilk, calcium fortified, 1 cup	299	Milk & milk products
Spinach, frozen, chopped or leaf, 1 cup	290	Vegetables & Fruit
Tofu (firm), calcium fortified ½ cup	253	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Tofu, soft, calcium fortified, ½ cup	138	Legumes, nuts, seeds, fish & other seafood, eggs or poultry (e.g., chicken), or red meat (fat removed)
Tortilla, corn, one, 15cm diameter	46	Grain foods
Tortilla, flour, one, 15cm diameter	32	Grain foods
Turnip greens, fresh, boiled, ½ cup	99	Vegetables & Fruit
Yogurt (frozen), vanilla, soft serve, ½ cup	103	Milk & milk products
Yogurt, fruit, low fat, ½ cup	258	Milk & milk products

The National Osteoporosis Foundation's position statement on PBM concluded that calcium and PA work synergistically to improve PBM (Weaver et al., 2016).

#### 2.6.2.6 Vitamin D deficiency

Vitamin D is important for bone health and, in young children, Vitamin D deficiency manifests as rickets. Vitamin D is a hormone produced mainly through the skin as vitamin D<sub>3</sub> (cholecalciferol) when skin is exposed to sunlight. In New Zealand, for most people the optimum source of vitamin D is 5 to 10 minutes of sunlight exposure to the face, arms and hands 4 to 6 times per week (Osteoporosis New Zealand,

2017b). It is recommended to avoid high ultraviolet levels particularly present during summer. Those at risk of vitamin deficiency such as those with darker skin, frail or institutionalised elderly, those with covered clothing such as veiled women, night-shift workers and those living at higher latitudes in New Zealand with limited sun exposure may require vitamin D supplementation (doses of 400–800 IU/day or 1.25 mg/month) (Nowson et al., 2012).

The dietary form of vitamin D is obtained through oily fish, some nuts and legumes. In New Zealand, inadequate sources of dietary vitamin D<sub>3</sub> are obtained usually from margarine, fish, eggs and milk in small quantities in some foods (refer to Table 4 for more detail). New Zealand limits the foods which are fortified to edible oils and margarine, some dairy and legume-sourced products (refer to Table 5 for more detail) (Department of Health and Ageing & Ministry of Health, 2006). This is unlike the situation in the northern hemisphere where many foods types are fortified with vitamin D such as cow's milk, bread, breakfast cereals and cheese. Some studies in the United States, Sweden, and Finland indicate that safe levels of fortification may be more effective than supplement-taking when vitamin D sources are deficient and help with bone health and other illnesses (for example, for respiratory illnesses) (Bischoff-Ferrari et al., 2012; Martineau et al., 2017). Studies suggest that foods fortified with calcium and vitamin D may have a role to play in improving their intake in individuals that struggle to meet their daily requirements (Martineau et al., 2017). For many, an average intake of 10 µg/day vitamin D is not easily achievable, especially considering that using supplements is not common (Buttriss & Lanham-New, 2020).

Inadequate sources of vitamin D reduces intestinal calcium absorption, which consequently reduces the supply of active calcium required for bone formation. During vitamin D activation, the endogenous 7-dehydrocholesterol that is produced in the skin through sun exposure and/or exogenous dietary vitamin D<sub>2</sub> (ergocalciferol) is processed by the liver and kidneys and becomes physiologically active (Shaker & Deftos, 2018).

**Table 4:** Dietary sources of vitamin D (Martineau et al., 2017; Ministry of Health & Cancer Society of New Zealand, 2012; U.S. Department of Health and Human Services & U.S. Department of Agriculture, 2015)

Sample of foods containing vitamin D	Amount of vitamin D
Fatty fish (e.g., canned pink salmon, herring, canned mackerel, canned sardines)	2.2–13.7 µg per 100 g (86–547 IU)

Portobello & shiitake mushrooms (raw)	0.3–0.4 µg per 100 g (10–18 IU)
Liver (beef)	1.2 µg per 100 g (49 IU)
Egg (large, 50g)	1.1 µg per egg (44 IU)
Fortified foods (e.g. margarine, some milks & yoghurts)	5–10 µg per litre (200–400 IU)
Edible oil spreads	1.0 µg/10g (40 IU)
Dairy products, some analogues derived from legumes & cereals	4–12.5 µg/L (160–500 IU)

**Table 5:** Fortified dietary sources of vitamin D

Examples of food fortification vitamin D	Country	Vitamin D per serving
Cow's milk, 1 cup (250 mL)	Canada, USA, Finland	100 IU
Bread (100g)	Jordan, USA	58-90 IU
Breakfast cereal, 0.75 cup	USA, Canada	40-100 IU
Cheese (16g)	USA	60 IU

### 2.6.2.7 Weight

Diet, nutrition and exercise affect weight, and BMI is a known predictor of bone health (Pilz et al., 2018). Higher body mass may protect against direct trauma, but excess weight may also lead to greater force and hence damage upon a fall (Berg et al., 2015). A meta-analysis of bone and BMI suggested that individuals with a BMI of 20 kg/m<sup>2</sup> or less are almost twice as likely to suffer hip fragility than those with a BMI above 25 kg/m<sup>2</sup> (De Laet et al., 2005). A conscious attempt to keep weight down for aesthetic appearances and/or better performance in sports such as rowing, martial arts, distance running and horse racing, even at a recreational level, can lead to detrimental consequences to both bone health and overall health. In females, this may lead to the female athlete's triad, a combination of low BMD, menstrual dysfunction and low energy levels (Ducher et al., 2011). On a broader level, the term RED-S (relative energy deficient-syndrome) is used for the syndrome that occurs both in males and females (Mountjoy et al., 2018).

A study aimed at identifying lifestyle predictors of bone health suggested that females with low BMI (<19 kg/m<sup>2</sup>) or excess BMI (>24 kg/m<sup>2</sup>) are prone to stress fracture and therefore that caution should be applied when encouraging physical activities to enhance bone health (Elgan & Fridlund, 2006).

While the significance of BMI on bone health is dependent on the level of BMI, in the general adult population, a higher BMI is thought to have an osteo-protective effect and rapid decrease in weight may be associated with bone loss (De Laet et al., 2005). A recent systematic literature review explored the

differences in bone health of children with normal and excess weight. This review found that the bone health of children with excess weight is significantly higher than in normal-weight children. However, the long-term impact of the excess weight on bone health was not clear (van Leeuwen et al., 2017). A recent Norwegian longitudinal study of adolescents aged 15 to 19 has shown that sufficient body weight to height ratio is critical for bone health in adolescence, particularly for those children who lost weight during the two-year follow-up study as the BMD accretion reduced, more so for underweight boys (Nilsen et al., 2019). As young people are still growing, BMI may not be a reliable measure of body composition during growth and maturation as body proportions, bone mass, muscle and fat tissue change at different times and at different rates (Troiano & Flegal, 1998). Ideally, measurements of body composition analyses (fat mass, fat-free soft tissue mass [FFST] and percent fat [%FAT]) should be used to assess the effect of skeletal muscle mass on bone tissue change due to HRSA (Duran et al., 2018).

## **2.6.2.8 Medication affecting PBM**

### **2.6.2.8.1 Oral contraceptives**

Medications such as the combined oral contraceptive pill (OCP) and intramuscular or subcutaneous hormonal contraceptives may negatively impact PBM accrual depending on the extent of use and age at which it was taken (Jackowski et al., 2016). In particular, early use of OCP during the teenage years may impact PBM development (Trémollières, 2013). A recent review of the effect of oestrogens and progestogens on bone health indicated a low dose of progestin-only contraceptives did not hasten bone loss in females (Hadji et al., 2019).

### **2.6.2.8.2 Corticosteroid medication**

Glucocorticoids can induce early bone fractures by impeding bone formation by osteoblasts, decreasing calcium absorption, increasing calcium lost in the urine, reducing growth hormone secretion and inducing changes in hormones (such as oestrogen or testosterone or parathyroid) (Cooper, 2012). Therefore, young people using oral glucocorticoids especially for allergies, asthma, psoriasis or eczema may have reduced bone mass (Melton et al., 2004). New Zealand has a high incidence of asthma according to the Asthma and Respiratory Foundation New Zealand: one in seven children and adults have medicated asthma and related issues; Māori and Pacific people are mostly severely affected (Asher et al., 2017; Asthma and Respiratory Foundation New Zealand, 2019; Health Navigator New Zealand, 2019). The situation may be compounded by vitamin D deficiency or other issues (Sarinho & Melo, 2017).

### **2.6.2.9 Tobacco and alcohol**

Smoking damages bones as it reduces blood flow to the bones, impairs the production and function of osteoclasts, decreases calcium absorption and reduces oestrogen function (Lucas et al., 2012). The mechanics of smoking are complicated as other lifestyle risk factors are often also present (including excessive drinking of alcohol, lower weight, lower PA and early menopause) (U.S. Department of Health and Human Services, 2009). Few studies have considered the impact of smoking on PBM. A systematic literature review indicated that a history of smoking is a significant risk for a reduction in BMD in later life, and therefore carries an increased risk of fracture (more so in current smokers than past smokers) (Kanis, Johnell, et al., 2005).

In a study on the effects of smoking on PBM in young women, BMD at the hip was found to be negatively associated with smoking, and often young women who smoked longer had a higher BMI, which might mitigate the adverse effects of smoking on bone health (Callreus et al., 2013).

As for cigarette smoking, few data are available in adolescents and young adults regarding associations of excessive alcohol consumption with bone health in adolescence and young adulthood (Kanis, Johansson, et al., 2005). A study of young male military recruits found smoking was detrimental to bone health and exercise, but suggested moderate alcohol intake may be beneficial to bone health (Eleftheriou et al., 2013). While moderate alcohol consumption may be good for bone health, a study of 87 female college students suggested that regular heavy drinking of alcohol is a factor in the failure to attain maximum PBM potential as those engaged in this lifestyle were noted to have decreased vertebral BMD (LaBrie et al., 2018).

## **2.7 Measures of osteoporosis – diagnostics**

Osteoporosis is often defined by low BMD and micro architectural deterioration of the bone tissue, with DXA considered the “*gold standard*” of diagnostic tests for osteoporosis (Quiros Roldan et al., 2017). DXA uses two different X-rays sources that typically penetrate through the non-dominant hip and vertebrate bones and soft tissue: their difference in measurement provides an estimate of skeletal mass (Lash et al., 2009).

DXA relies on ionising radiation which interacts on the chemical composition of the bone and surrounding tissues; two photon beams that pass through the bone separately and depending on mineral content in bone (hydroxyapatite), the beams are attenuated to give a measure of BMC which is related to

bone area to give a measure of the areal BMD (International Osteoporosis Foundation, 2015; Moayyeri et al., 2014).

Although DXA is considered the best tool to diagnose osteoporosis, it uses ionising radiation and is expensive to use, requiring specialist equipment and personnel, and is not always globally accessible (Clynes et al., 2020). Other alternative imaging tools are available to estimate BMD (Shewale et al., 2017). These include high resolution peripheral quantitative computed tomography (pQCT) that uses ionisation radiation to assess bone density three dimensionally, with measurements of geometry and volumetric bone density taken in trabecular and cortical areas, which are prone to fractures (Di Iorgi et al., 2018). High resolution peripheral QCT (HR-pQCT) measures bone structure and bone density. Magnetic resonance imaging (MRI) also measures three dimensional bone geometry and microarchitecture without ionising radiation. Hip structural analysis (HSA) uses DXA images to derive geometric measures for bone strength of the hip (Ito, 2011). The trabecular bone score (TBS) measure provides information on trabecular microarchitecture and bone strength by assessing the grey level texture on DXA images (Shawwa et al., 2016). These measures are affected by demographic patterns, BMI, age, gender and ethnicity. Prediction of bone mechanical strength is improved when measures of trabecular bone microarchitecture (which identifies those with fracture) are combined with a BMD measure (Silva & Bilezikian, 2014). Low TBS is associated with vertebral, hip and major osteoporotic fracture risk, with an increased risk of fracture (such as in type 2 diabetics) (Florez et al., 2019; Rianon et al., 2018).

In this thesis, the cQUS instrument was used as the tool to assess bone health in the quantitative study.

### **2.7.1 Use of cQUS**

Quantitative ultrasound is a simple, safe, and cost-effective method of assessing microarchitectural deterioration of the bone tissue that is sensitive to the mechanical and structural features of spongy trabecular bone of the calcaneus (heel) (Laugier & Haïat, 2011; Raum et al., 2014; Tatarinov et al., 2014). The calcaneal quantitative ultrasound device generates high frequency ultrasound waves that have a frequency that exceeds the normal human auditory range of >20kHz (Chin & Ima-Nirwana, 2013).

The heel ultrasound machine device generates the metrics of bone health by use of transverse longitudinal transmission ultrasound waves; where the transducers face each other (the emission and receiver probes); the ultrasound waves are transmitted through water that is contained within two



membranes and passes through the bone. In cQUS measurement ultrasound pulses are generated as sound waves to produce two bone measures: velocity (speed of sound; SOS in m/sec) and frequency attenuation (broadband ultrasound attenuation; BUA in dB/MHz). Sound wave energy is absorbed as it travels through heel bone and soft tissue. As such, the measures generated are dependent on the structure, chemical composition and mineral content in bone (hydroxyapatite) and soft tissues, and so are qualitatively different to DXA, that uses ionising radiation. The Achilles machine expresses ultrasound results as the SOS, BUA and the Stiffness Index (SI). The SI measurement is a composite measure that is formed from the algorithm of the SOS and BUA measures and has a lower precision error which accounts for the temperature variation and water equilibrium (GE Medical Systems Lunar, 2010). Although cQUS produces reliable standalone bone measures, DXA remains the gold standard of bone diagnostic testing (Hans & Baim, 2017; Torres-Costoso et al., 2018). There is no definitive agreement on the exact mechanisms on how ultrasound measurements change during transmission through the trabecular bone although there is good correlation ( $r>0.8$ ) with heel bone density *in vitro* that gives incremental information about bone strength (Wear et al., 2017).

According to a recent International Society for Clinical Densitometry (ISCD) statement, the heel is the only validated skeletal site for clinical use in the management of osteoporosis using QUS (International Society for Clinical Densitometry, 2019). A meta-analysis study indicated that all the different validated heel QUS machines available predicted the risk of different types of fracture with similar performance in older adults (Moayyeri et al., 2012). The same study also suggested that similar genetic determinants were found for heel BUA as have been demonstrated for DXA-derived BMD (Moayyeri et al., 2014). In a later meta-analysis, low cQUS values were found to be an independent predictor of fracture for older men and women (McCloskey et al., 2015). Although DXA is considered the “*gold standard*” of diagnostic tests for osteoporosis, (Quiros Roldan et al., 2017), an advantage of cQUS over DXA is that cQUS may reflect subtle changes to the bone such as the microarchitecture, giving insight to the elasticity and thickness mediated by lifestyle factors such as PA in adolescence (Gabel et al., 2017). The technology is particularly suitable for this study as another meta-analysis found that cQUS is responsive to exercise in all age groups (Babatunde & Forsyth, 2013), supporting observations in previous studies that found cQUS to be a safe, non-invasive method of assessing the skeletal health of healthy normal healthy children (Daly et al., 1997).

Many other studies support the use of cQUS in this thesis. Earlier studies found that comparisons between DXA and cQUS indicated that cQUS may detect low BMD in children with fragility fractures

(Baroncelli, 2008; Chin & Ima-Nirwana, 2013; Fielding et al., 2003; Torres-Costoso et al., 2018; Tuzun et al., 2003). Similarly, a Chinese study of adolescents found a close association between DXA-derived bones measures and the SI calculated from cQUS as did a large German study (Wunsche et al., 2000; Xu et al., 2014). The use of cQUS is popular in many research studies where assessing changes in BMD by DXA is not feasible. A study of 102 Nigerian professional male footballers and runners found cQUS measures higher than participants in other sports played at a professional level (volley-ballers, boxers, cyclists, badminton, cyclists handball, judo players and taekwondo players) although that study was limited by the smaller sample size of the groups of sports included (Laabes et al., 2008b). In other work cQUS was used in 18 to 30 year old sportsmen and found that in elite male track and field athletes and handball players, heel BMD was higher compared to sedentary controls (Solaja & Solaja, 2017). In the Australian CAPA Kids trial, a school-based PA intervention, cQUS (BUA) was able to detect positive changes in response to an exercise intervention (of regular ten minutes of high intensity workouts) when DXA was not (Nogueira et al., 2014, 2015). cQUS has been found to be a useful and practical tool for assessing bone health, particularly when DXA devices are less accessible to the general population (Chin & Ima-Nirwana, 2013).

## **2.8 Factors affecting awareness of PBM and understanding risk factors for poor bone health**

Current strategies for public health awareness of osteoporosis in New Zealand are driven by the Ministry of Health and organisations such as Osteoporosis New Zealand, whose goals include helping New Zealanders have healthier bones. As an internal structure, bones are not visible, and bone loss and deterioration often goes unnoticed. For this reason, osteoporosis is regarded as a silent disease (Kanis, 1989). In those aged over 50 years, osteoporosis is often diagnosed after individuals suffer an initial osteoporotic fracture, usually of the wrist, spine or shoulder (Osteoporosis New Zealand, 2017a).

A Canadian study suggested that to effectively educate the younger generation about osteoporosis, such information must be translated using both traditional methods and social media networks (Holland, 2017). Further, while adolescents and young adults do not tend to be concerned about the future risk of disease, the messages surrounding osteoporosis might be more effective by targeting matters of importance to adolescents and young adults, for example, focusing on the effects of osteoporosis on appearance and physical fitness. In addition, the study suggested that positive reinforcement of health promotion messages should recommend small, daily behavioural changes that represent achievable changes in diet and exercise (Holland, 2017).

Males tend to be unaware of their risks of developing osteoporosis (Cheng & Green, 2008). This is because osteoporosis is perceived to be a disease affecting mainly females due to menopause and hormonal changes. This is an area of concern as osteoporosis is often undiagnosed in men who consequently often suffer more ill-health for longer periods of time before detection, often through a severe fracture (Babatunde et al., 2017).

## **2.9 Conclusion**

Improving PBM potential in young people is an important consideration in reducing the increasingly heavy public health burden of osteoporosis at many levels in society. Given that lifestyle behavioural patterns at a young age may impact bone health in the later years, it is important to address modifiable behaviours and ensure young people are aware of the impact lifestyle choices have on their health in later years.

## **2.10 Chapter 2 summary, future implications and next steps**

Previous research has shown that there are ways of reducing the burden of osteoporosis by improving accrual of PBM. This thesis has focused on one possible particular modifiable lifestyle behaviour that might impact PBM in young people: HRSA.

Previous research has largely used DXA to measure bone changes. However, cQUS has also been shown to be an alternative tool to assess bone health and its response to sport. In this thesis I performed a systematic literature review to consider the literature available. Then, I performed a quantitative study of relationships between HRSA and cQUS in adolescents and young adults before undertaking a qualitative study to better understand knowledge of bone health, and specifically barriers and facilitators to HRSA in this group. The methods used are discussed in the next chapter.

### **3 Chapter 3: Methodology**

#### **3.1 Chapter 3 overview**

In this chapter the methodology and the tools used to assess bone health in the quantitative and qualitative studies are discussed. The methodology used in the systematic literature review is set out in Chapter 4 and details of the study protocol is available in the International Prospective Register of Systematic Reviews under the Registration number CRD42018080101 (Centre for Reviews and Dissemination, 2009). The ethical process and the methods used are discussed below. The research methodologies (mixed methods, triangulation and trustworthiness) are further discussed in Chapter 8. The combination of quantitative and qualitative methods in mixed methods research helps to provide a better understanding of the research topic, recording and re-checking to ensure a robust analytic procedure is maintained. The results may be triangulated together to give a more holistic and trustworthy picture of this study on the association of HRSA on bone health in young people (Carter et al., 2014; Creswell, 2014; Creswell et al., 2004; Schoonenboom & Johnson, 2017).

#### **3.2 Ethical Process**

Ethical approval was sought at the different stages of the study, with amendments sought concurrently to progress to the next stage of the study or carry on the studies in parallel. Victoria University of Wellington (VUW) ethics approval #023752 covered the quantitative part of the study of participants in the 16 to 35 year age group. There were no other exclusion criteria in participant recruitment in the study. The quantitative study commenced in December 2016, with an amendment to the study protocol to include non-university participants approved in August 2017.

In July 2018, the first amendment with HDEC was approved to commence the focus group work with the 16 to 35 year age group. A second amendment was approved in October 2018 to include "other participants" in the qualitative focus group study who had not participated in the original quantitative study with the heel bone ultrasound and online questionnaire, so as to permit a broader range of viewpoints in the 16 to 35 year age group.

The initial Māori consultation process covered the university students, alumni and others in the Wellington region and school environments. Incompletion of the survey and/or non-attendance to the site of the ultrasound scanning was at the participants' discretion. The study was undertaken on the

understanding that participation was totally voluntarily at any level and any participant could participate as much or as little as they chose to.

### **3.3 Sample size**

A sample size was determined using existing literature based on t-tests (Faul, 2009; Field, 2013; Gould et al., 2013; O’Keeffe et al., 2017; Winther et al., 2015). From this, a sample size of 560 was estimated to give 80% power at the 5% significance level for an effect size of 0.2. The Geelong osteoporosis study that used cQUS indicated a sample size of  $n=750$  was required for a 90% power for an effect size of 0.237 (Gould et al., 2013). Other comparisons in the same study between males and females indicated that an effect size of 0.4781779 would require a sample size of  $n=186$  and  $n=138$  for a 90% and 80% power size calculation respectively (Faul et al., 2009; Field, 2013). Therefore, a sample size of 250-1000 participants was sought for the university based population and others and for the purpose of the ethics application.

### **3.4 Recruitment**

Initially, potential participants were identified for recruitment from VUW, based on the age bracket of 16 to 35 years through fliers inviting all those interested within the specified age group to participate. The fliers were distributed through the institutions’ respective communication channels (including emails and newsletters). Potential participants with queries pertaining to the study were able to contact the principal investigator by email and were given the opportunity to ask as many questions as they like and obtain the bone health information pamphlet. Those wishing to participate in the study were emailed a confidential link to the online survey (for those aged 16 to 35 years) prior to the heel ultrasound scan or arranged an appointment for the heel ultrasound scan to be performed on-site at VUW. Written consent was obtained via the survey or when the ultrasound scan was performed, whichever came first.

As interest was shown by a non-university based population, an amendment from VUW ethics was sought to include participants other than those based at the university to give a broader scope to the study. This included two secondary girls’ schools, local sport complexes that the investigator was associated with. The mixed-centred locations of the study in several phases permitted the use of a different approaches with young people that helped to obtain a more comprehensive information for the study (Deyra et al., 2020).

Recruitment fliers were used to invite all those interested within the specified age group. As part of this fliers were distributed through schools' communication channels (including emails and newsletters). Potential participants (in the two schools that the investigator was associated with) were given envelopes containing the relevant information pertinent to the study. The heel ultrasound test was performed onsite in the school environment as part of a classroom activity, and the online confidential survey completed whenever they chose, with the option of additional support available if required. All participants had the option to opt out of the study even after consenting and were informed they did not have to participate or could withdraw from the study for any reason without any negative consequences.

For the qualitative focus group studies, students from the university and young adults aged 16 to 35 years associated with the university were approached to participate. The participants who had previously been involved in the quantitative bone health study who had consented to being contacted by email for further research were also contacted. Others were recruited through word of mouth, recruitment flyers and emails posted through the university's communication channels. Participants were provided with participant information sheets and informed consent forms. Written informed consent was provided by willing participants.

The recruitment of participants included participants from the quantitative study (as they were able to self-select themselves to be part of the of the qualitative study). This permitted integration between data collection from the questionnaires and field notes and focus group work during the different stages of the study. Therefore, by integrating qualitative and quantitative perspectives of the research it was possible to gain a better understanding of the research objectives (Creswell, 2014; Creswell et al., 2004).

### **3.5 Quantitative measurements – cQUS theory**

At the heel test, participants' demographic information (age, height, weight and ethnicity) were self-recorded. The heel ultrasound test was performed using the GE Achilles heel ultrasound machine to obtain measures of bone quality (broadband ultrasound attenuation (BUA), speed of sound (SOS) and stiffness index (SI)) (Frost et al., 2000; GE Medical Systems Lunar, 2010; Moayyeri et al., 2009).

With SOS measurement, the transit time of a sound wave signal passing through the heel bone is compared to the time required for the signal to pass through the water bath alone. This is accurately measured by an internal high-frequency, crystal-controlled clock. In trabecular bone the typical value of SOS is ~1520 m/sec. With the BUA measurement, the broadband ultrasound pulse is transmitted through

the heel bone and the reduction of intensity at different range of frequencies is measured and compared to the weakly attenuating reference medium (water). The differing ranges of frequencies are transformed to produce a net attenuation curve, where the value of the curve's slope is the BUA value. In the trabecular bone the typical value of BUA is 110 dB/MHz. With the SI measurement, the temperature variations in water and heel are able to equilibrate and cancel each other out in the linear combination algorithm of the SOS and BUA measurements. Thus, the SI measurement is produced faster and has an improved precision error compared to SOS or BUA alone, so fracture risk increases as the SI decreases. The SI algorithm is based on scaled and normalised SOS and BUA values ( $SI = (0.67 * BUA + 0.28 * SOS) - 420$ ) (GE Medical Systems Lunar, 2010).

The Achilles EXP II heel ultrasound device also provides T-score and Z-score measures for females only aged 20 years or older. Although, as reference data is not included in the device, these values are not available for males, ethnicity and those aged 19 years or under (GE Medical Systems Lunar, 2010).

The T-score is the SI above or below a reference (the young adult mean value SI) in standard deviation (SD) units. The % Young Adult measure is an individual's SI as a percentage of the mean SI for women aged 20 to 35 years. Similarly, the Z-Score is the SI expected age matched value in SD units, relative to the intra-population variation. The % Age Matched measure is an individual's SI value as a percentage of the expected values for a reference group of the same age and sex. SI values that are >16 units below that expected at a given age (i.e. Z-score is lower than 1 SD) suggest that age alone does not reflect bone status, therefore underlining conditions should be considered including age, health and relevant clinical risk factors (Cooper & Ferrari, 2019; Frost et al., 2000; GE Medical Systems Lunar, 2010; Kanis & Kanis, 1994).

### **3.6 Measurement in vivo**

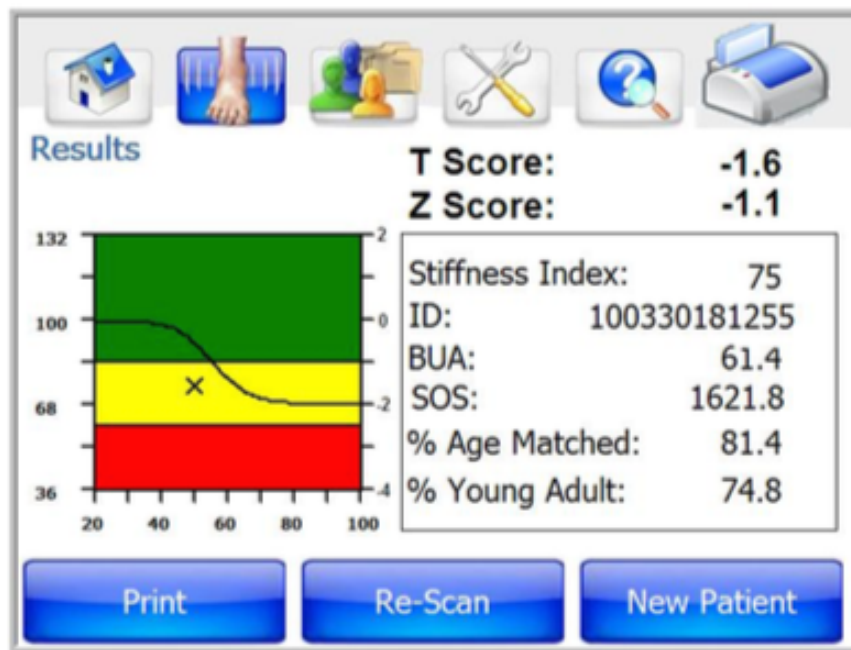
Prior to the heel test, the heel was sprayed with alcohol (which is used as a coupling agent) and placed on the machine footplate while the measurement was performed after the two inflated membranes were filled with warm water. The mean of both feet were recorded for the cQUS measures (Roux et al., 1993).



*Figure 8: Achilles heel ultrasound machine (GE Medical Systems Lunar, 2010)*

### Measurement results Screen

After a measurement, the LCD screen shows the Stiffness Index, results graph, and related values refer to Figure 3-9.



**Figure 3-9 Measurement Results**

*Figure 9: An example of cQUS results output (GE Medical Systems Lunar, 2010)*

### 3.7 Quantitative measurements – questionnaire

The questionnaire was implemented through the Qualtrics software programme obtained through VUW (Qualtrics, Provo, UT), accessed at the following link:

[http://vuw.qualtrics.com/jfe/form/SV\\_41tgRCe3Vtee0VT](http://vuw.qualtrics.com/jfe/form/SV_41tgRCe3Vtee0VT)

The online questionnaire was used to provide information that included: age; height; weight; ethnicity; personal and family history of fracture; pubertal status and oral contraceptive (OCP) use; cigarette smoking; alcohol intake; dietary calcium intake (dairy and food frequency questionnaire); past medical



history (co-morbidity score, to elicit information on possible other secondary causes of osteoporosis e.g. insulin dependent diabetes, hyperthyroidism); drug history; PA; and sporting activity.

The questionnaire incorporated validated sporting activity questions adapted from studies by Weeks et al. (2008) and Kowalski et al. (2004), modified for the New Zealand population. These questions were used to determine the modified past recreational sporting activity history score, modified weekly PA score and weekly sporting activity (Clark et al., 2012; Deere et al., 2016; Dolan et al., 2006; Kowalski et al., 2004; Saint-Maurice et al., 2014; Weeks & Beck, 2008). PA recorded included the duration and types of sport undertaken regularly. Respondents self-reported up to eight habitual recreational sporting activities engaged in over their lifetime in order to calculate a past habitual recreational sporting activity history score from age 0 to the present day. This score was based on the bone physical activity questionnaire score (BPAQ) which uses an algorithm that includes the effective load stimulus (ELS) derived from ground reaction force test, years of sport participation and an age-weighting factor (pBPAQ Algorithm:  $[ELS \times \text{Years of participation} \times \text{age weighting factor: } <15\text{years} = 0.25, >15\text{years} = 0.1])$  (Weeks & Beck, 2008, 2010). Age-weightings were incorporated into the algorithm by Weeks et al. (2008) to recognise the greater osteogenic effects of exercise during growth as opposed to exercise after skeletal maturity. As such, weighting did not specifically differentiate between those younger participants aged 16 to 17 years old compared to those in their thirties except through their linear age. Respondents also detailed current PA and current sporting activity (Kowalski et al., 2004). Current weekly sporting PA was further categorised as either high impact weight-bearing, weight-bearing, or non-weight-bearing sporting activities based on supporting literature (Kato et al., 2015; Weeks & Beck, 2008).

Assessing historical HRSA relies on recall and analysis of relevant past information. There are a number of measures of past HRSA available in the literature, including the BPAQ where the ELS score originated (Weeks & Beck, 2008, 2010). The study by Kato et al. (2015) in adolescents and young adults explored the correlation of past sporting activity on bone mineral content (BMC) with areal bone mineral density (aBMD) using an osteogenic index (OI). The OI is based on several factors, including the amount of loading required to stimulate the bone building process, which is about 4.2 times body weight: frequency of sporting activity (times per week); duration (years); and strain score of previous sporting activity, which was calculated by categorising the ground reaction force (GRF) of the sport (Nilsson et al., 2009). The GRF of sporting activities were categorised into four levels: GRF 3 (high impact, weight-bearing sporting activities involving jumping, such as volleyball, basketball, handball, rhythmic gymnastics,

baton twirling, gymnastics and classical ballet); GRF 2 (activities involving sprinting and turning such as sprinting, soccer, softball, badminton, futsal and tennis); GRF 1 (activities involving minimal impact such as table tennis, karate and shorinji-kempo (a martial art)); and GRF 0 (non-impact sports such as swimming, bicycling and sailing) (Kato et al., 2015). In addition, it is suggested that PA is more osteogenic during the skeletal growth phase than when the skeletal structure is more mature, as bone tissue responds more intensively during the skeletal growth to dynamic loading, which subsequently instigates a flow of osteogenic cellular actions (Groothausen et al., 1997; Turner & Robling, 2003). Daly and Bass (2006) assessed lifetime sport and leisure activity using OI and bone-parameters by DXA, cQUS and QCT and found that sustained weight-bearing activity in young adulthood reduced the risk of osteoporotic fracture later in life. This finding was supported by a Japanese study of adolescents and young adults using MRI and DXA tools to validate the sporting activity OI score which was found to be a feasible tool to assess PA (Kato et al., 2015). Studies using pQCT and DXA bones were supportive of the BPAQ score measure, finding it more predictive of positive bone characteristics in young females aged 18 to 30 years than in older women (Kim et al., 2018; Kim et al., 2016).

### **3.8 Statistical methods**

All descriptive statistics and statistical analyses were carried out using SPSS Statistics for Macintosh, Version 23.0 (IBM Corp., Armonk, NY, USA). A p-value of less than 0.05 was considered to be statistically significant. We first assessed univariate associations between predictors and cQUS bone measures.

Predictors included: gender; ethnicity; age; BMI; height; weight; pubertal timing; smoking; alcohol consumption; fracture (age of first broken, fracture history, family fracture history); daily calcium consumption; weekly physical activity; weekly sporting physical activity (categorised into: high impact weight-bearing activity; a combination of high impact weight-bearing and weight-bearing activity; non-weight-bearing activity; a combination of high impact weight-bearing, weight-bearing activity and non-weight-bearing activity); past recreational sporting activity history; and oral contraceptive use. Ethnicity was self-reported and then categorised into European, Māori and Pacific people, Asian, Indian, Middle Eastern, Latin American and African groups. For the purposes of this study, detailed sub-group analysis was not possible due to the small sample size of the sub-groups. As a result, classification of participants' ethnicity was either divided into three categories ("European", "Māori and Pacific people" and "Others" who were neither European, Māori nor Pacific people) for preliminary analyses, then in the final analysis between two groups ("European" and "Others" that included non-Europeans, Māori and Pacific people).

Those variables that were associated on univariate analysis at a level of  $p \leq 0.1$  were then included in multiple linear regression analyses. Variables included in the regression analysis were: BMI; age; gender; ethnicity; smoking status; alcohol consumption; pubertal timing; daily calcium consumption; physical activity; weekly sporting categories; and past recreational sporting activity. For each analysis, approximate normality was confirmed with histograms, Q-Q plots of residuals, residuals versus fitted plots indicated homoscedasticity of residuals, and Cook's distance did not identify any influential cases.

An additional analysis for the top ten popular sports was included, using multiple linear regression analysis to predict bone health from the sports played, age, gender, BMI and ethnicity. For descriptive statistics, the results were reported as mean  $\pm$  standard deviation (SD) or count and percent in each category.

### **3.9 Focus group work**

Study recruitment was undertaken from July 2018 to October 2018 in the Wellington region in New Zealand. Ethical approval was obtained from the New Zealand HDEC (reference #HDEC 18/CEN/18). The student population from VUW, and other adolescents and young adults associated with the university campus and students including school children aged 16 to 35 years were recruited: no other restrictions were in place. Participants were provided with participant information sheets and informed consent forms. Focus groups were held at the university in a neutral toned meeting room with comfortable seating. At the focus groups, participants were reminded that their participation was voluntary and could elect to use a pseudonym of their choice for the group discussion by writing their own name tags to be worn on their clothing (if they preferred). Participants were also reminded that they could choose not to answer any questions, could leave the group at their own discretion without giving any reasons and without any consequences, and that any data provided prior to leaving the group would not be withdrawn (but would be stored in de-identified form).

The participants were encouraged to discuss with each other what they understood about PBM and the risk of osteoporotic fracture affecting their bone health. Focus groups were semi-structured with open-ended questions. Participants were given an option to write points of discussion on scribble pads to avoid missing information thought of but not discussed openly for whatever reason. Discussions were recorded with two or more recording devices and an assistant recorded non-verbal communication (to capture information about the level of consensus and dissension to the topic under discussion).

At the end of each discussion, the lead interviewer summarised the ideas that had been discussed and asked for any final feedback to ensure all ideas, opinions and experiences were recorded. After each focus group, a debriefing session was held with the study facilitators to highlight any discussion issues to be addressed, including any keywords, themes or patterns and relationships identified. Subsequent focus group interviews used an iterative process whereby any previous emergent themes were followed up with open-ended probes to obtain further insights until all themes were fully explored to achieve theoretical data saturation.

The recordings of the focus group discussions were transcribed verbatim, and then verified by listening to the voice recordings several times to ensure all data was recorded correctly. All participants' data were de-identified. The transcription and any tabulated data, including any notes obtained from the focus groups, were thematically analysed. We used an iterative process of qualitative analysis whereby inductive patterns emerge into themes from the data itself by constant comparative analysis (Corbin, 1998). Sections of data were then assigned codes and compared for consistency. The assigned codes were categorised into themes. NVivo (qualitative data analysis software; QSR International Pty Ltd. Version 12, 2018) was used to organise the data.

### **3.10 Summary**

A mixed methods research approach was undertaken. A systematic literature review search was performed of the current literature, with quantitative methodology used to assess the relationships between HRSA and other lifestyles with bone health, as measured by cQUS. The qualitative focus group studies assessed young people's knowledge of PBM acquisition, osteoporosis and the lifestyle factors that influence HRSA participation. The mixed methods approach using quantitative and qualitative components were triangulated together to give a richer understanding of factors that influence PBM acquisition in young people, specifically the role of HRSA.

## 4 Chapter 4: Systematic literature review

### 4.1 Chapter 4 overview

Earlier chapters have discussed peak bone mass acquisition in relation to the burden of osteoporosis and its effect on the general population. Much of the available literature focuses on physical activity or sporting physical activity for those at an elite or competitive level of the sport or a group of sports at national or international levels. In the majority of these studies, the comparative level of measure for bone health is assessed through DXA, pQCT or some other form of ionising or radiating method. In this study, we aimed to systematically review the literature specifically in relation to non-elite activity at a recreational level and how it relates to bone health in young people as represented by calcaneal.

Therefore, we focused on non-elite activities performed at recreational levels as this is generalisable to more of the adolescent population, rather than the exclusive group of young people aged 11 to 35 years that are engaged in competitive sport at a higher level.

The findings of the systematic literature review are presented in Chapter 4.

The results of this systematic literature review have been accepted for publication and is referenced below:

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# **The Relationship Between Non-Elite Sporting Activity and Calcaneal Bone Density in Adolescents and Young Adults: A Narrative Systematic Review**

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## **4.2 Abstract**

**Introduction:** Osteoporotic fracture represents a major public health burden. The risk of fragility fracture in late adulthood is strongly impacted by peak bone mass acquisition by the third decade. Weight-bearing sporting activity may be beneficial to peak bone mass accrual, but previous studies have focused on elite sporting activity and used dual energy X-ray absorptiometry as a measure of bone density. The authors performed a narrative systematic literature review of individual sports performed non-competitively or at local level and calcaneal quantitative ultrasound (cQUS) bone measures in young people.

**Methods:** Multiple databases were systematically searched, up until 31<sup>st</sup> March 2019. The authors included studies of participants mean with a mean age 11 between 35 years reporting any level of recreational sporting activity and cQUS measures, excluding elite or professional sporting physical activity. Studies (title and abstract) were screened independently by two reviewers and a third reviewer resolved any discrepancies. STROBE guidelines were used to check the reporting of observational studies. The Newcastle – Ottawa Scale was used to assess the risk of bias of the studies included in the review. The systematic literature review was registered with the International Prospective Register of Systematic Reviews (PROSPERO).

**Results:** A search yielded 29,512 articles that considered relationships between bone density assessed by any technique and sporting activity. Duplicate and out of scope abstracts were removed. This left 424 papers which were screened by two reviewers, with six meeting inclusion criteria, including assessment by cQUS. The authors identified papers where sports considered included soccer (football), swimming, cycling, gymnastics, dancing, badminton, basketball, fencing, wrestling and judokas. Although study heterogeneity prohibited meta-analysis, all six included studies reported significant benefits of weight-bearing non-elite sports on cQUS outcomes.

**Conclusion:** Our study found beneficial effects of non-elite sports participation on cQUS in adolescence and young adulthood, although further work is now indicated.

**Keywords:** Calcaneal quantitative ultrasound (cQUS)<sub>1</sub> – adolescent<sub>2</sub> – sport<sub>3</sub> – bone<sub>4</sub> – systematic review<sub>5</sub>

### 4.3 Introduction

Osteoporosis is a major international public health problem through its association with fragility fracture (Cole et al., 2008). Osteoporosis is often described as a disease which occurs when one becomes older, more often in females, and preventative methods often focus on older people (Tan et al., 2014). However, childhood and adolescence are critical periods of bone development; modifiable lifestyle behaviours have a major impact on the development of bones throughout life and peak bone mass (PBM) is a major determinant of later fracture risk (Hernandez et al., 2003). Previous studies have suggested that physical activity (PA) and dietary calcium intake during childhood and adolescence play a critical, synergistic role (Weaver et al., 2016). There are, however, a limited number of studies looking at the impact of participation in individual non-elite sports on bone health at the calcaneum in young people, with most studies focusing on the effect of elite sporting activity or organised sports on bone health as assessed by using ionising methods such as dual energy X-ray absorptiometry (DXA) (Tan et al., 2014).

A number of previous systematic literature reviews have considered the relationship between sporting activity and bone health in this age group, but have studied associations between dual energy X-ray absorptiometry (DXA) and sporting activity. The effect of sporting activity varies according to sex, the skeletal sites and bone outcomes measured as assessed by DXA and peripheral quantitative computed tomography (pQCT) which gives an estimate of volumetric bone density and other assessment of bone strength at relevant sites, including the calcaneus (Zulfarina et al., 2016). A systematic literature review assessed PA and bone strength: the findings indicated that bone strength modifications due to PA were related to maturity level, sex and study quality (Tan et al., 2014). A review reported that weight-bearing exercise enhanced bone mineral accrual during early puberty, but it was unclear which form of exercise was the most beneficial (Hind & Burrows, 2007) while another systematic literature review of targeted exercise (any combination of weight-bearing impact, resistance, endurance training) for optimising bone strength throughout life supported the use of exercise to develop bone strength in children at weight-bearing sites (Nikander, Sievänen, et al., 2010).

Overall, previous studies that aimed to understand the relationship between sport in young people and bone health used ionising imaging tools, such as DXA (Deere et al., 2012b; Ito et al., 2017; Júnior et al., 2017; Matthews et al., 2006; McVeigh et al., 2019; Morris et al., 2000). There has been an increasing interest in the use of heel ultrasound as an alternative assessment of bone density that also provides structural information of the bone. Ultrasound technology is non-invasive, widely available,



low-cost and portable tool that provides an assessment of bone density and quality at a readily accessible weight-bearing site with a high trabecular bone content (GE Medical Systems Lunar, 2010). Ultrasound technology has been shown to be associated with fragility fracture in older adults (Krieg et al., 2008). In addition, a study by Hans & Baim (2017) suggested that there is potential to use QUS alongside an assessment of clinical risk factors and that cQUS should be considered as a method to assess bone health when DXA is unavailable. The aim of this review was therefore to assess the relationship between non-elite sporting activity and bone density, as assessed by heel ultrasound in adolescents and young adults, through a systematic search and a narrative synthesis.

#### **4.4 Methods**

The systematic literature review study protocol is registered with the International Prospective Register of Systematic Reviews under the Registration number CRD42018080101 (Centre for Reviews and Dissemination, 2009). The initial protocol described reviewing the association between non-elite sporting activity and bone density, with the latter being assessed using any bone measurement method. While the search and screening process adhered to this, for the current paper the authors only included studies that had assessed bone density through cQUS. This was a pragmatic decision based on the number of studies identified. The additional data retrieved will be used in a separate report on relationships between DXA and elite sporting activities.

An electronic search of PubMed/Medline, ProQuest, AUSPORT, AusportMed and Medline (Ovid) proceeded until 31<sup>st</sup> March 2019 to source the relevant articles under review (see Table 1 for a summary of search string used).

Observational studies were the main type of study for inclusion, however if baseline data could be extracted from trial or interventional studies, these were also included. Only full text, peer-reviewed journal articles published in English, unless they could be translated fully using Google Translate, were included (Google, 2019). There were no limitations on sample size or country of origin.

##### *Participants, interventions and comparators*

The following search strategy was applied:

(1) Exposure: Non-elite participation in sporting activity performed at school or leisure time as an organised or regular activity – either self-reported or measured objectively. Participation in any type of sporting physical activity (quantitative studies).

(2) Outcome: Any bone heel ultrasound measures such as speed of sound (SOS)/velocity of sound (VOS), broadband ultrasonic attenuation (BUA), stiffness index (SI)/quantitative ultrasound index (QUI).

(3) Population:

Inclusions: The age of study participants was a mean age between 11 – 35 years inclusive. Both sexes were included. Participation in a named sporting activity at a local or regional level.

Exclusions: Those with long-term disease or health issues such as physical or mental disability which directly affect bone health through treatment, supplementation or medication were excluded. Animal studies were excluded. Any participation in competition(s) at an elite or national level was also considered an exclusion, although typically elite sport is sport participation at a higher levels such as at division I and professional levels (Bellver et al., 2019; Lorenz et al., 2013).

Two independent reviewers (HP and LS) screened the abstracts and titles of relevant reports and articles in duplicate to determine whether these met the given criteria for inclusion in the systematic literature review. Any discrepancies were resolved through discussion or with a third reviewer (ED). Then, the reviewers independently screened the articles identified from the title and abstract screening to determine whether they met the inclusion criteria for the review, and a third reviewer's (ED) agreement was sought where appropriate. Where feasible, study authors were contacted by email for completeness and clarity. For those articles and reports meeting the inclusion criteria, their reference lists and bibliographies were screened for any additional relevant studies to be included in the systematic literature review.

#### *Methodological assessment: data extraction and presentation of study results*

The review is reported using the guidelines Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Moher et al., 2009).

#### *Risk of bias in the included studies*

The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines were used to check the reporting of observational studies (Vandenbroucke et al., 2007). The descriptive information of each study was extracted and summarised in Table 2. To assess the quality of the methods used in the selected studies, the Newcastle-Ottawa Scale (NOS) risk of bias assessment tool was used (Wells et al., n.d.).

## 4.5 Results

### *Study selection*

Figure 1 shows a flowchart of the literature search and the study selection process. The search yielded a reference list of a total of 37,042 articles. Duplicates were removed, leaving 29,512 articles to be screened by two independent reviewers. Based on the title and abstract, 29,090 articles were excluded, primarily because they did not use cQUS as a measure of assessment of bone outcomes. This left 424 papers to be assessed in full where available; the reviewers were unable to obtain the full manuscript for the study performed by Coaccioli et al. (2013), despite attempts that included direct approach to the authors. In addition, the reviewers were unable to obtain a full translation from Chinese of a study by Qian (2017). As such, those two studies were excluded. Following full text screening, a total of six studies remained as meeting the inclusion criteria for this systematic literature review. The sports identified from this process were soccer, swimming, cycling, gymnastics, dancing, badminton, basketball, fencing, wrestling and judokas (see Table 2).

### *Risk of bias assessment*

Using the NOS risk of bias assessment tool (Wells et al., n.d.), the risk of bias of the six articles included in this systematic literature review was generally assessed as low to medium, with one of the studies assessed as having a high risk of bias (see Table 3). The main area of bias identified was in the recruitment process of the studies; most studies failed to clearly indicate how the sample size calculation of the study was approached and how and why participants were invited to participate in the study. Some articles failed to report how many participants were approached to participate in the studies, and why they were selected or not screened for the studies.

The bias assessment tool indicated that three of the included studies had low bias with clear study designs, confounding factors such as diet and PA were acknowledged and detailed dietary assessment was available, and face to face interviews for PA (Gomez-Bruton et al., 2015; Nurmi-Lawton et al., 2004; Vlachopoulos et al., 2018). Of the studies with medium bias, Yung et al. (2005) had small sample

numbers in each of the four groups (n=15), with limited details of recruitment and had performed a questionnaire that assessed PA and diet of participants. The Madic et al. (2010) study was also assessed as medium bias due to the limitations of recruitment details and lack of dietary and PA assessment; while the Mentzel et al. (2005) study was assessed as high bias due to reduced clarity of the level and intensity participants' different sports activities.

### *Study designs and participant characteristics*

The studies extracted were too heterogeneous to allow for meta-analysis. A graphical display of the results and a summary of the key characteristics of the studies included in the review, along with a synthesis of the studies in a narrative form, is presented in Table 2. The sporting activity referred to in these studies included soccer, swimming, cycling, gymnastics, dancing and, to a limited degree, badminton, basketball, fencing, wrestling and judokas.

Of note, the level of activity in the control groups was very different across the included studies. In the Vlachopoulos et al. (2018) study compared 116 young Caucasian male adolescents that undertook regular swimming, soccer or cycling sports with active controls (including identifying participants that participated in other sports or swimming, soccer or cycling for less than three hours weekly). In the Gomez-Bruton et al. (2018) Spanish mixed gender cross-sectional study of 129 Caucasian children was part of a much larger controlled trial. That study compared the bone health of swimmers who competed at regional swimming tournaments at the start of the study with normally active control children who did other sports for less than three hours a week and did not participate in other aquatic sports (Gomez-Bruton et al., 2015). In the Madic et al. (2010) Serbian study of 62 participants, male soccer players were compared to controls who participated in regular school based sporting activity only. In the Yung et al. (2005) study of 55 Chinese male university students compared the bone effects of weight-bearing sports of swimmers, dancers and soccer by contrasting players with a sedentary control group of students who did not exercise. In the Mentzel et al. (2005) German study was a mixed study of 177 boys and girls from regional sports schools with various sports backgrounds whose bone health was compared against a reference population. That study presented limited details on how the levels of activity were assessed (Mentzel et al., 2005). Finally, in the Nurmi-Lawton et al. (2004) English study compared 97 female gymnasts and normally active controls (the controls did not participate in high impact sports for the past year at a competitive level, although two of the controls were competitive swimmers).

The six studies included in this review had a sample size that ranged from 55 to 177 participants. Five of the six studies included in this review studied school-aged children, with the study participants recruited from schools or sports clubs (Gomez-Bruton et al., 2015; Madic et al., 2010; Mentzel et al., 2005; Nurmi-Lawton et al., 2004; Vlachopoulos et al., 2018). The remaining study recruited students from their local university (Yung et al., 2005). The inclusion criteria varied amongst the six studies, with the main criteria being healthy children or adolescents with a reported sport history. General exclusion criteria in the studies included a history of chronic or musculoskeletal disease, and taking medication that affected bone metabolism. Gomez-Bruton et al. (2015), Mentzel et al. (2005) and Vlachopoulos et al. (2018) specifically stated that participants with a known fracture history were excluded. In the Mentzel et al. (2005) study also excluded children with a small shoe size as well as participants that missed appointments (drop-outs) and participants that could not be located.

The mean age of participants in the studies included in this systematic literature review were between 11 to 22 years. Pubertal status was considered in three of the six studies (Gomez-Bruton et al., 2015; Madic et al., 2010; Vlachopoulos et al., 2018). None of the reviewed articles included the upper age range from 23 to 35 years. Collectively, 210 females and 426 males were included in this systematic literature review. One study included females only (Nurmi-Lawton et al., 2004), three studies included males only (Madic et al., 2010; Vlachopoulos et al., 2018; Yung et al., 2005), and two studies included both male and female participants (Gomez-Bruton et al., 2015; Mentzel et al., 2005). The ethnicity of the study participants was clearly stated in four of the six studies. Two studies recruited those who were of white healthy Caucasian ethnicity only (Gomez-Bruton et al., 2015; Vlachopoulos et al., 2018). The third study declared all the participants were white except for one participant in their study (Nurmi-Lawton et al., 2004), while the fourth study exclusively recruited Chinese university students (Yung et al., 2005). The Serbian and German studies do not state the study participants' ethnicity but, for the purposes of this review, the authors assumed their ethnicity based on each study's locality (Madic et al., 2010; Mentzel et al., 2005).

Nutrition was acknowledged as a factor in bone health in all six studies: four of the six studies completed some form of dietary analysis (Gomez-Bruton et al., 2015; Nurmi-Lawton et al., 2004; Vlachopoulos et al., 2018; Yung et al., 2005). A trained researcher helped participants complete a calcium frequency questionnaire in the Gomez-Bruton et al. (2015) study. In Yung et al. (2005) university study students completed a 7-day recall for each participant's usual calcium intake. Similarly, the Nurmi-Lawton et al. (2004) longitudinal study used regular estimated food diaries for

the duration of the study. The Vlachopoulos et al. (2018) study stated that one of its limitations was the lack of nutrition-related covariates in the analysis despite the fact that such data was collected for the study (Vlachopoulos et al., 2018).

#### *Assessment tool*

The cQUS tools used include Lunar Achilles Insight (used in two studies), Sahara Hologic (used in two studies), Heel Ultrasound Densitometer Paris (Norland), Contact Ultrasound Bone Analyser, and Lunar Achilles Insight (TM Insight GE Healthcare, Milwaukee, WI, USA with OsteoReport PC (software version 5 GE Healthcare) (see Table 2). There was considerable variability in the bone measurements taken and the level of detail in the description of methods used to perform the measurements. All the papers employed statistical analysis using SPSS. The six study results were all presented *a priori* with *p*-values of  $<0.05$  being considered statistically significant but, due to the heterogeneity of the tools and methods employed, output values were not directly comparable.

#### *Sports participation – duration and intensity*

The sports measured in this review include soccer, swimming, cycling, dancing, badminton, basketball, gymnastics, fencing, wrestling and judokas. Lack of comparability of intensity of sports training and duration of involvement in regular sport made it hard to draw comparisons between studies. For example, in the Vlachopoulos et al. (2018) study, athletic sports male participants at baseline had been engaged ( $\geq 3$  hours/week) in osteogenic (soccer) and/or non-osteogenic (swimming and cycling) sports for the previous three years or more. Average years of training ranged from 3.9 to 5.9 years (Vlachopoulos et al., 2018). By contrast, the Gomez-Bruton et al. (2015) study assessed swimming training in both girls and boys who had a previous history of swimming and competing in regional tournaments for more than three years and training for a minimum of six hours per week. The inclusion criteria for this study was that participants had to have been training on a regular basis in a sport (cycling was not included) for more than three hours per week for at least three years prior to the study. The swimmers were divided into those who were considered as pure swimmers as they had only participated in other sports for one or two years and other swimmers who were classified as participants in other sports for more than two hours per week and/or other sports for a period of more than two years prior to the study (Gomez-Bruton et al., 2015). In the study by Madic et al. (2010) study on boys' soccer activity required that participants had a sport history of a minimum one year of active sports occupation in soccer with weekly training sessions typically lasting up to 10 to 15 hours. In the Yung et al. (2005) study male university students were categorised by main sporting activity from high to

low impact weight-bearing and non-weight-bearing exercises (soccer, dancing, swimming and no exercise). This exercise group of participants had to be engaged in supervised training in either soccer or dancing or swimming for at least two years, at twice a week, for at least two hour sessions (Yung et al., 2005). In the Mentzel et al. (2005) study with both boys and girls included eight sporting activities: soccer, badminton, basketball, gymnastics, fencing, wrestling and judokas (as only one child each represented tennis, triathlon and weight-training and, therefore, those sporting activities were not included in the analysis). Sport participants had for two or more 90-minute training sessions weekly at the start of the study; past and current sporting activity details of participants were not stated (Mentzel et al., 2005). Finally, Nurmi-Lawton et al. (2004) studied female artistic gymnasts who had trained two or more years with more than 10 hours weekly training and had competed at club or regional level.

Hence the studies were not comparable for many reasons, including due to disparities in the duration and intensity of sporting activity of participants. For example, the athletes in the Mentzel et al. (2005) study the potential activity levels of the sporting participants could potentially but not equivocally be equated to the control groups of the other studies (Gomez-Bruton et al., 2015; Vlachopoulos et al., 2018).

#### *Comparator (control) groups activity level*

The details provided in the six studies for the comparator (controls) measurement for potential past sporting history and other physical activities (which may have impacted the bone measurements) was often lacking and was too heterogeneous to compare across the studies.

In the study that athletic sports compared osteogenic soccer against non-osteogenic sports (swimming and cycling) and with a small control group of 14 active boys who did not participate in any sports (soccer, swimming or cycling) for more than three hours per week or in the three years prior to study commencing (Vlachopoulos et al., 2018). In the study by Gomez-Bruton et al. (2015) of swimmers were compared with a control group who had neither performed in any aquatic sports on a regular basis nor participated in any other sport activity for more than three hours a week. The study by Madic et al. (2010) on boys' soccer activity was compared to that of young boys not actively engaged in sport, aside from 90 minutes per week of PA at school. In the Yung et al. (2005) study of university male athletes were compared to a sedentary group who did not participate in exercise. In the study by Mentzel et al. (2005) the athletes were compared to local reference data of 3,299 healthy Caucasian children and adolescents obtained from an earlier study by the same author. The two studies used the

same conditions and same device, although details of the reference population's past sports history or PA level was not reported (Wunsche et al., 2000). The study by Nurmi-Lawton et al. (2004) gymnasts were compared to controls who were involved in normal activities (including walking to school and physical education classes at school) for an average of 2.6 hours weekly and not engaged in sports that required all year training at competition level. The potential sporting activity levels of the control participants from the studies by Vlachopoulos et al. (2018) and Gomez-Bruton et al. (2015) reached a maximum of 3 hours per week, may potentially equate to the sporting activity of the participants of the study by Mentzel et al. (2005), as this study included participants from a sports college that trained less than participants in other studies.

### *Bone measurement results*

Overall, high impact weight-bearing sports such as soccer playing and gymnastics or dancing were associated with the greatest benefits for bone health (Table 2). Swimmers and cyclists were not at any apparent bone advantage compared to controls. Hence, the study by Madic et al. (2010) of male soccer players reported significant differences in cQUS between soccer players and controls. The study by Yung et al. (2005) found weight-bearing and high impact exercise to be associated with higher QUS parameters. In particular, soccer players and dancers had significantly greater BUA, VOS and SI than swimmers and the sedentary control group. In the study by Vlachopoulos et al. (2018) soccer players had statistically greater cQUS ultrasound parameter SI compared to swimmers, cyclists and controls at baseline.

Similarly, the gendered study by Gomez-Bruton et al. (2015) compared swimmers with controls and found no significant differences in any cQUS parameters when measuring the non-dominant calcaneus between any of the groups. In the only study to compare a very wide range of sporting activities, and with attendant power considerations for that reason, the study by Mentzel et al. (2005) study showed significant differences between cQUS in SOS and BUA measures between the sports students (a mixed gender study of 177 children aged 11 to 18 years) and the reference group. Although direct sporting comparisons were more challenging, the authors reported higher SOS values in athletes than wrestlers, in basketball players than fencers, in basketball players than wrestlers, and in gymnasts compared with judokas sports players (Mentzel et al., 2005).

Some studies investigated the level (or impact) of weight-bearing activity and bone health. While the Mentzel et al. (2005) study did not observe strong correlations between increased weight-bearing



activity in basketball (n=7) and bone health, this may be reflective of the very small sample size and lower study power. As such, the authors consider that the results of the Mentzel et al. (2005) study should be interpreted with caution. In the study by Mentzel et al. (2005) judokas players and wrestlers showed a significant positive correlation between heel BUA versus level of activity. Further, when considering age related SOS as an outcome, significant differences were shown between badminton players and gymnasts, between basketball players and fencers as well as between judokas players and gymnasts (Mentzel et al., 2005). Finally, one study considered body build in more athletic young people; in the Numri-Lawton et al. (2004) study of gymnasts revealed that the gymnasts were smaller and lighter than controls, but they still had significantly higher cQUS.

#### **4.6 Discussion**

In contrast to many other reviews, this review focuses only on specific non-elite sporting activity performed at a non-competitive level in young people as assessed by calcaneal ultrasound. The quality of the six articles was generally assessed as moderate quality, though variability was present and methodological differences prevented a meta-analysis.

The overall aim of the six studies was to investigate the effects of different non-elite sporting activities, some of which were classified as weight-bearing and non-weight-bearing non-elite sporting activity of different intensities on bone mineral accrual in adolescence and early adulthood. The studies were heterogenous, but a consistent pattern emerged. Vlachopoulos et al. (2018) showed that boys playing soccer had better bone heel ultrasound outcomes than those who participated in cycling or swimming. Similarly, Nurmi-Lawton et al. (2004) showed that female gymnasts had significantly higher bone density than controls. The Gomez-Bruton et al. (2015) study indicated there were no differences found in cQUS parameters between swimmers and controls (both male and female) (Gomez-Bruton et al., 2015). The Madic et al. (2010) study of male soccer players reported significant higher cQUS values compared to controls. The Mentzel et al. (2005) comparison of those children involved in sports found the cQUS (SOS and BUA) parameters were significantly higher in sport participants engaged in weight-bearing activity compared to the reference data. The Yung et al. (2005) study indicated a linear increase in all cQUS measures as weight-bearing activity increased (Yung et al., 2005). In general, the six studies suggested that weight-bearing non-elite sporting activity was associated with higher cQUS, and that some dose effect was reported with greater levels of sporting activity (frequency and duration).

Weight-bearing PA is thought to stimulate bone formation and thus improve bone mineral density (BMD) by exposing the skeleton to mechanical strain, provided that it is performed at high enough frequency and high impact intensity (as evident in the studies that included swimmers or cyclists who had similar cQUS results to their comparative controls) (Gomez-Bruton et al., 2015; Vlachopoulos et al., 2018; Yung et al., 2005). Importantly, there is little epidemiological evidence that walking improves BMD (Martyn-St James & Carroll, 2008). Rather, mixed loading programmes that included jogging, walking and stair climbing consistently improve hip BMD in older people, although far fewer data exist in young adults (Martyn-St James & Carroll, 2009). The optimum type, intensity and level of PA for improving BMD remains unknown, and it is unclear whether a specific threshold strain needs to be exceeded. It is also unclear if different loading movement in different sports may have varying effects on BMD and whether the effects are identifiable at different sites. Lower limb impact during weight-bearing activities reflects their ground reaction force. In a study of adolescents from the Avon Longitudinal Study of Parents and Children, using pQCT and DXA, found that vigorous PA (equivalent to jogging) was positively related to cortical bone mass, but no independent relationship was seen for moderate PA after adjusting for vigorous PA: highlighting the importance of vigorous PA in this age group (Sayers et al., 2011). This also highlights the importance of quantifying the intensity, frequency and duration of PA in comparators controls when assessing the changes in cQUS measures associated with non-elite sporting activity.

There are several limitations to this systematic literature review. The cQUS tools used varied, with distinct model versions used in the measurements undertaken. As such, the output values are not directly comparable. There was considerable variability of the bone measurements taken and the level of detail provided of methods used to perform the measurements. These methods varied from measuring both feet separately to find the mean of the two, performing measurements in duplicate or triplicate, performing measurements either on the dominant foot or the non-dominant foot, and measuring both left and right feet but presenting the results of the left foot only. Overall, the reproducibility of the cQUS measurements within the individual studies themselves were within an acceptable range and researchers followed manufacturer's instructions validating the use of the cQUS measurement. Unfortunately, two articles were not obtainable despite numerous attempts to search the English translations of the full article or contact the authors (Coaccioli et al., 2013; Qian, 2017). Funding precluded the use of an official translation service and so we were reliant on Google Translate. This is a limited service; although the study by Mentzel et al. (2005) was subject to translation bias, its inclusion was justified as it was within the scope of this review. The study by Mentzel et al. (2005)

was therefore translated from German to English using Google Translate, a freely available online tool. This translation may include inaccuracies as sentences could be translated out of context, especially when translating colloquial words or words with multiple meanings. Another limitation of this review is that the age of the study participants under review leaned towards the younger end of the 11 to 35 year age group. The lack of detail regarding power of the studies made it difficult to assess whether and how the sample size recruited, if at all, affected the results. The ethnicity of the study participants was not always clearly stated in the study. Further, although nutrition was acknowledged as a factor in bone health in all six studies, only four of the six studies completed any dietary analysis. Details for sports measurement for sporting history, duration and other physical activities included was heterogeneous and sometimes the methods of recording and confirming the details were ambiguous. For example, the duration of participation in regular sporting activity prior to enrolment in each study was often not provided. The mean weekly sport training regimes ranged from a minimum of three hours to up to 27 hours, and the level of participation in non-elite sporting activity between studies were not directly comparable. Inter-study comparisons of results could not be made as in the six selected studies the selection criteria for participants and the controls were inconsistent between the studies. For example, some study participants selected for controls in one study would be sufficiently active to be participants in another study in this group of six studies. Finally, resource limitations meant we were unable to include SPORTDiscus and Web of Science in our search.

In comparison, a number of other systematic literature reviews have assessed bone health at other bone sites using various imaging tools, and this review complements those data. Our results are also complementary, and support the findings of those studies. Specifically, weight-bearing sporting activity, and particularly high impact weight-bearing activity, appears beneficial while swimming does not enhance bone mineral accrual. Previous studies compared differing age ranges or assessed bone outcomes in relation to pubertal status, while some reviews have been undertaken in groups of young people participating in exercise regimes or individual sports such as swimming, soccer, gymnastics, ballet which may be at a combination of recreation or elite or competitive level. For example, in a systematic literature review that assessed targeted exercise, the authors found using various imaging techniques, such as DXA, pQCT, MRI (Magnetic Resonance Imaging) and HSA (Hip Structural Analysis), that in children an exercise regime lasting more than six months enhanced bone strength at loaded sites but this effect was not seen in adults (Nikander, Sievänen, et al., 2010). In the systematic literature review by Gomez-Bruton et al (2016) suggested that swimmers may not be reaching PBM potential. In that systematic literature review the authors found higher DXA-derived BMD values in

young Causasian children and adolescents engaged in osteogenic sports relative to swimmers and controls (Gomez-Bruton et al., 2016). A more recent systematic literature review by the same authors in 2018 focused on young adult swimmers aged 18 to 30 years and found that in these young adults, limited osteogenic effects of swimming during adolescence persisted through early adulthood (Gomez-Bruton et al., 2018). In another systematic literature review that also used various imaging tools and found that children aged 6 to 18 years playing soccer had positive bone mass outcomes compared to the controls (Lozano-Berges et al., 2018). In a systematic literature review that reviewed participation in gymnastics during the pre-pubertal growth period found there was skeletal health benefits mostly for the upper body regions (Burt et al., 2013). Similarly, a systematic literature review of pre-professional female ballet dancers found site-specific osteogenic effects compared to the controls (Wewege & Ward, 2018). A systematic literature review that addressed the effects of weight-bearing sports such as soccer and gymnastics on bone geometry in children and adolescents, and found that the benefit was dependent on the frequency and intensity of the PA measured (Krahenbühl et al., 2018). Another systematic review assessed bone health in children up to the age of 24 years, measured PA subjectively through questionnaires or objectively using an accelerometer, with a focus on sedentary behaviour rather than a specific non-elite sport (Koedijk et al., 2017). Three of the studies identified in the review by Koedijk et al. (2017) that were of higher quality indicated that there was no association between sedentary behaviour and total body bone outcomes as measured by DXA; although twelve of the studies included in the same review assessed the lower peripheral bone outcomes with DXA or QUS found a negative association with sedentary behaviours (Koedijk et al., 2017).

The authors chose to undertake this systematic literature review of non-elite sporting activity with bone health using cQUS as the outcome measure in order to capture studies that may not have been included in previous systematic literature reviews. The authors used heel ultrasound as the outcome measure in this study to assess the effects of non-elite sports. Many studies indicated that heel ultrasound is used to assess bone structure and strength and is used worldwide for osteoporotic fracture risk assessment when DXA, the gold standard tool in diagnosis, is not available, although it is not to be used as a diagnostic tool (Fitzgerald et al., 2020; ISCD, 2013; Quiros Roldan et al., 2017). The positive attributes of the heel ultrasound test are that it involves no risks or harm, and is a cost-effective, comfortable, pain-free, radiation-free test that is easy to use and only takes a few minutes to perform (Komar et al., 2019; Shewale et al., 2017). Studies have shown the quantitative ultrasound densitometry technique to be useful in assessing skeletal health status changes due to exercise in all age groups and as a research tool (Babatunde & Forsyth, 2013; GE Medical Systems Lunar, 2010; Yesil et al., 2013). The studies

have found the use of ultrasound in normal healthy children to be a safe and non-invasive method when comparing the skeletal status of exercising children (Baroncelli, 2008; Daly et al., 1997; Jaworski et al., 1995). Different studies have used either the dominant heel, the non-dominant heel or a mean of the two as the reported outcome. While it is possible that this might impact findings, the consistency of our results suggest this was not a major consideration here, particularly given the sports studied. Perhaps this plays a lesser role compared to the effect on the dominant limb in racquet sports such as tennis (Kontulainen et al., 2003).

#### **4.7 Conclusion**

Although study heterogeneity prohibited meta-analysis, all six studies reviewed reported significant benefits of weight-bearing non-elite sporting activity in children and young adults. While both sexes were studied in several of these individual reports, small sample sizes made it difficult to dissect differences in outcomes between the two sexes. The studies revealed habitual levels of high impact sports, such as soccer, produced better bone outcomes (particularly in males) compared to non-weight-bearing sports such as swimming and cycling. Sporting behaviours commencing in the early years is an opportunity to improve PBM potential and set in place other healthy long-term lifestyle behaviours. More studies, especially in young adults in their twenties and thirties, are now urgently required to examine this issue in greater detail with more clearly defined control groups.

#### **Conflict of Interest**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Elaine Dennison has received consulting fees from Pfizer and UCB.

#### **Author Contributions**

HP performed the searches, HP, LS and ED reviewed the search results and extracted the data, HD provided advice and guidance regarding the systematic literature review methods, and HP, ED, HD, PTS and LS edited the manuscript. All authors contributed to manuscript revision, and read and approved the submitted version.

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**Table 1:** Summary of search string used

(sport OR sport* OR exercise OR exercis* OR physical OR soccer OR football OR rugby OR athlet* OR swimming OR tennis OR gym* OR basketball OR “martial art” OR boxing OR cycling OR recreation OR cricket OR hockey OR Ball or golf OR badminton OR cycling OR wrestling)
AND
(bone AND health) OR (bone AND mass AND density) OR DXA OR DEXA OR BMD OR BMC OR SOS OR BUA OR SI OR (hip OR spine OR heel) AND ultrasound
AND
(adolescent OR child OR girl OR boy OR juvenile OR teen* OR young OR people OR student OR youth OR minor OR college OR school OR paed* OR pedia*)
Include: Synonyms, related terms, opposites, international terms, alternative spellings, plurals, truncations and wildcards ( * or \$ or # to substitute for one character within a word), and proximity operators NEAR, NEXT, ADJ.

**Table 2:** Key study characteristics

Author/ Country Setting	Type of study	Study size Population Sport	Sports Activity	Comparator/ Controls	Bone Measure & Site	cQUS Imaging Tool	Key findings
<b>Vlachopoulos et al. (2018)</b> <b>England</b> <b>Sport clubs and schools</b>	Longitudinal (PRO-BONE study)	Total n=116 Caucasian males Aged 13.1.+/- 0.1 n=37 footballers n=37 swimmers n=28 cyclists n=14 active controls	Sport (swimming, soccer, cycling) duration > 3 years Actual average years of training ranged from 3.9 to 5.9 years Actual average hours of training per week ranged from 5.2 to 9.4 hours Actual average MVPA(min/day) ranged from 85.0 to 119.8	Controls: no sport like soccer, swimming or cycling for more 3 hours/week nor 3 years prior  Actual average MVPA(min/day) ~83.2	QUS heel mean of both feet, measured twice SI only	Lunar Achilles Insight (TM Insight GE Healthcare, Milwaukee, WI, USA).	12 months football participation associated better SI than for cycling or swimming
<b>Gomez-Bruton et al. (2015)</b> <b>Spain</b> <b>Clubs and high schools</b>	Cross-sectional study within a larger randomised controlled trial	Total n=129 Caucasian males & females Aged 11 to 18 n=77 swimmers (34 females/43 males) n=52 normoactive controls (23 females/29 males)	Sport (swimming) duration > 3 years, minimum of 6 hours/ week Competing in regional tournaments	Controls: normo-active with no participation in sports like swimming or aquatics regularly and no sporting activities more 3 hours/week	QUS heel (non-dominant ) SI, SOS, BUA	Lunar Achilles Insight (Achilles Insight, GE Health- care, Diegem, Belgium	cQUS results showed no significant differences between swimmers and controls
<b>Madic et al. (2010)</b> <b>Serbia</b> <b>Schools</b>	Observational	Total n=62 male soccer players Aged 10 to 12 n=32 soccer n=30 control regular school PA	Sport duration > 1 year Actual average hours of training per week ranged from 10 to 15 hours	Control 90 minutes of PA/week at school	Both heels QUS SOS Left and right BUA Left and right	Sahara (Hologic, Inc., MA, USA) sonometer	Higher BUA and SOS Soccer players than controls

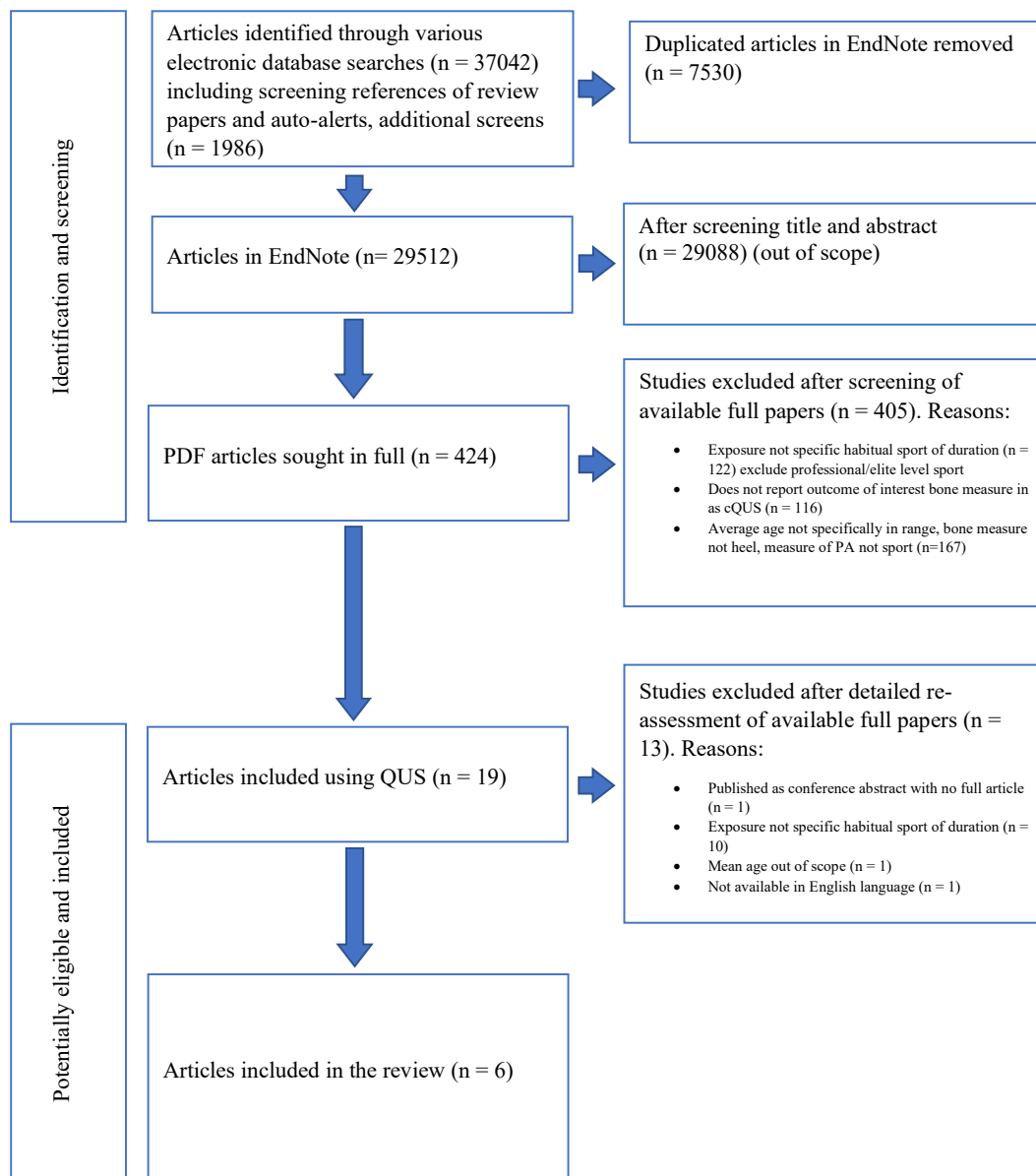
**Table 2:** Key study characteristics (continued)

Author/ Country Setting	Type of study	Study size Population Sport	Sports Activity	Comparator/ Controls	Bone Measure & Site	cQUS Imaging Tool	Key findings
<b>Yung et al. (2005) China Local university students</b>	Cross- sectional study	Total n=55 Chinese male university students Aged 18 to 22 n=15 soccer n=10 dancing n=15 swimming n=15 no exercise/sedentary control group	Sport (swimming, dancing, soccer) duration > 2 years ; at least twice week for at least 2 hours	Control no exercise (sedentary control)	QUS heel dominant and non- dominant heel measured, analysis on dominant heel VOS, BUA, SI	Paris, Norland Medical System, Fort Atkinson, WI, USA	All QUS parameters showed a significant linear increasing with the weight-bearing and high impact exercise BUA, VOS, SI Soccer players > dancers > swimmers > sedentary control group
<b>Mentzel et al. (2005) Germany Regional sports schools</b>	Cross- sectional study	Total n=177 sportspeople, of which 3 participants excluded because of lower limb fracture Aged 11 to 18 (n=121 boys; n=56 girls) n=43 athletes n=38 soccer players n=12 badminton players n=7 basketball players n=8 gymnastics n=18 fencers n=16 wrestlers n=29 Judokas players n=1 (each for tennis triathlon and weight training)	Sport duration undetermined; 2 training sessions/week of at least 90 minutes	Reference population used (age, size, and gender related)	Both heel (mean) QUS SOS (SDS) and BUA (SDS)	Sahara (Hologic, Inc., Waltham, MA, USA) sonar	For the level of activity: significant correlation to BUA only judokas and wrestlers For training sessions: SOS low negative correlation and BUA positive correlation
<b>Nurmi-Lawton et al. (2004) England Clubs</b>	Mixed longitudinal 3 years/cross- sectional for mothers	Total n=97 females Age Baseline 8-17 years of age n=45 gymnasts n=52 controls	Sport duration average for 6 years, 2 or more 90 minute training sessions weekly; trained greater than 10 hours/week; competed at club or regional level	Normo-active sedentary controls including walking to school and attended school PE classes No sports training requiring year around training; included two competitive swimmers as they were engaged in an activity the authors considered non-weight- bearing	QUS heel Mean of both feet, measured twice	Contact Ultra- Sound Bone Analyser (CUBA; McCue Ultrasonic Ltd., Winchester, UK)	Gymnasts had up to 24 –51% higher BMC and 13–28% higher BMD, depending on skeletal site than controls.

**Table 3: Risk of bias (NOS)**

NOS Tool	Yung et al. (2005)	Nurmi-Lawton et al. (2004)	Gomez-Bruton et al. (2015)	Mentzel et al. (2005)	Madic et al. (2010)	Vlachopoulos et al. (2018)
How well described is recruitment of the exposed group?	Chinese University students – numbers approached not stated	Gymnasts recruited from 5 clubs – numbers approached not stated	Source of recruits was local swimming clubs and numbers approached/ recruited provided	Recruited from College of Physical education – numbers approached not stated	Unclear – numbers approached not stated	Provided in separate referenced article; sports recruited were swimming/ football/cycling. Recruits came from sports club and schools
How were the exposed group selected?	At least 4 hours sport each week for at least 2 years; different sports described	At least 10 hours per week, and competing in competitions.	Swimmers training for at least 3 years, training for a minimum of 6 hours per week. Group subdivided according to whether participants were also training in another sport	At least 90 minutes per week	Soccer training for 10-15 hours weekly for at least one year	Training for over 3 hours per week for 3 or more years. Level of training provided for cases
How well described is recruitment of the control group?	Chinese University students	Local schools; taking part in PE lessons only though 2 were competitive swimmers	Source of recruits was local schools and numbers approached/ recruited provided. Could not be doing any sport for more than 3 hours per week	Used local reference data – so exposure to sport in this group was unclear	'Not engaged in active sport'. Other details not provided	Provided in separate referenced article
Length of exposure to sporting activity	Variable between duration and time/ week in different sports. Typically 2-3 years, range 7-15 hours per week	Training for range of 2-12 years; average 6.5 years	At least 3 years	Unclear	At least one year	Range 4-6 years
Information on important confounders	Provided	Provided	Provided	Unclear	Unclear	Provided
Overall risk of bias	Moderate	Low	Low	High	Moderate	Low

**Figure 1:** Flowchart for the systematic literature review





#### **4.9 Chapter 4 summary, future implications and next steps**

This systematic literature review was the first to assess the relationship between bone health as assessed by cQUS and non-elite sporting activities. Although study heterogeneity prohibited meta-analysis, all six studies reviewed reported significant benefits of weight-bearing non-elite sports on cQUS outcomes.

The results complements other systematic literature reviews that used other imaging tools. Many of the studies included under the review in this chapter focused on the younger age group aged between 11 to 22 years. There were fewer studies in those aged 23 to 35 years and the participants were mostly of Caucasian origin. This indicates that further studies in this area are required in respect of young adults in their late teens, twenties and thirties. Such individuals will likely be able to recall relatively recent sports activities, and are at a critical turning point in their lives in terms of behavioural and lifestyle changes which impact their bone health (Wilson-Barnes et al., 2019).

Therefore, we performed a quantitative study that used cQUS and an online questionnaire in young people to report the relationships between HRSA and bone health, as reported in the next chapter.

In addition future work will include a systematic literature review of interventions to improve bone health knowledge in college-aged students and a subsequent intervention study to improve knowledge and initiate behavioural changes.

## 5 Chapter 5: Quantitative study in young adults aged 16 to 35 years

### 5.1 Chapter 5 overview

The findings of the systematic literature review in Chapter 4 showed that there are few reports on the relationship between HRSA and bone health, as measured by cQUS. The aim of the quantitative study is to report the relationships between HRSA and bone health, as measured by cQUS, in young people aged 16 to 35 years. Therefore, we addressed this evidence base by performing a larger quantitative study.

The manuscript of this quantitative study has been submitted for publication and is under review as referenced below:

*Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2020). A cross-sectional study of the relationship between recreational sporting activity and calcaneal bone density in adolescents and young adults. The Physician and Sportsmedicine [under review]*

Please note the referencing style, table and figure numbering and legend formats are as required by the associated journal this paper was submitted to with minor textual edits: The Physician and Sportsmedicine.

The findings of two earlier studies on bone health in young people (aged 16 to 35 years) to understand the influence of lifestyle factors on bone health using the cQUS measures were presented as abstract and poster presentations (referenced below) and are provided in the Appendix:

1. *Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2018). Alcohol intake and bone health in New Zealand young adults: Reason for concern? Osteoporosis International, Krakow.*

2. *Patel, H., Woods, L., Teesdale-Spittle, P., & Dennison, E. (2019). Bone health in New Zealand young adults: Cause for concern? Osteoporosis International, Sydney.*

# **The Relationship Between Recreational Sporting Activity and Calcaneal Bone Density in Adolescents and Young Adults in New Zealand**

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## **Running title**

Sports and calcaneal bone density in young people

## 5.2 Abstract

*Objective:* Childhood and adolescence are critical periods of bone development. Sporting activity is thought to impact peak bone mass, but most studies have used dual energy X-ray absorptiometry (DXA) to assess bone health and reported associations between bone mass and elite sporting activity. The objective of this study was instead to assess the relationship between recreational sporting activity (RSA) and another bone assessment, calcaneal quantitative ultrasound (cQUS), in adolescents and young adults.

*Methods:* We related recreational sporting activity, assessed through a lifestyle questionnaire, to heel ultrasound bone parameters in a cohort of New Zealand students aged 16 to 35 years. Complete datasets with relevant confounders (body mass index (BMI), pubertal timing, smoking status and alcohol consumption) were available for 452 participants. cQUS was performed using a Lunar Achilles EX II machine. Bone parameters, broadband ultrasound attenuation (BUA), speed of sound (SOS) and stiffness index (SI) were calculated.

*Results:* Reported lifetime sport participation declined after an individual's mid-teens. Bone cQUS parameters (SI and BUA and T-score) were all positively associated with BMI, and current physical activity (SI, SOS, BUA and T-score) with SI and SOS measures most strongly associated with current high impact and past recreational sporting activity (all  $p < 0.05$ ).

*Conclusion:* Calcaneal heel ultrasound bone parameters were associated with physical activity, with SI and SOS rather than BUA more strongly related to current and past recreational sporting activity in young New Zealand adults.

*Keywords:* Adolescent, Bone, Calcaneal quantitative ultrasound (cQUS), Cross-sectional, Recreational sporting activity (RSA)

### 5.3 Introduction

Osteoporosis is a major public health problem through its association with fragility fracture (Cole et al., 2008). Osteoporosis is often described as a disease which occurs when one becomes older, is more commonly described in females and preventative methods often focus on older people (Tan et al., 2014). However, optimisation of peak bone mass (PBM) is critical during the periods of childhood and adolescent bone development (Baxter-Jones et al., 2011). Modifiable lifestyle behaviours such as physical activity have a major impact on the development of bones throughout life, with impact sports appearing more beneficial to bone mineral accrual than non-impact sport (Agostinete et al., 2020). PBM is a major determinant of later fracture risk (Hernandez et al., 2003; Weaver et al., 2016). The importance of engagement in sporting activity in childhood and adolescence was recently demonstrated by Mantovani and colleagues, who reported that in a study of 225 men and women, men who reported they were inactive in childhood and adolescence had bone mineral content around 11% lower than active men in childhood or adolescence, whereas for women, this difference was larger at 14% (Mantovani et al., 2018).

Despite these observations, only a limited number of studies have examined the impact of recreational sporting activity (RSA), that is sport undertaken at a non-elite level, on the bone health of young people in adolescence and young adulthood. To date, most studies that have been undertaken have focused on the effect of elite levels of sporting activity on bone health as assessed by dual energy X-ray absorptiometry (DXA) (Tan et al., 2014; Tenforde & Fredericson, 2011), with a recent systematic literature review by our group highlighting the need to consider the relationship between RSA and other bone outcomes (Patel et al., 2020). There has been an increasing interest in the use of calcaneal heel ultrasound (cQUS) as an alternative assessment of bone health that also provides structural information of bones, and which has been shown to be responsive to exercise in all age groups (Babatunde & Forsyth, 2013). Ultrasound technology is a non-invasive, widely available, inexpensive and portable tool that provides an assessment of bone density and quality at a readily accessible weight-bearing site with a high trabecular bone content, and has been shown to be able to discern risk of fragility fracture in older adults (Chin & Ima-Nirwana, 2013; Moayyeri et al., 2012), with the cQUS bone outcomes stiffness index (SI) appearing more predictive of fracture than speed of sound (SOS) or broadband ultrasound attenuation (BUA); albeit further research is required. The technique provides estimates of SOS and BUA by the transmission of a signal through the calcaneus bone of the heel. Stiffness index (SI) is derived from these variables, as is an estimate of bone mineral density (BMD), reported as a T score or Z score.

The aim of this study was therefore to assess the relationship between RSA and bone health, as assessed by cQUS in a group of New Zealand adolescents and young adults, recruited from schools, a local university and local gyms.

## **5.4 Methods**

### *Study design*

Study recruitment was undertaken from March 2017 to October 2018 in the Wellington region, New Zealand. Ethical approval was obtained from the New Zealand Health and Disability Ethics Committee (reference #HDEC 18/CEN/18). A student population was recruited, together with other adolescents and young adults associated with the university campus or local gyms, with school children recruited from local colleges and all participants aged 16 to 35 years; no other restrictions were in place. Recruitment took place through appropriate email mailings, interactions with teachers at the college and advertising on the university campus and at local gyms in the Wellington area. Participants were invited to pass study flyers to others to encourage participation. We obtained written informed consent forms signed by participants.

The questionnaire incorporated validated sporting activity questions adapted from studies by Weeks et al. (2008) and Kowalski et al. (2004), modified for the New Zealand population. These questions were used to determine the modified past recreational sporting activity history score, modified weekly physical activity score and weekly sporting activity (Clark et al., 2012; Deere et al., 2016; Dolan et al., 2006; Kowalski et al., 2004; Saint-Maurice et al., 2014; Weeks & Beck, 2008). Physical activity recorded included the duration and types of sport undertaken regularly. Respondents self-reported up to eight habitual recreational sporting activities engaged in over their lifetime in order to calculate a past habitual recreational sporting activity history score from age 0 to the present day. This score was based on the bone physical activity questionnaire score (BPAQ) which uses an algorithm that includes the effective load stimulus (ELS) derived from ground reaction force test, years of sport participation and an age-weighting factor (Weeks & Beck, 2008, 2010). Age-weightings were incorporated into the algorithm by Weeks et al. (2008) to recognise the greater osteogenic effects of exercise during growth as opposed to exercise after skeletal maturity. As such, weighting did not specifically differentiate between those younger participants aged 16 to 17 years old compared to those in their thirties except through their linear age. Respondents also detailed current physical activity and current sporting activity (Kowalski et al., 2004). Current weekly sporting physical activity was further categorised as either high impact weight-

bearing, weight-bearing, or non-weight-bearing sporting activities based on supporting literature (Kato et al., 2015; Weeks & Beck, 2008).

The questionnaire was used to obtain participants' age, height, weight, ethnicity, personal and family history of fracture, alcohol intake, calcium intake, physical and sporting activity and past medical history. Pubertal timing was self-assessed with reference to the age of menarche for females and start of growth of facial hair for males. Use of the oral contraceptive pill and menstrual function was recorded. Smoking status was recorded as either never smoked or smoker. The questionnaire was implemented through the Qualtrics software programme (Qualtrics, Provo, UT).

Participants' demographic information (age, height, weight and ethnicity) was recorded. A heel ultrasound test was performed (using an GE Achilles heel ultrasound machine) to obtain measures of broadband ultrasound attenuation (BUA), speed of sound (SOS) and stiffness index (SI). Estimated bone mineral density (BMD) was calculated by the machine from an algorithm utilising these parameters, and T- and Z-scores were recorded for females (aged 20 years and above), representing a comparison to a young adult mean (T-score) and an age matched mean (Z-score) (Frost et al., 2000). The same ultrasound machine was used throughout the study. A daily quality assurance calibration check was performed on the machine before each use using the manufacturer's standardised phantom. We evaluated the short-term *in vivo* precision of cQUS from triplicate scans in 15 participants. The overall coefficient of variation (%CV) varied from -0.5% to 0.67% for bone mass measurements for all bone measures: (T-score from -0.5% to -0.33%; Z-score from -0.30% to 0.67%; SI from 0.0% to 0.06%; BUA from 0% to 0.09%; and SOS from 0% to 0.01%) (GE Medical Systems Lunar, 2010).

### *Statistical methods*

A sample size was determined using existing literature based on t-tests (Faul, 2009; Field, 2013; Gould et al., 2013; O'Keeffe et al., 2017; Winther et al., 2015). From this, a sample size of 560 was estimated to give 80% power at the 5% significance level for an effect size of 0.2. The Geelong osteoporosis study that used cQUS indicated a sample size of n=750 was required for a 90% power for an effect size of 0.237 (Gould et al., 2013). Other comparisons in the same study between males and females indicated that an effect size of 0.4781779 would require a sample size of n=186 and n=138 for a 90% and 80% power size calculation respectively (Faul et al., 2009; Field, 2013). Therefore, a sample size of 250-1000 participants was sought for the university based population and others and for the purpose of the ethics application.

While cQUS scans were obtained for this number, missing questionnaire data led us to restrict our sample size to 452.

All descriptive statistics and statistical analyses were carried out using SPSS Statistics for Macintosh, Version 23.0 (IBM Corp., Armonk, NY, USA). A *p*-value of less than 0.05 was considered to be statistically significant. We first assessed univariate associations between predictors and cQUS bone measures.

Predictors included: gender; ethnicity; age; BMI; height; weight; pubertal timing; smoking; alcohol consumption; fracture (age of first broken, fracture history, family fracture history); daily calcium consumption; weekly physical activity; weekly sporting physical activity (categorised into: high impact weight-bearing activity; a combination of high impact weight-bearing and weight-bearing activity; non-weight-bearing activity; a combination of high impact weight-bearing, weight-bearing activity and non-weight-bearing activity); past recreational sporting activity history; and oral contraceptive use. Ethnicity was self-reported and then categorised into European, Māori and Pacific people, Asian, Indian, Middle Eastern, Latin American and African groups. For the purposes of this study, detailed sub-group analysis was not possible due to the small sample size of the sub-groups. As a result, classification of participants' ethnicity was either divided into three categories ("European", "Māori and Pacific people" and "Others" who were neither European, Māori nor Pacific people) for preliminary analyses, then in the final analysis between two groups ("European" and "Others" that included non-Europeans, Māori and Pacific people).

Those variables that were associated on univariate analysis at a level of  $p \leq 0.1$  were then included in multiple linear regression analyses. Variables included in the regression analysis were: BMI; age; gender; ethnicity; smoking status; alcohol consumption; pubertal timing; daily calcium consumption; physical activity; weekly sporting categories; and past recreational sporting activity. For each analysis, approximate normality was confirmed with histograms, Q-Q plots of residuals, residuals versus fitted plots indicated homoscedasticity of residuals, and Cook's distance did not identify any influential cases.

An additional analysis for the top ten popular sports was included, using multiple linear regression analysis to predict bone health from the sports played, age, gender, BMI and ethnicity. For descriptive statistics, the results were reported as mean  $\pm$  standard deviation (SD) or count and percent in each category.



## 5.5 Results

*Summary* statistics for the study population are displayed in Table 1 and include smoking, alcohol consumption and dietary calcium intake. 452 participants undertook the cQUS assessment and provided complete questionnaire data regarding sporting activity. Of the 452 participants, the ethnicities represented overall were 69.2% European, 10.6% Māori and Pacific people, 10.6% Asian, 6.2% Indian, 1.8% Middle Eastern and Latin American, and 1.5% African. The overall mean age was  $22.2 \pm 4.4$  years (women  $21.7 \pm 4.3$  years and men  $23.5 \pm 4.4$  years). The overall self-reported BMI recorded was  $23.8 \pm 4.2$  (women  $23.7 \pm 4.2$  and men  $24.2 \pm 4.3$ ).

Current weekly physical activity was similar in both sexes: the physical activity score for women was  $2.0 \pm 0.5$  and  $2.1 \pm 0.6$  for men. The average time reported spent in high impact weight-bearing sporting activity each week (minutes) was  $126.8 \pm 250.3$  in women and  $107.5 \pm 146.5$  in men. Time spent in high impact weight-bearing sporting activity and weight-bearing sporting activity each week (minutes) was  $467.2 \pm 456.9$  in women and  $413.9 \pm 445.6$  in men. Time spent in all sporting activity, including non-weight-bearing sporting activity each week (minutes), was  $494.9 \pm 470.8$  in women and  $468.6 \pm 505.1$  for men. Time spent in non-weight-bearing sporting activity specifically each week (minutes) was  $27.7 \pm 73.8$  in women and  $54.7 \pm 150.0$  in men. The mean past recreational sporting activity history score from age 0 to the present day score was  $33.0 \pm 31.7$  for women and  $28.0 \pm 24.6$  for men.

Supplementary Table 1 demonstrates relationships between lifestyle and demographic factors and cQUS bone measures. Associations were found with BMI, later puberty, physical activity, high impact weight-bearing sporting activity, non-weight-bearing sporting activity, past recreational sporting activity score, ethnicity and alcohol intake above the median of 3.5 units per week. Prior fracture was associated with a lower SOS in women, but not in men. Current physical activity was positively associated with all bone parameters in both sexes, but interestingly, despite a smaller sample size, many relationships were stronger in men. For example, past recreational sporting activity score was positively associated with SOS and SI for men, but not for women. Weekly number of minutes spent performing weight-bearing high impact sporting activity was positively associated with SI and SOS in both sexes, but was additionally associated with BUA in men.

Table 2 shows the questionnaire variables associated with the three cQUS measures (SI, SOS and BUA) on multiple linear regression. T- and Z-scores were only available for women (aged 20 and above), so the analysis for T-scores excluded gender as a predictor and the analysis for Z-scores excluded both

gender and age. We saw differences in relationships between the questionnaire variables and the various cQUS outcomes. Hence while current physical activity was strongly associated with all bone parameters ( $\leq 0.001$ ), past sporting activity was more related to SI and SOS than BUA ( $p < 0.1$ ), and age, gender and alcohol intake was associated with BUA rather than SI or SOS. Current BMI was positively associated with SI and BUA.

Figure 1 is a graphical demonstration of recalled RSA over the lifespan of the study population. The participants reported playing at least one sport over their lives; it was found that during the mid-teens to late-teens there was a decline in reported RSA, with a higher proportion of participants reporting that they did not engage in sporting activity at older ages.

There were 104 different types of RSA indicated by participants which were played over a range of one to 13.5 years by the participants. The most commonly reported activities were running, swimming, netball, soccer, walking, resistance, cycling, dance, rugby, badminton, basketball, tennis, hockey, cricket, hiking, volleyball, gymnastics, ballet, yoga and athletics. A positive correlation was seen in both men and women between bone cQUS measures and a history of running or playing basketball, soccer, rugby or cricket, with participants in those sports recording significantly better bone health measurements than those who did not play those sports. Those participants who reported walking as a sporting activity actually had comparatively poorer bone health. Finally, we observed higher T-score and Z-scores in women who played rugby.

Finally, for each bone health measure, a multiple linear regression analysis was run with cQUS as the outcome with the top ten sports played as exposures, with age, sex, BMI and ethnicity included in these models. A summary of the results are shown in Table 3. Bone SI was significantly higher in participants that reported running ( $p = 0.022$ ) and playing soccer ( $p = 0.047$ ), and significantly lower in participants that reported walking ( $p = 0.009$ ). Bone SOS was significantly higher in participants that reported running ( $p = 0.01$ ). Bone BUA was significantly higher in participants that reported playing soccer ( $p = 0.042$ ). Both T-score and Z-score were significantly higher in participants that reported playing rugby ( $p = 0.034$  and  $p = 0.035$ , respectively). When the sexes were considered individually, playing soccer was associated with higher SI, SOS and BUA measures in males but not in females, while playing rugby was associated with higher bone parameters for females. In females, walking and cycling were negatively associated with SI and SOS but no such relationship was apparent in men. There were no statistically significant interactions between calcium intake and physical activity in these models (all  $p > .05$ ).

## 5.6 Discussion

This study reported that levels of past recreational sporting activity, current physical activity and other lifestyle factors were associated with measures of bone health in an adolescent and young adult population in New Zealand. Results indicated that over 80% of males and females in this study reported engaging in at least weekly sporting physical activity. Our findings chime with the systematic literature review and meta-analysis of global participation in sport and leisure-time physical activities that suggested those from Western Pacific (Australia, China, Hong Kong, Japan, New Zealand and the Philippines) were more likely to participate in lifelong physical activities than those from other nations (Hulteen et al., 2017). In addition, a 2018 report by Sports New Zealand suggested that 72% of adults participate in weekly physical active play, exercise, recreation or sport, and over 90% participation amongst those aged between 15 to 17 years (Brocklesby & Sport New Zealand, 2019). Therefore, the results of our study may be a reflection of the local New Zealand population in this age group. However, similar to other reports we found that this level of recalled activity declined during adolescence.

While this study was unable to indicate which specific sports were more beneficial to bone health, the results appeared to suggest that adolescents and young adults who participated in weight-bearing sports (such as rugby, soccer and running) enjoyed better bone health. These results are consistent with previously published data studies that have considered cQUS as an outcome and the benefits of participation in individual sports on bone health (Agostinete et al., 2020; Brocklesby & Sport New Zealand, 2019; Hulteen et al., 2017; Vlachopoulos et al., 2018); such studies suggested that football or dancing conferred better benefits to bone health than swimming or cycling (Vlachopoulos et al., 2018; Yung et al., 2005), and that gymnasts enjoyed better bone health compared to controls (Nurmi-Lawton et al., 2004). Unexpectedly, walking was negatively associated with bone health in this group. It is possible that participants not engaged in regular sports chose to report “walking” as a form a sport rather than appear inactive, while others that engaged in organised sporting activity did not include time spent walking which in effect serves almost as a baseline activity level. Adiposity and consequent perturbation of the GH/IGF1 axis may be contribute to these relationships, although our observations remained significant after adjustment for BMI (Júnior et al., 2013; Luiz-de-Marco et al., 2020).

This study has a number of strengths and limitations. The sample size was larger than other studies of cQUS and RSA, with information on relevant confounders collected by questionnaire. However, while a sample size of 560 was estimated to give 80% power at the 5% significance level for an effect size of

0.2, and cQUS scans were obtained for this number, missing questionnaire data led us to restrict our sample size to 452. Some information, including height and weight, were obtained by self-completed questionnaires, which may lead to recall bias. In addition, we were unable to provide in-depth separate analyses for each sport group separately, as many participants reported a number of activities. Sporting activity was self-reported and not validated by accelerometers, therefore intensity and level of the activity was not objectively reported.

Date of age at menarche and appearance of facial hair was reported to the nearest year for all events. Facial hair development has been reported as a marker of gonadal hormones (Emmanuel & Bokor, 2020; Petersen et al., 1988). We note that while self-reported secondary sexual characteristics is a more common way to assess contemporaneous progression through puberty (Beccuti & Ghizzoni, 2000; Mendle et al., 2019), correlation with physical examination can be modest (Baird et al., 2017). As such, we considered that the use of such correlations was not necessary for this study. We sought to identify outliers in regard to pubertal progression only, as this could have impacted bone development.

Importantly, we based this study on a university campus and a high proportion of the subjects recruited were university students, although we also included participants recruited at local gyms and colleges. Participant recruitment was designed to be inclusive in that any person was able to be recruited into the study provided they met the age inclusion criteria of 16 to 35 years inclusively. This gave all people an opportunity to be involved in the bone health study with access to bone health information, including those with a health disability or impairment. Although the generalisability of this study may therefore be considered limited to the university environment, the participants came from different backgrounds and a range of locations within New Zealand and internationally, ensuring a wide ethnic mix; although some groups were not sufficiently represented to allow relationships between individual ethnicities and bone health to be reported. It should be noted that a high proportion of young people access university education in New Zealand, higher than in many other countries; in New Zealand in 2018 there were 61,297 domestic school leavers and of these, 59.7% (36,582 students) enrolled in tertiary education at all levels during 2019 (Ministry of Education, 2020). It will of course be important to replicate these findings in other settings to ensure generalisability of our results.

We observed benefits of high impact weight-bearing activity in our study. It is generally accepted that mechanical load induced by exercise training enhances osteoblastic activity (Fleg, 2012; Palombaro et al., 2013; Raisz, 2005). However, not all exercise modalities are equally osteogenic. Weight-bearing high

impact exercise such as hopping and jumping has been shown to have the greatest benefits (Min et al., 2019). Bone formation is increased in regions of high strain, with the skeletal effect of mechanical loading being site-specific, with greater responses at skeletal sites where loading impacts are greater (Morel et al., 2001; Tan et al., 2014; Weaver et al., 2016). The majority of weight-bearing exercises elicit physical loading to the lower limbs. To generate the adaptive response of bone to mechanical loading, sufficient magnitude, rate and frequency of loading are necessary if adequate intensity of loading is to be achieved: relatively few loading repetitions are sufficient to generate an adaptive skeletal response (Rubin & Lanyon, 1984). Further, as osteocytes are de-sensitised by repetitive loading, short bouts with intervals of rest are more beneficial than the same number of loads performed continuously (Robling et al., 2001). Sporting activity is particularly important as it has been suggested that adaptations to mechanical loading in adolescence and young adulthood may be translated into greater bone strength over a lifetime (Warden et al., 2014). Bones may become less sensitive to mechanical loading after skeletal maturity is reached at 18 to 25 years of age (Kontulainen et al., 2003).

In this study we chose cQUS as the bone outcome measure, rather than fracture. Fractures in adolescence and young adulthood often reflect significant trauma, and it is controversial how they relate to later osteoporotic fracture (Escott et al., 2019; Lynch et al., 2019; Moon et al., 2016). The heel bone is an easily accessible, weight-bearing site, composed mostly of trabecular bone, and intuitively might be expected to respond to exercise. Similar to the vertebral spine, it has a bone high turnover. A limitation of this approach is that we do not have measures of lean mass in this group; muscle bone interactions are very important in determining bone health, but might be expected to have a greater effect at the hip (Fricke & Schoenau, 2007). A systematic literature review and meta-analysis of twelve longitudinal studies attested to the sensitivity of cQUS to exercise induced changes in bone health (Babatunde & Forsyth, 2013). Earlier studies found comparisons with DXA and cQUS, and indicated that cQUS may detect low BMD in children with fragility fractures and that BUA parameters have been shown to reflect BMD changes in bone development (Baroncelli, 2008; Chin & Ima-Nirwana, 2013; Fielding et al., 2003; Torres-Costoso et al., 2018). However, no study to date has focused on different predictors of outcome for the different cQUS measures made and this will be a fascinating area to explore further. In addition to the differences in relationships seen with physical and sporting activity, we also observed some sex differences. Interestingly some relationships observed were stronger in men than women, and further work is required to determine whether these are real differences and what the biological explanation may be. Previous studies have suggested that sexual dimorphism may operate in the relationships seen (Holland A & Lorbergs, 2019; Zymbal et al., 2017).

Finally, dietary dairy intake, vitamin D and physical activity together potentially enhance bone health during childhood and adolescence (Bianchi et al., 2009; Uenishi & Nakamura, 2010). Previous reviews have suggested that physical activity and dietary calcium intake during childhood and adolescence play a critical, synergistic role with the potential to improve bone health with sufficient calcium intake (Julián-Almárcegui et al., 2015; Weaver et al., 2016). The dietary intake of calcium by recall was assessed in this study, with the average daily calcium intake across participants falling well below the recommended dietary requirement of 1000mg/mL or more for this age (Ministry of Health, 2012). The relationship between cQUS and sporting activity has been shown to indicate differential levels of benefit according to levels of milk intake (Babaroutsi et al., 2005; Prais et al., 2008). In this present study, we did not find evidence of an interaction between dietary calcium with bone health in this group. This may reflect the dietary calcium intakes we observed in this group: a calcium supplementation intervention study of young gymnasts found that with sufficient intake of dietary calcium, additional calcium supplementation provides no additional benefit (Ward et al., 2007).

## **5.7 Conclusion**

In this cross-sectional study, we reported levels of recreational sporting activity in New Zealand adolescents and young adults, as well as relationships between cQUS and current and past sporting activity, including weight-bearing high impact sports such as running, soccer and rugby. The benefits of RSA need further longitudinal investigation in other populations where validated measures can be made to determine a dose-relationship.

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**Table 1:** Summary of participant characteristics (*n*=452)

Participant descriptive characteristics		Female				Male			
		Mean $\pm$ SD	Category (n)	%	Respondents (n)	Mean $\pm$ SD	Category (n)	%	Respondents (n)
Age (years)	<i>Years</i>	21.7 $\pm$ 4.3			309	23.5 $\pm$ 4.4			143
Ethnicity (six ethnicities)	<i>European</i>		216	69.9	309		97	67.8	143
	<i>Māori and Pacific people</i>		33	10.7	309		15	10.5	143
	<i>Asian</i>		34	11	309		14	9.8	143
	<i>Indian</i>		16	5.2	309		12	8.4	143
	<i>Middle Eastern Latin America</i>		6	1.9	309		2	1.4	143
	<i>African</i>		4	1.3	309		3	2.1	143
BMI (kg/m <sup>2</sup> )	<i>Self-reported BMI (kg/m<sup>2</sup>)</i>	23.7 $\pm$ 4.2			309	24.2 $\pm$ 4.3			143
SI	<i>SI</i>	113.0 $\pm$ 16.2			309	116.0 $\pm$ 19.5			143
SOS	<i>SOS</i>	1605.9 $\pm$ 38.2			309	1606.6 $\pm$ 49.2			143
BUA	<i>BUA</i>	125.3 $\pm$ 12.6			309	129.7 $\pm$ 11.7			143
T-score	<i>T-score</i>	0.9 $\pm$ 1.2			190				
Z-score	<i>Z-score</i>	0.9 $\pm$ 1.2			190				
Oral contraceptive pill (OCP) use	<i>OCP use (Yes)</i>		203	65.7	309				
Age of pubertal timing (years)	<i>Age of pubertal timing (menarche/facial hair)</i>	12.7 $\pm$ 1.4			309	14.6 $\pm$ 2.3			143
Smoking status (yes or no)	<i>Never smoked</i>		234	75.7	309		87	60.8	143
	<i>Smoker</i>		75	24.3	309		56	39.2	143
Alcohol status (yes or no)	<i>Yes, alcohol consumed</i>		284	91.8	309		133	93	143
Age of alcohol consumption (years)		15.4 $\pm$ 2.3			281	15.1 $\pm$ 3.1			133
Consumers of alcohol above the median of 3.5 units per week			129	41.7	309		77	53.8	143
Total weekly units of alcohol including non-drinkers		4.0 $\pm$ 3.4			309	5.4 $\pm$ 4.5			143
Fracture status (yes or no)	<i>Self-reported fracture</i>		115	37.5	307		60	42	143
Age of first broken bone (years)	<i>Age of first fracture</i>	9.9 $\pm$ 4.6			115	12.6 $\pm$ 5.0			58
Daily calcium intake (mg)	<i>Dietary calcium daily</i>	666.6 $\pm$ 628.4			309	752.7 $\pm$ 593.0			143
Weekly physical activity score	<i>Modified Kowalski PA mean score</i>	2.0 $\pm$ 0.5			309	2.1 $\pm$ 0.6			143
Weekly high impact and weight-bearing sporting activity (minutes)	<i>Time spent in high impact weight-bearing activity each week (min)</i>	126.8 $\pm$ 250.3			309	107.5 $\pm$ 146.5			143
Weekly high impact and weight-bearing and weight-bearing sporting activity (minutes)	<i>Time spent in high impact weight-bearing activity &amp; weight-bearing activity each week (min)</i>	467.2 $\pm$ 456.9			309	413.9 $\pm$ 445.6			143
Weekly weight-bearing high impact and weight-bearing and non-weight-bearing sporting activity (minutes)	<i>Time spent in all activity each week (min)</i>	494.9 $\pm$ 470.8			309	468.6 $\pm$ 505.1			143
Weekly non-weight-bearing sporting activity (minutes)	<i>Time spent in non-weight-bearing activity each week (min)</i>	27.7 $\pm$ 73.8			309	54.7 $\pm$ 150.0			143
Past recreational sporting activity score	<i>Past BPAQ modified</i>	33.0 $\pm$ 31.7			309	28.0 $\pm$ 24.6			143

^ Data are presented as mean  $\pm$  SD (standard deviation)

Abbreviation: BMI = body mass index; BUA = broadband ultrasound attenuation; BPAQ = bone physical activity questionnaire; cQUS = calcaneal quantitative ultrasound; HI = high impact; NWB = non-weight-bearing; OCP = oral contraceptive pill; PA = physical activity; SI = stiffness index; SOS = speed of sound; WB = weight-bearing.

**Table 2:** Summary of linear regression (n=452)

	<b>n=452 (Females and males)</b>		<b>n=309 (Females)</b>		<b>n=143 (Males)</b>	
Source	Sig.	B	Sig.	B	Sig.	B
<i>Dependent Variable: SI</i>						
Ethnicity (European or Other)	0.086	3.018	0.988	0.03	0.011	9.017
BMI (kg/m <sup>2</sup> )	0.006	0.514	0.01	0.572	0.21	0.455
Weekly non-weight-bearing sporting activity (minutes)	0.066	0.014	0.41	0.01	0.195	0.014
Past recreational sporting activity score	0.064	0.05	0.193	0.037	0.558	0.041
Physical activity score	<.001	6.754	0.013	4.641	0.005	9.303
Smoking status	0.104	3.078	0.943	-0.159	0.009	9.258
Gender (female)	0.326	-1.914				
<i>Dependent Variable: SOS</i>						
Ethnicity (European or Other)	0.002	13.427	0.142	7.157	0.002	27.829
Total daily calcium intake (100mg)	0.079	-0.548	0.04	-0.718	0.763	-0.198
Weekly non-weight-bearing sporting activity (minutes)	0.046	0.038	0.538	0.018	0.105	0.044
Past recreational sporting activity score	0.029	0.143	0.164	0.096	0.314	0.173
Physical activity score	<.001	15.042	0.033	9.596	0.011	20.855
Smoking status	0.13	6.996	0.554	-3.188	0.002	26.975
Gender (female)	0.975	1.566				
<i>Dependent Variable: BUA</i>						
Ethnicity (European or Other)	0.473	-0.906	0.083	-2.708	0.38	1.96
Consumers of alcohol above the median of 3.5 units per week	0.059	-2.341	0.032	-3.239	0.995	0.015
Age	0.037	-0.281	0.12	-0.258	0.145	-0.348
Pubertal timing	0.111	0.531	0.019	1.204	0.854	0.079
BMI (kg/m <sup>2</sup> )	<.001	0.613	<.001	0.722	0.05	0.453
Physical activity score	0.001	3.793	0.042	2.919	0.013	5.209
Gender (female)	0.023	-3.192				
<i>Dependent Variable: T-score (n=190, females aged 20 and above)</i>						
Ethnicity (European or Other)	0.553	0.118				
BMI (kg/m <sup>2</sup> )	0.045	0.042				
Physical activity score	0.041	0.377				
<i>Dependent Variable: Z-score (n=190, females aged 20 and above)</i>	0.125					
Ethnicity (European or Other)	0.134	0.449				
BMI (kg/m <sup>2</sup> )	0.057	0.04				
Physical activity score	0.054	0.352				

**Table 3:** Summary of linear regression (sport)

Variable	Top ten sports n=452		Female Top ten sports n=309		Male Top ten sports n=143	
	<i>p</i>	<b>B</b>	<i>p</i>	<b>B</b>	<i>p</i>	<b>B</b>
<i>SI</i>						
Ethnicity (European or Other)	0.147	2.593	0.392	-1.726	0.004	10.294
Gender	0.311	-2.154				
Running	0.022	3.766	0.039	3.828	0.238	3.796
Swimming	0.157	2.292	0.531	1.139	0.273	3.558
Soccer	0.047	3.594	0.572	-1.217	0.002	10.186
Walking	0.009	-4.613	0.027	-4.226	0.217	-4.645
Cycling	0.124	-3.056	0.017	-5.574	0.969	-0.142
Rugby	0.289	2.212	0.001	8.255	0.233	-4.256
BMI	0.023	0.445	0.015	0.537	0.315	0.393
<i>SOS</i>						
Ethnicity (European or Other)	0.003	12.81	0.472	3.454	0.001	30.874
Gender	0.787	1.397				
Running	0.01	10.385	0.05	8.636	0.076	14.449
Soccer	0.14	6.502	0.48	-3.621	0.015	19.924
Walking	0.04	-12.481	0.011	-11.542	0.263	-10.63
Rugby	0.283	5.453	0.002	18.781	0.29	-9.53
Cycling	0.175	-6.559	0.008	-14.811	0.705	3.498
<i>BUA</i>						
Ethnicity (European or Other)	0.292	-1.347	0.013	-3.942	0.194	2.751
Gender	0.01	-3.943				
Age	0.057	-0.259	0.214	-0.209	0.103	-0.364
BMI	<.001	0.582	<.001	0.699	0.074	0.42
Soccer	0.042	2.635	0.898	-0.217	0.001	6.684
Swimming	0.316	1.159	0.958	-0.075	0.083	3.371
Dance	0.679	-0.591	0.373	-1.37	0.094	7.477
Rugby	0.433	1.168	0.02	4.709	0.264	-2.38
T-score (n=190, females aged 20 and above)						
Rugby	0.034	0.609				
Z-score (n=190, females aged 20 and above)						
Rugby	0.035	0.601				

**Supplementary Table 1: Pearson correlations**

Variable	SI (n=452)	SOS (n=452)	BUA (n=452)	T-score (n=190)	Z-score (n=190)	SI (F) (n=309)	SOS (F) (n=309)	BUA (F) (n=309)	SI (M) (n=143)	SOS (M) (n=143)	BUA (M) (n=143)
<i>Age (years)</i>	-0.026	-0.003	-0.041	-0.012	0.03	-0.089	-0.077	-0.07	0.039	0.113	-0.086
<i>BMI (kg/m<sup>2</sup>)</i>	.130**	0.045	.199**	.144*	0.141	.124*	0.016	.206**	0.129	0.093	0.162
<i>Height (cm)</i>	0.047	-0.086	.222**	0.111	0.11	0.072	-0.059	.211**	-0.136	-.214*	0.025
<i>Weight (kg)</i>	.133**	-0.009	.286**	.176*	.174*	.157**	-0.01	.300**	0.049	-0.019	0.154
<i>Pubertal timing (years)</i>	0.073	0.009	.145**	0.093	0.094	0.1	0.045	.141*	-0.022	-0.035	-0.003
<i>Daily calcium intake (100mg)</i>	-0.029	-0.066	0.026	-0.077	-0.08	-0.062	-0.106	0.012	0.017	0.001	0.024
<i>Physical activity score</i>	.255**	.236**	.200**	.179*	.174*	.191**	.167**	.151**	.358**	.351**	.281**
<i>Past recreational sporting activity score</i>	.112*	.138**	0.027	0.072	0.08	0.096	0.107	0.04	.179*	.221**	0.042
<i>Weekly weight-bearing high impact sporting activity (minutes)</i>	.145**	.154**	0.088	0.055	0.05	.131*	.140*	0.076	.235**	.231**	.185*
<i>Weekly weight-bearing high impact and weight-bearing sporting activity (minutes)</i>	0.054	0.064	0.023	0.071	0.073	0.05	0.073	0.002	0.076	0.052	0.107
<i>Weekly weight-bearing high impact and weight-bearing and non-weight-bearing sporting activity (minutes)</i>	0.077	0.087	0.041	0.082	0.085	0.061	0.082	0.011	0.111	0.095	0.122
<i>Weekly non-weight-bearing sporting activity (minutes)</i>	.120*	.120*	0.088	0.084	0.088	0.08	0.069	0.06	0.146	.167*	0.092
<i>Weekly weight-bearing sporting activity (minutes)</i>	-0.02	-0.013	-0.024	0.053	0.059	-0.027	-0.004	-0.05	-0.001	-0.025	0.048
<i>Smoking status (yes = 1 or no = 0)</i>	0.042	0.054	0.013	0.021	0.02	0.016	0.031	-0.016	.168*	.185*	0.089
<i>Ethnicity (European = 1 or Other = 0)</i>	-0.084	-.149**	0.029	0.006	-0.002	0.012	-0.065	0.101	-.251**	-.288**	-0.123
<i>Consumers of alcohol above the median of 3.5 units per week (yes = 1 or no = 0)</i>	0.049	-0.006	.112*	0.099	0.09	0.081	0.014	.135*	-0.031	-0.043	0.005

**(F) Female**

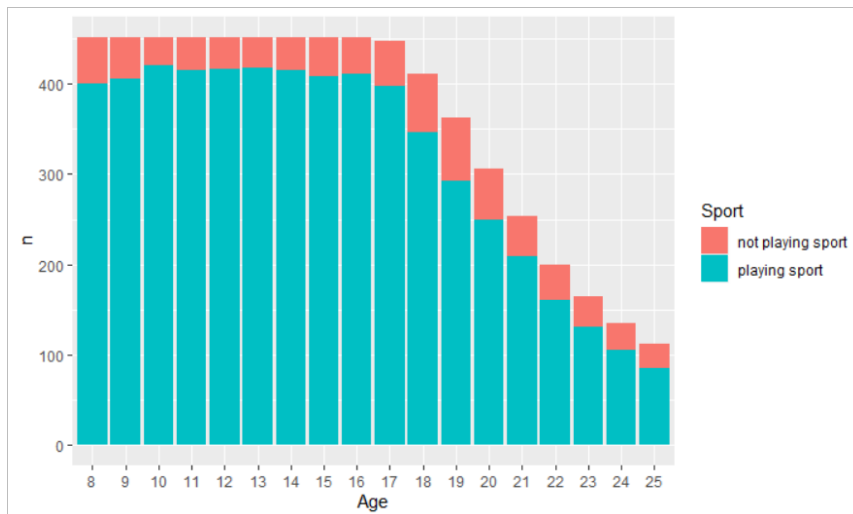
**(M) Male**

**\*\* Correlation is significant at the 0.01 level (2-tailed).**

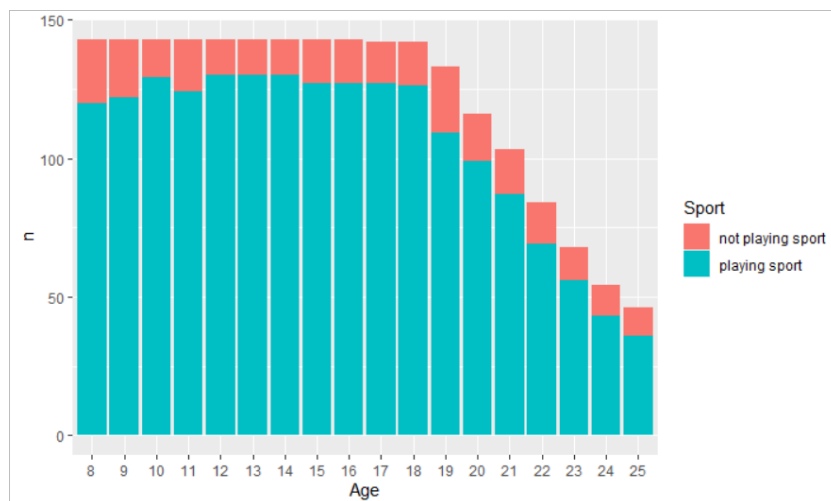
**\* Correlation is significant at the 0.05 level (2-tailed).**



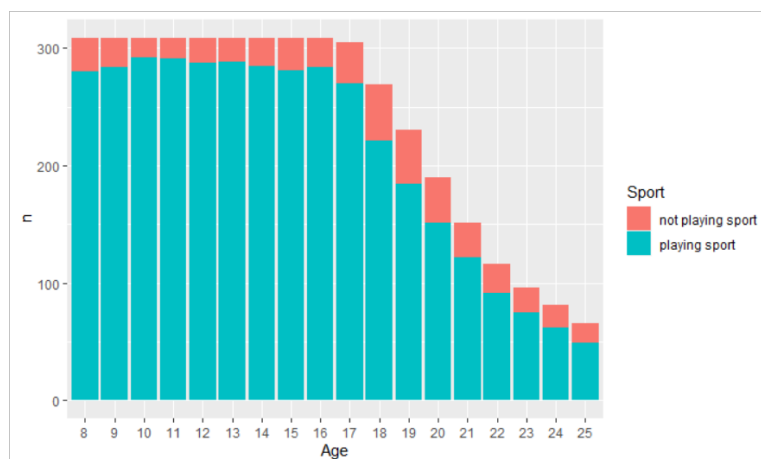
**Figure 1:** Recalled sports participation from age 8 to 25 years in 452 young people participating in this study (y-axis = n, the number of participants)



**Figure 1A:** Recalled sports participation from age 8 to 25 years in 143 young males participating in this study



**Figure 1B:** Recalled sports participation from age 8 to 25 years in 309 young females participating in this study



## **5.9 Chapter 5 summary, future implications and next steps**

The results found in the quantitative study gave further evidence that higher impact activities such as running, soccer and rugby appeared to confer greater benefit for bone health. This quantitative study also indicated that most males and females reported regular weekly HRSA participation, although the participation rates dropped off at older ages.

Although the use of cQUS technology in this young population needs to be validated against the gold standard of the DXA bone measurement benchmark, the study demonstrated that cQUS bone parameters are associated with loading HRSA in young adults. Therefore, it is imperative that young people continue to remain active and partake in HRSA beyond their school years to achieve PBM potential. The choices they make during this critical period reduces their risk of osteoporotic fracture later in life. Given that HRSA levels decline in the late teens and beyond, it is important that we appreciate what adolescents and young adults recognise about peak bone mass and osteoporosis terminology, and their knowledge and understanding of how lifestyle factors impact PBM acquisition.

Qualitative studies of young people's knowledge about osteoporosis and the lifestyles affecting PBM may be helpful when designing guidelines to improve bone health knowledge in young people, and this is the focus of the second duet of papers in this thesis.

## 6 Chapter 6: Qualitative focus group study – knowledge

### 6.1 Chapter 6 overview

The previous chapters indicated that the modifiable lifestyles adolescents and young adults undertake have an influence on their PBM accrual potential. The aim of the qualitative study focus groups were designed to better understand what adolescents and young adults comprehend about PBM, the risk of osteoporotic fracture and how lifestyle factors impact PBM. Therefore, we performed a qualitative focus group study with young adults aged 16 to 35 years in nine focus group discussions, the findings of which are presented in Chapter 6.

The results of this qualitative study under review for publication and is referenced below:

*Patel, H., Denison, H., Zafar, S., Teesdale-Spittle, P., & Dennison, E. (2020). Knowledge of osteoporosis and lifestyle behaviours impacting peak bone mass: Might we be able to modify behaviour in young adulthood to prevent osteoporosis in later life? OBM Geriatrics, 4(1) [under review]*

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# **Knowledge of osteoporosis and lifestyle behaviours impacting peak bone mass: might we be able to modify behaviour in young adulthood to prevent osteoporosis in later life?**

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## **6.2 Abstract**

Osteoporosis is a major public health problem through its association with fragility fracture. Low peak bone mass (PBM) is a major contributor to later osteoporosis risk. Despite this, most studies concentrate on older people when the window of opportunity to impact PBM has passed. This study aimed to understand what adolescents and young adults understand about PBM, the risk of osteoporotic fracture and how lifestyle factors impact PBM. Such information may inform educational interventions to reduce future risk of fracture, and provide important public health benefits. New Zealand university students were approached to participate in this study. Nine focus groups of a total of 44 adolescents and young adults aged 17 to 33 years were conducted using a semi-structured approach with open-ended questions and prompts. Transcripts were thematically coded using an inductive content analysis approach. We found that knowledge of PBM and risk of osteoporotic fracture was limited. There was a general awareness of the positive and negative impacts of many lifestyle behaviours such as physical activity, diet, tobacco smoking and alcohol consumption on health in general, but not specifically how these impact PBM and good bone health in later life. We conclude that in a cohort of New Zealand University students, current knowledge of osteoporosis and lifestyle factors that impact PBM is limited. Educational interventions in young adults are now warranted to improve PBM and prevent osteoporosis in late adulthood.

### **Keywords**

Knowledge – bone – qualitative – lifestyle – peak bone mass (PBM) – osteoporosis

### 6.3 Introduction

Osteoporosis is a major public health problem through its association with fragility fracture (Cole et al., 2008). Preventative methods often focus on older people (Tan et al., 2014). However, a critical period of bone development occurs during childhood and adolescence, with bone development reaching a peak in an individual's twenties and thirties. Lifestyle behaviours which are major determinants of attaining maximum peak bone mass (PBM) may be modified to improve bone health and reduce fracture risk later in life (Hernandez et al., 2003; Weaver et al., 2016; Winther et al., 2015). However, engagement of adolescents and young adults with such lifestyles depends upon their knowledge of factors associated with good bone health and a motivation to lead healthy lives (Holland, 2017).

A systematic literature review in 2018 identified 34 studies that used self-designed or validated questionnaires to assess bone health and concluded that most adolescents and young adults had poor knowledge of bone health and osteoporosis (Chan et al., 2018). That review suggested both this lack of knowledge and misconceptions about osteoporosis lead to behaviours that might result in suboptimal PBM acquisition. The study concluded that personal susceptibility and acknowledging the importance of osteoporosis would encourage changes in behaviour to lessen the burden of osteoporosis (Chan et al., 2018). This study aimed to examine what adolescents and young adults understand about PBM, and the lifestyle factors that impact it through qualitative methodology, in the form of focus groups set in the university environment in Wellington. There is a need to recognise what adolescents and young adults understand about bone health because, if they understand the implications of their lifestyle behaviours, they may be able to make informed choices of the risks and benefits of those behaviours and hence act to reduce their risk of fracture later in life. This novel preventative approach may lead to significant public health benefits through reduced risk of fragility fracture in older age.

### 6.4 Methods

#### *Participants*

Study recruitment was undertaken from July 2018 to October 2018 in the Wellington region in New Zealand. Students from Victoria University of Wellington, and other adolescents and young adults aged 16 to 35 years associated with the university, were approached to participate in the study. The participants who had previously been involved in a larger quantitative bone health study (reported elsewhere) had consented to being contacted by email for further research. Others were recruited through word of mouth, recruitment flyers and emails posted through the university media service. Participants were provided

with participant information sheets and informed consent forms. Written informed consent was provided by willing participants. The participants were encouraged to discuss with each other what they understood about PBM and the risk of osteoporotic fracture affecting their bone health. The focus groups were semi-structured with open-ended questions. The discussions were recorded with two or more recording devices and an assistant recorded non-verbal communication (to record information about the level of consensus and dissension to the topic under discussion).

At the end of each discussion, the lead interviewer summarised the ideas that had been discussed and asked for any final feedback to ensure all ideas or opinions and experiences were recorded. After each focus group, a debriefing session was held with the study facilitators. Subsequent focus group interviews used an iterative process whereby any previous emergent themes were followed up to obtain further insights until all themes were fully explored to achieve theoretical data saturation.

#### *Ethics Statement*

Ethical approval was obtained from the New Zealand Health and Disability Ethics Committee (reference #HDEC 18/CEN/18).

#### *Data analysis*

The recordings of the focus group discussions were transcribed verbatim and then verified by listening to the voice recordings several times to ensure all data was recorded correctly. All participants' data were de-identified. The transcription and any tabulated data, including any notes obtained from the focus groups, were thematically analysed. We used an iterative process of qualitative analysis whereby inductive patterns emerge into themes from the data itself by constant comparative analysis (Corbin, 1998). Sections of data were then assigned codes and compared for consistency. The assigned codes were categorised into themes. NVivo (qualitative data analysis software; QSR International Pty Ltd. Version 12, 2018) was used to organise the data.

## 6.5 Results

Nine focus groups discussions were held in total between August and October 2018, with 3 to 11 participants attending each group. The sample size was 44 individuals in total, with a mean age of 22.9 and an age range of 17 to 33 years. The majority of participants were of European descent, 10 were of mixed ethnicity including Māori, Pacific people, Asian and Indian, and approximately two thirds were female, with one third male (29:15).

Three main themes emerged from the focus groups: there is a limited understanding of PBM and the risk of osteoporotic fracture; seeking bone health advice is uncommon; and although participants had a good understanding of lifestyle factors that contributed to good health, they had little knowledge of how these could lead to improved PBM acquisition.

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### *Participants had a limited understanding of PBM and the risk of osteoporotic fracture*

Generally, participants had a good understanding of lifestyle factors that contributed to good health, but little knowledge of how these related to PBM, that is, they were aware of the overall health and well-being benefits of exercise and good nutrition, but not specifically in relation to bone health. Participants' knowledge of specific bone health issues and PBM was limited.

*“More common in older people and it’s to do you know with bone strength and that you should drink milk. Yeah I don’t have a very good understanding of like causes or preventative measures or anything like that.”*

*“[I] think of bones as [a] skeleton structure where the meat just hangs off...think more about exercise and diet and organs being affected.”*

Participants did not always have a clear understanding of the supplements or medication taken.



*“I started taking Vitamin D because it’s supposed to help with asthma. But I feel like on the bottle it says something about bone health (laughing). I have actually read the bottle. I went to my GP and said I was having problems controlling my asthma and he suggested Vitamin D and I just take Vitamin D now.”*

Participants did not feel susceptible to acquiring osteoporosis and many considered osteoporosis to be specific to women, and a problem in later life.

*“I thought osteoporosis was just old people, just getting old (agreement)... and breaking their bones, but it makes more sense to encourage it from a younger age rather than waiting till you’re old type thing, to think about it.”*

*“Is it the older women get, the more brittle our bones get?”*

*“Not many worry about what’s going to happen when they are 90 years old.”*

Participants found the descriptive terminology and “*medical jargon*” difficult to understand, confused osteoporosis with other conditions such as “*osteoarthritis*” and confused the use of supplements such vitamin D with vitamin C.

*“I’ve heard of osteoarthritis. Is that a different thing?”*

*“Oh, is that, you get scurvy, is that it?”*

*“That’s vitamin C.”*

***Seeking bone health advice is uncommon***

Participants used various methods to obtain information about general health but did not actively seek information on osteoporosis or bone health unless a fracture had occurred. Seeking medical advice for bone health was uncommon. Further, participants felt there is a lack of readily available information about osteoporosis prevention, and were unaware that there are fracture risk assessments currently available in New Zealand in both hard copy and online versions.

#### *Bone health information available online*

Generally, participants spoke more about the internet as their first source of information for many topics, as it is readily accessible and used it to gather information for most health related matters, including nutrition. However, unless a fracture had occurred, few participants had searched the internet for information specifically related to bone health.

*“Heaps of information on their website, my dad likes it so...there’s information you have to find it and look for it, but like again you have to do it yourself.”*

#### *Bone health information from general practitioners*

Participants found that health professionals do not typically advise them about bone health, and do not advise specifically about attaining PBM aside from preventative measures to avoid fracture (such as by taking care when participating in sport and avoiding excessive alcohol consumption).

*“I really don’t know much about it at all, and I can’t even think of a doctor visit where it was brought up in conversation other than me stubbing my toe, fracturing it, yeah.”*

#### *Education*

Participants reported learning much of what they knew about health, and lifestyles favourably associated with health, from school or from studying biology and science at university. When talking about osteoporosis awareness, a participant recalled learning about osteoporosis at school.

*“I think for myself I heard about it in high school and in nutrition papers they did in high school and that was it. I did one year of that. That was all the information I had about it.”*

Another participant became aware of the availability of vitamin D testing while studying a health topic at school although was informed by their doctor that the test was not routinely available.

*“People don’t know what to ask for like I, I read about this because I am studying biology, because I happen to have like a huge interest in like all of this kind of stuff like personally. But most people don’t have that. And she said that it used to be part of standard (...) but it’s not anymore. Because I am studying biology, because I happen to have like a huge interest.”*

### *Media*

Participants spoke at length about media, internet and television sources and historical healthy living and physical activity campaigns that they remembered. In terms of nutritional and healthy lifestyle factors, many participants vividly recalled previously advertised physical activity campaigns. A participant recalled media marketing directed at women and older people.

*“They tend not to be marketed towards, like, 18 to 35 year olds. It’s more like a, sort of, 60 year old, around women, is sort of there, seems to be bone health marketing, around sort of different supplements you can take. Sort of, general bone health for young people isn’t something that I’ve ever seen.”*

Another participant remembered having heard or read about astronauts breaking bones after going into space; they recalled having a very visual reaction to this information.

*“I just remember hearing one story – like I just have no idea who or the details of it, but someone, like an astronaut, coming back to earth and then like stepping onto ground, and the bone just like breaking.”*

*And that stuck with me 'cause it, I remember having a very visceral reaction to it. Just being like, “ahh”.*”

#### *Family and social circles*

Participants had a limited understanding of their own personal family health history but acknowledged there may be heredity factors impacting their future health status.

*“...my grandma broke her hip and I don’t know, I mean I think it was age-related, but I don’t know.”*

Some participants were aware of older family members with fragility fractures. Although they may believe that they are at a potential risk of eventual osteoporosis, those participants did not think there is anything they can do at their current age to prevent osteoporosis and considered that osteoporosis may be an inevitable part of getting old.

*“I thought osteoporosis was just old people, just getting old.”*

*“It’s not something that you really think much about when you’re young.”*

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#### ***Participants had a good understanding of lifestyle factors that contributed to good health, but little knowledge of how these applied to PBM***

Participants’ knowledge and understanding of how their lifestyles, including alcohol consumption, smoking, drugs and nutrition, affect bone health and PBM was limited. These individual lifestyle factors are discussed below.

#### *Recreational sporting activity*

Participants understood the need to be active for better health. Many of the participants enjoyed participating in recreational sporting activity for “fun”. Their chosen activities did not specifically arise

from an intention to improve bone health but rather from the enjoyment of the sport or for muscle strength.

*“I am thinking of making things stronger, I am thinking like muscles and like this or that. But, I never think about, I could do something that could change my bone structure.”*

#### *Alcohol consumption and smoking*

Participants were aware that the alcohol and smoking had long-term negative effect on their health but not that long-term alcohol consumption was detrimental to bone health.

*“It’s just generally bad for you and it might hinder your ability to I guess process nutrients and grow, but I’m not sure. I don’t think it would have a detrimental effect would it, if you’re just drinking as an adult?”*

#### *Nutrition, diet and bone health*

Participants did not know about the possible impact of different diets on bone health. However, participants understood the importance of including calcium in diets mainly sourced through dairy products and the benefits of taking supplements for vegetarian or vegan diets. Parents and family members were commonly cited as reasons for drinking milk.

*“My mum always used to make me drink milk, but I didn’t know too much.”*

Another participant compared their own high milk consumption and sporting abilities with a sibling’s low milk consumption and frequent fractures.

*“I really like my milk, my blue top. Um, so that sort of became a joke, starting with like my sister. I do it for yeah, I have strong bones and teeth, ‘cause she’s like fragile and breaks everything.”*

Participants believed food types with high calcium content such as milk also increases cholesterol levels.

Although the majority of participants previously consumed milk daily during childhood, several participants held ethical concerns regarding milk, dairy and meat consumption, based on information obtained through social media and the internet.

*“It’s mostly an environmentally conscious decision, um just to you know, help improve the environment and not contribute to pollution in that way with dairy farming and farming.”*

Ethical and environmental concerns may influence lifestyles changes. Reasons given for changing their lifestyles, including becoming vegan or otherwise changing their diet, often showed that participants did not always consider the impact of such lifestyle changes on their bone health.

*“I definitely change and then read later. Yeah I think I yeah based on my experiences, I pretty much decided to go vegan sort of with a snap of the fingers and then read up afterwards what I needed to do. It sure was healthy.”*

Some participants did not always trust the motives of health campaigns and preferred independent research-based campaigns.

*“The only ads for bone health tend to be, like, supplement and pharmaceutical companies, or, little companies that are trying to milk [profits]. And they like know – whereas like, I wouldn’t exactly trust.”*

Some participants were well-informed about supplementation information from the doctor as students may be recommended vitamin D supplementation due to spending significant periods of time indoors studying.

*“I haven’t heard of vitamin D in relation to bones. Like sunshine in general, but not like [for bones].”*

Females were more aware of their personal health and more likely to seek regular medical help for other health issues, such as contraceptive advice. Easy access to the contraception at an early age of around 15 was common in females. They were not aware of the potential detrimental effects of the oral contraceptives on bone health and do not remember being told of such effects by their doctor.

*“[Doctors] don’t talk about the medication, they just take your blood pressure.”*

## **6.6 Discussion**

Osteoporosis is a condition associated with huge personal and societal burden in later life, with a high proportion of older adults affected. However, this qualitative focus group study suggests that adolescents’ and young adults’ knowledge of bone health and PBM was limited despite being highly educated (Ministry of Education, 2020); some had never heard of PBM or osteoporosis before. Many were confused by medical terminology and did not identify with osteoporosis, as they mostly perceived it to be a disease that occurred in elderly females. This view was consistent with a recent study that highlighted a lack of awareness amongst males that osteoporosis affects males as well (Minns Lowe et al., 2019).

Some adolescents and young adults in this study underestimated their vulnerability to health risks in general but more so for osteoporosis. This is partly due to the misconception that bone growth occurs only in the very young, bones are not visible and often are unnoticed and there was little to do to prevent osteoporosis as it was an inevitable part of getting old: *“I thought osteoporosis was just old people, just getting old.”* This misconception leads to a belief that lifestyle choices in early adulthood do not affect bone health, for example, that bones are mostly unaffected by alcohol consumption. The participants recognised themselves to be adults over the age of 18 years and did not perceive themselves as being in the growth phase. Adolescents and young adults were not aware of recreational sporting activity as a method of improving bone health, as they did not appreciate that bone health could be improved with increased high impact weight-bearing activity. Participants recognised that muscular strength and appearance improved with regular exercise and good nutrition. Further, they understood that a reduction

in detrimental lifestyle behaviours (for example, alcohol consumption, smoking or drugs) may improve general health and mental well-being, but not specifically affect bone health. The findings of this study highlight the need to intervene earlier in the life course to promote behavioural change that will result in reduced risk of osteoporotic fracture in late adulthood, with all its attendant health consequences.

In focus group study, overall, females were more aware of factors affecting their health: this finding is consistent with that of other studies (von Hurst & Wham, 2007). Female participants were generally more aware of their personal health and often obtained contraception at an early age of around 15, although were less aware of potential detrimental effects of oral contraceptives on bone health. Hormonal contraceptives potentially negatively impact PBM accrual depending on the extent of use and age at which it was taken (Jackowski et al., 2016). In particular, early use of OCP during teenage years may impact PBM development (Trémollières, 2013). As such a greater understanding and education of the use of OCP and the alternative options is warranted.

Conventional sources of health information came from family and friends, health professionals and the education and sport sectors. Similar to other studies, adolescents and young adults vividly recalled past public health campaigns for recreational sporting activity and milk consumption from childhood (Maddison et al., 2010). Adolescents and young adults triangulated information-seeking using online sources, their immediate social circles and education or health resources. They were aware that the information available may be biased and untrustworthy. Many participants did not recall the past experiences and bone health complications of friends and family members' bone health clearly: as such, communicating and recording of pertinent family health history may be warranted.

The strengths of the qualitative focus study include the participants' wide ethnic diversity and age range. Although the generalisability of this study may be considered limited to the university environment, the data was sourced from a range of participants from the university campus who came from different backgrounds, and a range of locations within New Zealand and internationally, reflecting the population of the Wellington region (Statistics New Zealand, 2013). Despite being relevant in this population, the study did not include address those with mobility disabilities and those identifying as gender diverse: health research is typically inadequate in these areas (Clark et al., 2014; Graham et al., 2011; Shannon et al., 2019).



Trustworthiness in a qualitative study may be judged by its credibility, transferability, dependability and confirmability (Loh, 2013). The data presented here were sourced from a range of participants from the university campus who came from different backgrounds, affirming credibility. Ideas were summarised after each discussion group. The reflexive diary (preliminary analysis) after each focus group meeting with the study facilitators permitted continuous comparisons and consensus, and the data were interpreted independently. The study protocol and reflexive diary of the iterative research process permitted transferability of the methods used to other contexts. An appraisal of the research protocol by an external party and other qualified researchers in the field ensured dependability of the research process. The emergent themes were auditable in NVivo the software program used for managing the data, and continuously compared to develop the emerging themes. Debriefing sessions held with the study facilitators were used to highlight any discussion issues to be addressed, including any keywords, themes or patterns and relationships identified from the focus groups and recorded in the reflexive diary to objectively confirm that findings and interpretations were true to the participants' views. The data obtained from the nine focus group interviews held, field notes and responses to the open-end probe questions, and the objective independent observations from the different facilitators were triangulated and synthesised to provide confirmation of the findings and different perspectives true to the views of the participants in the qualitative study (Carter et al., 2014).

However, this focus group study has some limitations. No formal data were collected on the participants' socioeconomic status. Due to low group numbers our study was not able to perform sub-group analysis based on ethnicity. Additionally, some of the views of the participants may reflect a more an international perspective, due to spending differing amounts of time in and out of New Zealand. Finally, we acknowledge the modest sample size of the study population and the need to conduct similar studies in other populations; reassuringly data saturation was reached despite this.

Adolescents and young adults reported a desire for access to online unbiased information about PBM supported by well-conducted health research. Information about the role of supplements or osteogenic food types in the general diet to aid bone health in adolescents and young adults would be beneficial (Seem et al., 2019). Although the lack of safe levels sunlight exposure in those with darker pigmentation is a risk factor for bone health, some participants of Asian and Indian origin revealed a lack of knowledge in the benefits of sun exposure as a source of vitamin D (Darling et al., 2019; von Hurst & Wham, 2007). In darker skinned individuals vitamin D absorption through the skin through sun exposure is less efficient

particularly if clothing such as veils or veils and full-body-coverage clothing is used (Ministry of Health & Cancer Society of New Zealand, 2012)

## **6.7 Conclusion**

Adolescents and young adults demonstrated a lack of knowledge of osteoporosis and the lifestyles behaviours that can improve PBM acquisition to reduce their risk of osteoporotic fracture later in life. Adolescents' and young adults' limited understanding of bone health and PBM acquisition hinders their ability to modify their lifestyles to improve their PBM potential. A greater understanding of the consequences of the modifiable lifestyle factors, and making long-term, osteogenic lifestyle choices such as participation in osteogenic types of HRSA and changes in diet has the potential to help reduce risk of osteoporotic fracture later in life, with significant public health benefits.

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## **Author Contributions**

Elaine Dennison and Hayley Denison designed the study, with Hansa Patel. Hansa Patel and Sana Zafar performed data collection. Hansa Patel performed data analysis, supervised by Hayley Denison. All authors oversaw data collection and manuscript production.

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## **Competing Interests**

The authors have declared that no competing interests exist.

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## **6.9 Chapter 6 summary, future implications and next steps**

The findings of this chapter indicate that these young people, despite being mostly university educated, had limited knowledge of osteoporosis and PBM acquisition, although they were aware of the many benefits of an active lifestyle to general health. They did not know that there was a window of opportunity to improve their current bone health status, or that improving their PBM status would help to reduce the risk of osteoporotic fracture later in life. In particular, they were not aware that sustained loading HRSA would increase their PBM potential as well as their general health status.

Discussion of young people's understanding of the barriers and access to HRSA and the methods of reducing the risk of osteoporotic fracture later in life will be presented in Chapter 7.

Additional future work to recognise young people's understanding (including those in their late teens) of the lifestyle factors that may improve PBM accrual such as HRSA participation is required to help young people be able to access beneficial health lifestyles to achieve optimal PBM potential.

## 7 Chapter 7: Qualitative focus group study – barriers and enablers

### 7.1 Chapter 7 overview

The findings of the previous chapter indicated that young people had limited knowledge of osteoporosis and PBM acquisition. We need to understand why knowledge of bone health is lacking amongst adolescents and young people, along with how to improve their PBM potential through HRSA and other osteogenic lifestyles and reducing those lifestyle factors that are detrimental to bone health. Strategies to increase PBM accrual need to be directed to young people in a manner that leads a lasting impression on their long-term bone health.

Therefore, we aimed to understand how to effectively improve levels of HRSA in young people by understanding why young people engage in HRSA, the barriers they face and how to reduce the impact of those barriers. By understanding the story behind the barriers and enablers to HRSA may strengthen a resolve in young people to engage in recreational sporting activities to improve long term bone health.

The qualitative focus group study with young adults aged 16 to 35 years (set out in Chapter 6) was used to understand barriers and enablers to HRSA participation and good bone health. The findings of that study are presented in this chapter.

The results of this qualitative study have been accepted for publication and is referenced below:

*Patel, H., Denison, H., Teesdale-Spittle, P., & Dennison, E. (2020). Understanding the barriers and enablers to sporting activity in relation to bone health: A qualitative narrative study among adolescents and young adults in New Zealand. Journal of Osteoporosis and Physical Activity, 8(220). <https://doi.org/10.35248/2329-9509.20.8.220>*

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# **Understanding the Barriers and Enablers to Sporting Activity in Relation to Bone Health: A Qualitative Narrative Study among Adolescents and Young Adults in New Zealand**

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## 7.2 Abstract

**Background:** Sports participation may be considered a method of reducing the risk of fragility fracture in later life by maximising peak bone mass (PBM) in the growing years. However, sports participation typically declines during late adolescence and adulthood. This qualitative study aims to identify barriers and facilitators to engaging with regular weight-bearing sporting activity in adolescents and young adults in New Zealand.

**Methods:** 44 adolescents and young adults aged 17 to 33 years participated in nine focus groups. The study was conducted using a semi-structured approach with open-ended questions and prompts. Transcripts were thematically coded using an inductive content analysis approach.

**Results:** The three main barriers to sports participation that emerged were (a) structural (disorientation in a new living environment, facilities, access to healthcare), (b) social (financial and time constraints) and (c) personal (social pressures and lack of an understanding of why sporting activity matters for bone health) while enablers of sports participation included (a) supportive environments, (b) access to health checks including support to avoid injury and (c) education to better understand benefits of recreational sporting activity.

**Conclusions:** Current awareness of osteoporosis and lifestyle factors that impact PBM is limited. Educational interventions are now warranted and urgently required.

**Keywords:** Barriers<sub>1</sub> – enablers<sub>2</sub> – adolescents and young adults<sub>3</sub> – recreational sporting activity<sub>4</sub> – qualitative<sub>5</sub> – lifestyle<sub>6</sub> – peak bone mass (PBM)<sub>7</sub> – osteoporosis<sub>8</sub>

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### 7.3 Introduction

Osteoporosis is a major public health problem through its association with fragility fracture (Cole et al., 2008). Such fractures are typically described as occurring at the hip, spine and distal forearm, and are associated with considerable mortality and morbidity, which has huge personal and societal cost (Cole et al., 2008). Peak bone mass (PBM) is an important contributor to osteoporosis risk in later life (Hernandez et al., 2003), and can be modified through regular weight-bearing sporting activity in the teenage years and young adulthood (McVeigh et al., 2019; Nikander, Sievänen, et al., 2010; Tan et al., 2014), as highlighted by recent systematic literature reviews (Gomez-Bruton et al., 2018; Krahenbühl et al., 2018; Lozano-Berges et al., 2018; Patel et al., 2020; Wewege & Ward, 2018). Despite this, sporting activity tends to decrease in late adolescence (Dumith et al., 2011). A study by Sport New Zealand in 2016 showed that the rate of adult participation in sporting physical activity (PA) declined over a 16 year period by nearly 8% in all adults, with a greater decrease (13.9%) in young people aged 18 to 24 years. The study also indicated that the rate and pattern of sporting PA decline is dependent on ethnicity, with the greatest decline (over 11%) in the Pacific group (Sport New Zealand, 2016). Furthermore, patterns established in earlier life may carry through to later life; the World Health Organization's (WHO) global action plan on PA 2018–2030 aimed towards a 15% reduction in the level of physical inactivity but globally, one in four adults and three in four adolescents do not meet the global PA levels required for optimum population health (World Health Organization, 2018).

PBM is typically attained in the late twenties, and while weight-bearing sporting activity is an important contributor, although other modifiable lifestyle behaviours are also contributory, including dietary calcium intake, smoking and alcohol consumption (Hernandez et al., 2003; Weaver et al., 2016). Given the particular importance of weight-bearing sporting activity to PBM acquisition it is important to understand what factors limit activity in such sport, and what factors might encourage young adults to engage in sporting behaviour that could have long lasting health benefits. Therefore, in this study we sought to document barriers and facilitators of sporting activity among adolescents and young adults in New Zealand through a qualitative focus group study. Information gathered in this study may help inform future public health initiatives to improve bone health in young adults.

## 7.4 Methods

### *Participants*

Study recruitment was undertaken from July to October 2018 in the Wellington region in New Zealand. Ethical approval was obtained from the New Zealand Health and Disability Ethics Committee (reference #HDEC 18/CEN/18).

Students from Victoria University of Wellington, and other adolescents and young adults aged 16 to 35 years associated with the university, were approached to participate in the study. The participants who had previously been involved in a larger quantitative bone health study had consented to being contacted by email for further research. Others were recruited through word of mouth, recruitment flyers and emails posted through the university media service. Participants were provided with participant information sheets and informed consent forms. Written informed consent was provided by willing participants. Focus groups were held at the university in a neutral toned meeting room with comfortable seating. At the focus groups, participants were reminded that their participation was voluntary and could elect to use a pseudonym of their choice for the group discussion by writing their own name tags to be worn on their clothing (if they preferred). Participants were also reminded that they could choose not to answer any questions, could leave the group at their own discretion without giving any reasons and without consequence, and that any data provided prior to leaving the group would not be withdrawn (but would be stored in a de-identified form).

The focus groups were semi-structured with open-ended questions. Participants were given an option to write points of interest on scribble pads to share information that they did not want to discuss openly for whatever reason. The discussions were recorded with two or more recording devices and an assistant recorded non-verbal communication (field notes, to record information about the level of consensus and dissension to the topic under discussion). Examples of guide questions are shown below in Table 1.

**Table 1:** Guide questions for focus group discussions

Opening Questions
• How important is recreational sporting activity in your day to day life?
• What prompts you to stay physically fit?
• What made you take up recreational sport? What kept you going?
• Was there anything that stopped you from taking up recreational sport?

<ul style="list-style-type: none"> <li>• How happy are you with your recreational sporting activity level?</li> </ul>
<ul style="list-style-type: none"> <li>• Have you ever sought any medical care for sports related injury?</li> </ul>
<b>Closing Questions</b>
<ul style="list-style-type: none"> <li>• If you had to sum up the barriers you face daily to undertake regular recreational sporting activity, what would they be?</li> </ul>
<ul style="list-style-type: none"> <li>• How would you overcome those barriers?</li> </ul>

At the end of each discussion, the lead interviewer summarised the ideas that had been discussed and asked for any final feedback to ensure all ideas, opinions and experiences were recorded. After each focus group, a debriefing session was held with the study facilitators to highlight any discussion issues to be addressed, including any keywords, themes or patterns and relationships identified in a reflexive diary (preliminary analysis). Subsequent focus group interviews used an iterative process whereby any previous emergent themes were followed up to obtain further insights until all themes were fully explored to achieve theoretical data saturation.

### *Data analysis*

The recordings of the focus group discussions were transcribed verbatim and then verified by listening to the voice recordings several times to ensure all data was recorded correctly. All participants' data were de-identified. The transcription and any tabulated data, including any notes obtained from the focus groups, were thematically analysed. We used an iterative process of qualitative analysis whereby inductive patterns emerge into themes from the data itself by constant comparative analysis (Corbin, 1998). Sections of data were then assigned codes and compared for consistency. The assigned codes were categorised into themes. NVivo (qualitative data analysis software; QSR International Pty Ltd. Version 12, 2018) was used to organise the data.

## **7.5 Results**

Nine focus groups discussions were held in total between August and October 2018, with 3 to 11 participants attending each group. The length of the discussions for each focus group ranged from 35 to 60 minutes (excluding the time taken for introductions, completion of the consent forms and post interview discussion). The sample size comprised 44 individuals, with a mean age of 22.9 years and an age range of 17 to 33 years. The majority of participants were of European descent, 10 were of mixed

ethnicity including Māori, Pacific people, Asian and Indian, approximately two thirds were female, with one third male (29:15).

### *Themes*

The themes that emerged are displayed in Table 2.

**Table 2:** Key barriers and enablers to recreational sporting activity

<b>Barrier</b>	<b>Enabler</b>
Structural <ul style="list-style-type: none"> <li>• disorientation in a new living environment</li> <li>• facilities</li> <li>• access to healthcare</li> </ul> Social <ul style="list-style-type: none"> <li>• financial constraints</li> <li>• time constraints</li> </ul> Personal <ul style="list-style-type: none"> <li>• social pressures</li> <li>• lack of an understanding of why sporting activity matters for bone health</li> </ul>	<ul style="list-style-type: none"> <li>• Supportive, social environment that promotes mental wellbeing</li> <li>• Support to avoid injury</li> <li>• Financially viable, i.e. affordable access to university and sports facilities</li> <li>• Better education to understand the advantages of recreational sporting activity on long term health</li> </ul>

The analysis of the results indicated the presence of three main types of barriers to sports participation: structural (disorientation in a new living environment during the transition to adulthood, facilities, access to sports injury care), social (financial and time constraints) and personal (social pressures, self-image and lack of an understanding of why sporting activity matters for bone health).

The results indicated that enablers for sports participation included having supportive environments in social groups that improved mental well-being, having regular health checks and support structures to avoid injury, understanding the specific attributes and benefits of habitual recreational sporting activity, supportive socio-economic structures, and the affordability of university and sport facilities.

The types of barriers and enablers to sports participation that emerged from the focus group discussions are explored in further detail below.

### ***Structural barriers***

#### ***Participants felt disoriented in new environments***

Participants were aware of structural changes occurring throughout life; that the decisions made by families or educators during the different phases of school life can change the course of a life. Previously parents and educators modelled sporting activity behaviours, encouraged sporting activity. The change of routines and behaviour during the transition from a home environment to independent living at university or as adults may be considered a barrier to sporting activity initially. Previously, young people indicated that they had a more structured and relaxed weekly routine in their home environment so there was more time available to enjoy participating in sporting activity. Despite having more free time available in tertiary education, young people felt scheduling sporting activity arduous.

*“It’s just kind of like adult life gets the best of you, seriously.”*

There seems a definite lull in sporting activity during the transition to university life. Without the assistance of parental management or sports co-ordinated activities young people found organising new club memberships or activities or meeting new people in unfamiliar environments a barrier to engaging in new activities.

*“It’s all too new and so much is going on – you are not even sure who your friends are yet and who you want to hang out with.”*

### ***Environmental facilities affecting access to sports***

The physical environment (space and place experiences, including indoor and outdoor culture) affects levels of participation in recreational sporting activity. When attending university, the recreational sporting activity participated were mostly indoor sports, and during the evenings to around study or work schedules. Those who had previously lived in rural areas or had beach or small-knit communities with unlimited outdoor access or communities within the bigger urban structure wanted to feel protected, *“still feels safe.”*

*“It’s easier to go outdoors and get sunshine when you are at home and get into a routine of PA, with the dog going for walks...or go play in the garden...when flatting there is no garden no...and sitting outside in the garden for sun exposure...the buildings are not designed for outdoor living.”*

Weather dependency, seasonal changes with long dark nights and poor weather disrupted the recreational sporting activity routine.

*“When you realise you have been indoors all day and haven’t seen the sun,”*

Although nearby the university’s gym and sports complex is regarded as *“not the best facility”* perceived as small, overcrowded with limited options and an expensive option when on a limited budget.

*“Accessibility and ease of use is important.”*

### ***Managing sports injury and accessing to health care***

Others avoided or delayed seeking medical or other healthcare attention and, especially after injury or sickness which would permit periods of sedentary behaviour, young people found it difficult to return to routine recreational sporting activity.

*“So that put me off for like ages, but I don’t know what I did to myself, I never checked it out.”*

Injury prevents sporting activity participation. The likelihood of significant injury in sports such as rugby was a concern, for example being spear headed in rugby was *“scary.”*

Inadequate supervision and training is a barrier to sporting activity as, in New Zealand young players maybe supervised by senior students as coaches and umpires who may be inexperienced in understanding potential risks to injury.

*“You have to coach and umpire games younger players as part of your training and commitment to the game as they don’t have enough people to help otherwise you don’t get to play.”*

In addition, there was a general agreement that winter sport was *“off-putting,”* because of the very early start of Saturday gameplay times, *“cold damp weather which made playing with foggy glasses difficult”,* and *“falling onto wet concrete was not fun”,* (dangerous) and *“would rather sleep-in on a Saturday*

*morning,” and “always felt tired”, as there was always a busy schedule of, “something every day of the week.”*

Discussions with friends may lead to conflicting ideas of the benefits of some activities. For example, a vegan participant remarked that his flatmates claimed that milk is not related to strong bones, but repeated prolonged high impact forces (through Kung-Fu or boxing) strengthened bones by damaging bone tissue.

*“The pain doesn’t put you off, it’s like sitting and riding a bike it becomes ok.”*

Inadequate healthcare and support structures impacts on sporting activity and bone health. One participant who regularly trained in long distance agreed his shins were painful and suffered lower extremity overuse bone injury (LEOBI) continue to enter marathon events regularly and chose to rely support from his physiotherapist as he was not prepared to give up running.

Participants found access to health care difficult. Doctors’ visits were considered costly and a deterrent to seeking appropriate healthcare, and sometimes would prefer cheaper options.

*“Physios always good at claiming through ACC, so it’s \$5 versus \$45.”*

A participant (who previously was a sports trainer) suggested sport had financial incentives which themselves were barriers to sporting activity as players would play even when injured.

*“There is a lot of money going on performance even at high school, as [some are] recruited for scholarships at around 14.”*

Participants viewed distance running as competitive and addictive. Participants wanted to run further and faster, weigh less and receive accolades for weight loss and endurance. Despite being very knowledgeable about healthy diets and behaviours, some participants would continue to run or play sports while injured using internet for advice for self-treatment or did not permit adequate injury recovery time to resolve the injury.

*“Changes to running style helped.”*

Although they trusted their doctor's knowledge and competence, most participants felt rushed during doctors' visits and did not receive detailed information or suggestions of ways for maintaining good bone health.

*"Seeing doctors [was] really bad, can wait for a specialist for 2-3 months of waiting, letter in the post – who uses the post anymore?"*

*"You do make an effort to avoid things but try to get back to doing it again and will still find a way to play."*

*"Would get to my brain – I need to play."*

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### ***Social barriers***

#### ***Sports participation were dependent on finances***

During the transition period from home to university life students experience new financial constraints. With newfound independence, students have to self-manage their own limited funds. Allocating money to sporting activity may be not as feasible when considering the cost of transport, sports equipment such as bikes, training boots and specific sport clothes.

*"Played touch for 8 hours, rolled ankle – had really bad shoes."*

Gym or sports memberships were selected for a number of reasons such as: the price of the membership (resulting in participants often choosing the cheapest gym available); the type and size of facilities available; the activities offered; the opening hours; the ease of access (whether they were able to walk or commute to the venue); and the quality and level of personal privacy available in the changing rooms. Some of these factors were a barrier to engaging in sporting activity.

*"When the scholarship money ended so Kung Fu ended."*



*“Ridiculous fees to be part of a [sports club or] team, so expensive as a PhD student, basically on the minimum wage and with Wellington rent being so expensive...”*

*“Student course fees are so expensive, so exercise is a luxury. It is so wrong.”*

Balancing work and study commitments impacts sports participation. Academic pressure, especially for those students with the burden of limited student living costs, to perform well outweighed the benefits of sports participation. International fee paying students and those students lacking parental financial assistance were further disadvantaged and often sought paid employment to support themselves.

*“Needed to work and study... trying to hold down three jobs and have to study harder, so harder to be committed to exercise, and gained weight.”*

*“I couldn’t...to join the university netball team it was like 350 bucks for the season and, because I’d never paid before, so stopped playing so much, as it was so very expensive.”*

### ***Managing time commitments independently was a progressive learning curve***

During the school years, young people felt that they were more likely to enjoy sporting activity when they were supported by family and peers, and were involved in volunteering to assist sports activities at school. The lack of parental support with coaching and managing teams or transport impacted some young people’s level of sports participation.

*“My sister was playing netball, my brother was playing rugby and I was playing football, which was always real hard for my parents, ‘cause like, drop that one off, go and watch half of this one, go back watch half of that one, pick them all up again.”*

Finding the time to engage in sporting activities independently required time management. Being too busy, tired, or wanting to sleep were deterrents to engaging in sporting activity. Additionally, conflicts of agendas manifest as further barriers to sporting activity participation. These conflicts include: academic demands (including lack of coordination of exam loads between course work and exams); work

commitments; food preparation and household chores; public transport costs and time taken in travelling or commuting; and the inability to drive a car or have access to a car.

*“I think something a little like that. If I have something to do like I will put exercise on a backburner or do it tomorrow like it’s, when I was in summer I would do it regularly but then come back to Uni, I kind of, yeah push it aside.”*

*“More responsibility here. Living in the Hutt transport is an issue, don’t drive – how to get here is a problem.”*

Participants used electronic devices to procrastinate or to distract themselves from other activities.

*“I spend a lot of time on my phone, I don’t even realise it.”*

Time spent in small screen recreation (SSR), that is, television, computer, video, and DVD distraction, represent lost opportunities to participate in sporting activity.

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### ***Personal barriers***

#### ***Social pressures and self-image issues***

Extracurricular sports activities are common at an early age in New Zealand with a high expectation to engage in both summer and winter sports during the school years. The high personal and peer expectations to achieve sporting success was seen as a barrier to sporting activity. The pressure of social media recognition through the internet magnifies the response of achievements (or non-achievements).

*“I saw you in the newsletter.”*

Another participant said that their parents wanted them to play sports, most commonly rugby, followed by athletics.

*“Dad was rugby born, born to play rugby. Good but not good enough to dad’s standards. Motivation – because family also pushed.”*

Successful sport role models include national and international sports personalities who inspire sporting activity participation from an early age; although, this may also lead to despondence and lack of self-esteem by not achieving similarly high levels.

In New Zealand, gender was not seen as a deterrent to sports participation with mixed gendered teams at primary school level common, although at senior school males often played rugby and cricket, females played netball and badminton.

*“Social barriers like gender – no!”*

*“In our family everyone talked and played, watched the footie weekdays and weekends either on the field, on the side-lines or on the telly or at the pub.”*

Negative aspects of sporting activity include fear of disappointment or under-performing especially in team sports. Therefore, non-competitive sporting activity is preferable for some young people. College rivalry encouraging heroism amongst young may also be perceived as a barrier to sporting activity; with feelings of psychological pressure to attain goals which may impact on mental health.

*“It’s in the culture, how you are perceived at school. It’s cool to play (rugby), it’s part of who you are in NZ... being selected for the top team is cool, at school.”*

Young people are influenced by social media and are challenged by self-awareness of how their own physique, fitness status, self-perceived athletic prowess or lack of ability or skills or confidence, shyness, self-consciousness is portrayed often publicly. The fears may be masked by showing lack of interest or willingness to participate in sports which may cause feelings of conflicts and exclusion and the fear of being judged or embarrassed. Self-image and body dissatisfaction was common some for female participants.

*“I feel like I’m really out of shape.”*

*“You get bullied – kids are cruel when you are chubby.”*

*“My boobs get in the way!”*

One participant was not able to play rugby as it was considered dangerous to have a small physique.

*“A beanpole.”*

### ***Lack of an understanding of why sporting activity matters for bone health***

How different types of sporting activity affected bone health was not well understood. The concept of weight-bearing activity was detrimental to bone health as it may cause injury.

*“Underwater hockey is not too bad for your bones – not weight-bearing.”*

*“Never think about, I could do something that could change my bone structure?”*

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### ***Enablers***

Participants suggested a number of drivers to increase sporting activity and PBM potential including the lifestyles young people adopt including: increasing bone health knowledge; free access to sports and healthcare especially when injured; positive reinforcement of healthy behaviours from health professionals with nutritional advice; migration away from alcohol consumption; support from academics regarding workloads, social groups (friends and family); and a desire to learn and enjoy new sporting experiences including cycling as an alternative form of transport.

### ***Supportive environments***

Some young people were aware of their carbon footprint and wider concerns for climate change but were unsure of how to change their lifestyle and how this impacts on their bone health. They felt that environmentally conscious modes of transport such as walking and biking would have the added benefit of increasing their PA.

*“Now it’s biking primarily as I don’t have a driver’s licence – logically it is easier to bike for a good combination of reasons.”*

*“It was definitely environmental to begin with...I went through my whole process of finding things up, mostly to do with industry and the environment. Then you just suddenly grow to appreciate every aspect of it and just how better it is.”*

### ***Fun, friendly routines in social groups***

The social interactions young people have play a crucial role in young people’s decision making and encouraging positive lifestyle patterns such as sporting activity. Social motivations that encouraged regular sporting activity included forming new friendships, discovering new opportunities, positive peer influence, enjoyment away from studying and the benefits of having routine, the prospect of healthy competition, outdoor spaces with sun exposure and general mental health benefits.

*“The main motivation was fun and to do what your parents want you to do.”*

Including reaffirming family social connections using sporting activity such as, *“skiing with the family as an annual trip.”*

Having the company of friends and family inspires confidence and reduces the anxiety and shyness felt in unfamiliar group situations.

*“It makes it easier that others go in the family – don’t like going in by myself.”*

*“Played with siblings – plays touch, at the games, ...we are there, so may as well play rather than get bored... in my family everyone plays touch – it’s easier.”*

*“The motivation was the social aspects, fun, less awkward to do something with others.”*

Going as a group was found to involve more fun, more motivating to participate in classes and sports.

*“You have to show up or others will notice...having a friend helps you show up, saying, let’s go, so going in groups helps you to show up. Definitely helps to meet friends – a more normal routine.”*

*“It’s always game, competitive, mostly as a kid you choose sports just for fun and it’s enjoyable, just want to sleep and hang out with friends. That’s what you did as a kid – it’s not a waste of time, it’s a mind-set.”*

*“When someone asks you where you were when you didn’t come the week before.”*

### ***Taking caring of mental well-being***

Engaging sporting activity induces increased energy levels to feel energised and improves mental health status.

*“Playing sports – feel good, is good, feel awake. Bad, also enjoy the stiffness, sore muscles feel good. Pain is good makes you feel strong – wouldn’t do it again if it hurts too much.”*

*“Main motivation – help with my mental health.”*

Self-organisation was the key to organising a sporting activity schedule.

*“I like to get it out of the way. I find working to the natural daylight cycle helps.”*

Students found regular sporting activity (such as football) beneficial to health and was a stress reliever during exam periods of intense studying.

In the winter, participants were aware to be supportive of each other as a team to get some sun exposure.

*“We try to make each other go outside [for sunshine and a break], the reasons were not always specifically to get some vitamin D, just going outside and feel good.”*

Participants found sporting activity reduces frustration and anxiety, choosing a variety of different activities to keep motivated.

*“I started off with soccer, then tennis, then around my puberty basically nothing... then sometimes went to the gym to impress the ladies.”*

Participants found negative self-image issues a driver of sports activities.

*“As a kid... raised for academic studies, for debating classes. Dad thought I was getting too fat as a child and encouraged me to play badminton every day.”*

A participant found a positive attitude helped to achieve good health.

*“Now more health conscious and want to be active at 60-80 and still be active for my kids – healthy is good!”*

*“But I used to use the excuse be like I am too busy or too tired so I will do it later but I sort of recently realised that you are not actually ever that busy that you can’t find an hour, 3 or 4 times a week to do this. And it just improves like everything like my mood, my ability to think and all that kind of stuff. Also if I am tired, it actually you know helps. So I find that very easy to motivate myself to go. It’s probably also a large part procrastination I much, much prefer to go to the gym and lift weights for an hour than to sit at my desk and do work.”*

Negative attitudes to sporting activity may be masked by showing lack of interest or willingness to participate but may also be motivators of action.

*“Feeling out of shape, motivates, you need access to sports, timing and scheduling, so and up walking and hiking most of the year – it’s really enjoyable.”*

### ***Health checks and support to avoid injury***

Regular health check-ups may permit awareness of changes and motivate positive changes. One participant suggested that young people were concerned more about the present situation and the immediate benefits rather the future impacts or benefits.

*“Psychology of teenagers are always going to make risky behavioural decisions. Need a hard sell or reverse psychology. Not many worry about what’s going to happen when they are 90 years old.”*

Most adolescents and young adults felt that if their doctors gave them choices to adapt their behaviour especially through sports and nutrition to obtain good bone health and, that if they were aware of their risks of fragility fracture or osteoporosis, they would proactively modify their behaviour.

*“If was told, like was told by my GP or something that I am on track to develop osteoporosis or I am not doing something I should be. Then I would be happy to like add something extra to my diet to help or maybe if there is like a particular type of exercise that would be better then maybe incorporate that into my routine.”*

### ***Making sporting activity more accessible and affordable***

Financial constraints impacted sports participation as expected. Access to free and nearby sports facilities was perceived as a motivator for sporting activity especially with social group activity incentives, that may encourage regular PA with moral support and guidance to training and help build PA routines.

*“I heard about that, how they have a free gym at Otago, and I’m so jealous. I would totally, oh my god, I would go to the gym every day if it was free, I’m not even kidding.”*

### ***Relevance: understanding why sporting activity matters for bone health***

Young participants found self-awareness and positive affirmation their health was on track gave them feelings of wellness, fitness, strength and pleasing physical appearance which further motivated sporting activity.

*“I was younger; I never did at all. Yeah, so when I did that [heel bone] scan, that was probably me at my most unfit, unhealthiest and now it’s like come in to healthiest I have ever been.”*



There was a suggestion that there is a need to plan sporting activity especially when there is a big project coming up.

*“Everything improves when I exercise, I don’t want to ruin the benefits of the exercise.”*

There is an internal driver to engage in sporting activity to balance less healthy lifestyle habits.

*“Guilt – because I tend to eat more when I stress.”*

As a form of procrastination young people may choose to exercise or go to the gym rather than to be at the desk studying.

*“Mum and dad wanted me to swim and started when I was two years old. At 11 started kick boxing and scuba-diving – more through clubs, competitive teams and so much fun in between studies. Important to keep a work life balance – more to do sport than to study.”*

Students felt time management skills were important to allow time for sporting activity for bone health, leisure, day routine chores such as planning healthy meals and other domestic tasks. Strategies incorporating routine sleep and work patterns such as meditation and yoga assisted managing work and study commitments.

*“Sports did not impact on academic sides, still got good grades just managed time better.”*

*“Force yourself to break out your comfort zone/habit, routine makes it easier to go, not to question yourself just go.”*

Many participants recalled nutritional and healthy lifestyle advertised campaigns from childhood such as the “Push Play,” and “exercise, sun and fresh air;” “Five plus a day,” and “food pyramid,” and “eat

*your colours;*” as well as campaigns targeted at parents that encouraged milk or dairy consumption when they were younger.

To incentivise individual or team challenges young people used fitness or mobile tracking devices and training Apps such as Pokémon Go to monitor fitness levels and sporting activity.

*“Sets up team challenges at work, crazy competitive, crazy number of steps.”*

*“It’s like, public boasting right.”*

*“See your ranking in the same stretches makes you competitive, it’s a challenge.”*

*“Using sports to stay active, is a method to keep up the fitness level.”*

*“By signing up for two marathons. Not much support after the day event. For those doing super long distances you are basically on your own. Need proper shoes, you can find the information out there but more professional info available – feels like you sign up they have your money. The information given is just basic information. But likes the banana and cookie at the end – so good! Support for training apps, coaching pamphlets, get a running coach, or a running group.”*

*“Guidelines – there are experts out there but there is information, just need to know to get it. Runners know what a good recovery period is – but will keep on going, can’t stop, keeps pushing yourself tracks himself 200kms – 5 hours, it’s “part of the bravo thing” going 27kms on Saturday and runs 2 hours every day. “Gets used to it”. See your ranking in the same stretches makes you competitive, it’s a challenge.”*

Once committed to the team, the pressure to perform and not let the team down was a motivator to continue playing and turning up for the games and practice sessions.

*“In team sports you can’t just not turn up!”*

*“Addicted to competing, using mobile apps to track his progress and public competitions to motivate himself as competitive as hell.”*

*“He’ll do...he’ll do...he actually, he tracks his thing on (...) like, “I have to do 100km this week”.”*

Competitiveness and demonstrating fitness by following exercise regimes, or endurance feats may be drivers to action.

*“F45 – 3 hours, 5 days a week, an intense workout for a few weeks – can make you vomit as you eat very clean, no sugar, no calories.”*

*“Don’t want to be seen chickening out.”*

## **7.6 Discussion**

Promotion of sporting recreational activity may be considered a tool to reduce the impact of fragility fracture and help in the prevention of osteoporosis disease later in life. Young people understand nutrition and sporting activity are important for overall health, but general knowledge about osteoporosis is typically lacking (Holland, 2017; Minns Lowe et al., 2019). In this study, participants did not identify with the concept that bone health could be improved with increased high impact weight-bearing recreational sporting activities.

It was noticeable that barriers to sports participation were more vividly recalled by the participants compared to enablers of sporting activity. The barriers young people faced in adopting lifestyles associated with better bone health revolve around the transition stages in life. This is similar findings in an Australian study of children the behaviours of transition from primary schooling to secondary schooling (Marks et al., 2015). In particular, the transition from secondary schooling to tertiary education, that involves newfound independence, financial independence, the opening of new horizons and social interactions without the familiar social support of home life. Participants acknowledged that many of their teenage sporting activities would not have occurred without parental support. Other constraints to sports activity included complexities in managing increasing academic pressure with part-time work and

social commitments. In particular, at the start of tertiary education, some young people prioritised social engagement over sports activities.

Our study concurs with a systematic literature review of barriers to sporting activity that found a lack of time, financial affordability, social aspects along with physical access issues placed significant barriers to participating in sports activities (Somerset & Hoare, 2018). A New Zealand study suggested that the prioritisation of sports participation diminishes when trying to balance study and work commitments (Dovey et al., 1998). Without formal time structures around activities such as tertiary education, young people in the qualitative focus group study felt their time management were barriers to engaging in sporting activity.

A review of women's sports participation in Southern Europe suggested that gender inequality played a significant role (Cooky et al., 2016). Our study found some female participants felt they had to be good at everything both academically and physically. Gender stereotypes in sports participation do not seem to be a barrier until a lower college level, with females commonly playing rugby, cricket and football (Sport New Zealand, 2019).

Obstacles in accessing appropriate healthcare also formed a barrier to participating in sporting activity by complicating and delaying comprehensive and timely recovery from prospective injuries. Injuries occurring when young people participate in sporting activity may impact in future playing abilities of young players; reduce the fun factor and motivation to play (McManus et al., 2006). A recent New Zealand study of sport participation and association to injury found that early sports specialisation (before 13 years of age) was not associated with an increase the likelihood of reporting a history of injury (McGowan et al., 2019). Research by National Basketball Association and USA Basketball suggested that the engagement in sports should be a positive experience; that the focus on achieving results rather than for "fun" can distract from the long term physical and mental health benefits achieved with sporting activity. The same study suggested there may be detrimental consequences due to early childhood high intensity training, single-sport specialisation, frequent competitions leading to increased burnout and overuse injury and for reduced competency and life skills in other areas in life (DiFiori et al., 2018). Our study found that fun with family and friends was an important driver of sporting activity. Some participants wanted to enjoy sports for fun but found the competitive nature of sports participation to be

a barrier to joining games as selection and ranking during sports trials was off-putting (Brocklesby & Sport New Zealand, 2019; Fitzpatrick, 2013; Walters et al., 2015).

Participants generally noted access to a variety of sporting activity facilities available but the associated costs did not always make them viable. The cost of purchasing sports equipment, club membership costs and transport to sports venues imposed further financial barriers. Participants felt the financial burden in various ways.

Participants in our study suggested positive reinforcement of healthy behaviours and to improve sporting activity sports coaching, friends, family, support from academics with study and work load, free access to sports and healthcare. Other suggestions for enablers to sporting activity include aid for: student loans, the costs incurred for sporting activity access, equipment, dress codes and any protective gear required; health care access (including associated GP costs, nutritional and dietary advice, physiotherapy, long-term injury recovery support, injury prevention; including appropriate shoes, sport-protective spectacles or supportive sportswear or sports library to loan equipment and verified and qualified sport club or school trained coaches and umpires (Hardy et al., 2010).

The strengths of this study include the participants' ethnic diversity, age range and spread of socio-economic groups. Although the generalisability of this study may be considered limited to the university environment, the data was sourced from a range of participants from the university campus who came from a wide variety of backgrounds, reflecting local population diversity in the Wellington region (Statistics New Zealand, 2013). Trustworthiness in a qualitative study may be judged by its credibility, transferability, dependability and confirmability (Loh, 2013). An appraisal of the research protocol by an external party and other qualified researchers in the field ensured dependability of the research process. The study protocol and reflexive diary of the iterative research process permitted transferability of the methods used to other contexts. The data presented here were sourced from a range of participants from the university campus who came from different backgrounds, affirming credibility. Participants were encouraged to talk freely; the interviewer's interactions were minimised after the initial introductions to the group. Ideas were summarised after each discussion group in the debriefing sessions held with the study facilitators to highlight any discussion issues to be addressed, including any keywords, themes or patterns and relationships identified from the focus groups and recorded in the reflexive diary. The data were interpreted independently and by continuous comparisons and consensus

to confirm that the findings and interpretations were true to the participants' views. The emergent themes were auditable in NVivo, the software program used for managing the data, to objectively compare and develop the emerging themes.

However, this study has some limitations. No formal data were collected on the participants' socioeconomic status. Although it is known that the rate and pattern of decline varies by ethnicity, due to low group numbers our study was not able to perform sub-group analysis based on ethnicity. It is well known that generally, Māori participate favourably in sport participation and volunteering to assist as coaches and mentors at an intergenerational level, these positive attributes may be further expanded to improve health and educational outcomes within communities, including bone health (Sport New Zealand, 2017). Further work is required in this field with a focus on ethnicity, given the largest decline (of 11.4%) in sports participation in New Zealand is amongst Pacific adults (Sport New Zealand, 2016). Our study did not include those with mobility disabilities and for young people who do not neatly fit into the dichotomous gender categories of other genders, gender diversity has not been addressed although very relevant in this population (Clark et al., 2014; Graham et al., 2011). Some of those in this study participated in sporting activity beyond a recreational level at different stages of their lives. Additionally, some of the views of the participants may reflect a more an international perspective, due to spending differing amounts of time in and out of New Zealand. Finally, we acknowledge the modest sample size of the study population and the need to conduct similar studies in other populations; reassuringly data saturation was reached despite this.

Our participants strongly recalled past health campaign strategies which had a lasting impact on adolescents' and young adults' lifestyle behaviours and have encouraged PA and healthy eating habits. Studies have indicated that national Push Play campaign increased awareness and intention to increase PA to become more active and were recalled by participants easily (Bauman et al., 2003). Given that globally nearly 25% of adults and 80% of young people, most so in females, do not achieve the recommended levels of PA for good health; for adults this is 30 minutes of moderate or 15 minutes of vigorous activity most days and, for young people 60 minutes of moderate or vigorous activity every day (World Health Organization, 2018) further intervention is required.

## **7.7 Conclusion**

We have found in this study of New Zealand adolescents and young adults affiliated to tertiary education that participation in sporting activity is often motivated by enjoyment and by developing and maintaining social support networks. Barriers to sporting activity participation included financial and academic pressures and personal time management issues. During the transitions from secondary school and home life to adulthood and tertiary education, young people struggle to independently and proactively engage in sporting activity in a new world of exciting opportunities. While some of these themes will resonate with those in higher education, many will be more generally applicable. The findings of this study will aid young people and policy makers to recognise the barriers to sporting activities that enable beneficial bone health lifestyles. Further studies are required to understand how the current available policies to support sporting activity translate into good bone health in young people to maximise PBM potential in young people.

## 7.8 References

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## **7.9 Chapter 7 summary, future implications and next steps**

The findings of this chapter indicated that the young people in the qualitative focus group study faced multiple barriers to engaging in HRSA. The study included discussion of the factors that may facilitate their engagement in HRSA. Making long-term, osteogenic lifestyle choices particularly through HRSA is especially important during the transitional stages of life for young people (for example, moving to independent living environments).

This part of the study indicated that individuals who engaged in some form of HRSA during school years often continued with some level of activity; though those who broke the regular cycle of activity found it difficult to prioritise HRSA amongst their studies and other commitments, unless a closer social intervention occurred. In particular, the findings of this study indicate that social interventions should be targeted early upon leaving the school environment to encourage appropriate HRSA as a long-term lifestyle choice. Young people have wider concerns that may affect them making changes to their lifestyles (such as finances, work, social interactions, dietary and transport changes), including in relation to their individual carbon footprint, climate change and the environment. Young people desire to be fit and eat well, well-informed, educated, knowledgeable and to be able to obtain trusted reliable information through a variety of complementary sources including sound practical medical advice, their inner circles and the internet to acquire better bone health in the long-term.

Future areas of study performed that are scheduled to be performed up until December 2021 have ethical approval (pending an updated amendment with appropriate documentation and a progress report that is due in May 2021). The HDEC Letter “18CEN18AM06\_Aproved Annual Progress Report 05 May 2020” is attached in the Appendix. Those involved in all stages of the study have given positive feedback, in that the studies so far have permitted increased awareness of bone health not only amongst young people but with extended family, friends and those in the education sector.

Of special note, this study was undertaken before the global COVID-19 pandemic emerged in early 2020. Future work requires innovative, safe methods to explore the impact on HRSA in these unsettling times, especially in young people in the school aged group, teenagers and those transitioning to young adulthood. Comparisons of behaviours for those involved in the current study and during and after the pandemic represent an area of potential future research.

## **8 Chapter 8: Discussion**

### **8.1 Chapter 8 overview**

In this chapter, the main findings of the thesis are summarised and synthesised to give an overall understanding of how HRSA and other modifiable lifestyle factors are related to PBM acquisition in young people. The qualitative studies that form part of this thesis provide insight into young people's understanding of osteoporosis, PBM acquisition and the lifestyle factors impacting bone health and future risk of osteoporotic fracture. We discuss our decision to use cQUS to assess bone health in this study, along with the strengths and limitations of the study, suggest future research to be undertaken and the plans for the dissemination of the study findings.

The systematic literature review performed highlighted a significant lack of quality research that specifically assesses relationships between non-elite recreational sporting activity and bone outcomes using heel ultrasound as the bone measure rather than DXA, pQCT or other ionising or radiating measures, as used in other systematic literature reviews. The previous literature available suggested that regular weight-bearing non-elite sporting activity such as soccer and recreational gymnastics is associated with better bone health, as assessed by cQUS, and our own quantitative study supports these observations.

We chose to use heel ultrasound to derive bone outcome measures in the quantitative element and in the systematic literature review of this study for many pragmatic reasons. The heel is an easily accessible, weight-bearing site measure and the technology does not use ionising radiation so is completely safe in a research study of young adults. The technology has been used and validated in many large studies, having been shown to capture other aspects of bone quality that contribute to fracture risk that are not measured by DXA (Moayyeri et al., 2014). cQUS measures have been previously correlated with DXA in children and is a validated tool for predicting the risk of osteoporotic fractures in older people (Babatunde & Forsyth, 2013; Moayyeri et al., 2012). In addition, a meta-analysis of genome-wide association (GWA) studies to assess the genetic determinants of heel BUA and VOS found a commonality in the effect of several genes that are central to DXA-derived BMD measures and heel ultrasound measures (Moayyeri et al., 2014). Importantly, the cost, portability, availability and ease of use of the heel ultrasound machine compared to other techniques used in past literature made it an obvious method of choice in the young population in this study.

In our quantitative study, we found further evidence in support of the observations made by previous systematic literature reviews, with particular benefit to bone health found for sports associated with higher impact activities such as running, soccer and rugby, which appeared to confer greater benefit even after adjusting for other lifestyle confounders. The quantitative study also indicated that over 80% of males and females studied reported participating at least weekly in sporting physical activity, although participation rates dropped off at older ages. Our own findings are in accord with previous studies which used DXA or pQCT (Deere et al., 2012a; McVeigh et al., 2019).

Finally, the qualitative focus study of young people's knowledge about bone health highlighted a current lack of knowledge of PBM acquisition and osteoporosis, but also a desire to know more. This study provides more contextual information about young people's lifestyles and the factors influencing their decisions that ultimately can affect both their PBM acquisition and consequent risk of osteoporotic fracture later in life. As young people have a limited understanding of PBM, there is a need to educate young people about PBM acquisition in particular in terms of osteogenic nutrition and physical activity (PA), specifically HRSA.

## **8.2 Summary of main findings**

### **8.2.1 The systematic literature review**

The main finding of the systematic literature review was that regular weight-bearing HRSA was associated with better bone health as assessed by cQUS (Chapter 4). This systematic literature review was the first to assess the relationship between bone health as assessed by cQUS, along with the duration and frequency of the different types of specific sports activity (and inactivity for the comparative control participants), and whether they were in combination with other activities or not. Analysis of other contributing lifestyle factors were not always available, including diet, alcohol consumption, smoking, use of medication or supplements, and indoor or outdoor sun exposure. The systematic literature review highlights that further work is now required, especially in relation to young adults in their 20s and 30s, to examine this issue in greater detail with more clearly defined control groups using cQUS and HRSA. The results complement other systematic literature reviews that used other imaging tools. Although study heterogeneity prohibited meta-analysis, all six included studies reported significant benefits of weight-bearing HRSA on cQUS outcomes.

The age of the study participants under review leaned toward the younger end of the 11 to 35 year age group we had specified, indicating more research is required to evaluate the effect of specific HRSA on the bone health of young adults by cQUS.

A particular challenge in performing this systematic literature review was establishing, from the information provided within the retrieved articles, the level and intensity that participants engaged in different sports and training schedules: future work might make this more explicit.

### **8.2.2 The quantitative study**

The main finding of the quantitative study indicated that calcaneal heel ultrasound bone parameters were positively associated with loading HRSA such as running, soccer and rugby (Chapter 5). These results are consistent with the findings of the systematic literature review undertaken in this thesis and that sustained levels of HRSA conferred better bone health as seen by cQUS measure (Chapter 4). The cQUS bone measurement tool was found to be reflective of young people's bone health and in particular to the type and level of HRSA engaged in. The findings were similar to other studies that used DXA as the bone outcome measure (Colantonio et al., 2018; Egan et al., 2006; Sarmiento et al., 2019; Ubago-Guisado et al., 2015).

This present study was cross-sectional but reported recalled lifetime sporting activity that indicated a high rate of sports participation consistent with that found in many Pacific countries (Brocklesby & Sport New Zealand, 2019; Hulteen et al., 2017). The finding that the level of recalled HRSA declined during adolescence is a consistent finding globally (World Health Organization, 2018). This is important given that this is a favourable time to improve bone health through osteogenic long-term lifestyles habits such as increased HRSA to help improve PBM acquisition.

We collected information on dietary calcium intake in this study but did not find evidence of interactions between dietary calcium and bone health in this group, in contrast to other studies (Julián-Almárcegui et al., 2015; Weaver et al., 2016). This may reflect the nutrition of the participants: this explanation would be supported by a previous study of young gymnasts that found that among young women with sufficient intake of dietary calcium, additional calcium supplementation provides no additional benefit (Ward et al., 2007). Against this, is the observation that calcium intakes were reported as modest in our study sample. Other studies should consider this issue in samples of young adults.

### **8.2.3 The qualitative studies**

In these chapters we report that current knowledge of osteoporosis and lifestyle factors that impact PBM is limited. We also report both the barriers and enablers young people face to sporting activity engagement in relation to improving their bone health and PBM potential (Chapter 6 and 7).

In this work we found that young people are generally aware of the positive and negative impacts of many lifestyle behaviours such as HRSA, diet, tobacco smoking and alcohol consumption on health, but not specifically how these impact PBM and good bone health in later life. Importantly, there was a limited understanding of bone health and PBM acquisition that hinders young people's ability to modify their lifestyles to improve their PBM potential. A greater understanding of the consequences of the modifiable lifestyle factors, such as participation in HRSA, may help reduce risk of osteoporotic fracture later in life and encourage improved overall health outcomes. Young people reported a desire to be fit and eat well, well-informed, educated, knowledgeable and able to obtain reliable information. Similarly, a qualitative study that assessed the knowledge of older females found that participants considered osteoporosis important, but did not feel susceptible to developing osteoporosis themselves, which may hinder proactive measures to reduce their risk of developing osteoporosis later in life (von Hurst & Wham, 2007). Our focus group participant wanted osteoporosis educational information to aid a change in lifestyle behaviours relevant to improve bone health in particular to increase awareness low calcium and low vitamin D on bone health, a similar other studies (Chan et al., 2018; Rizzoli et al., 2014).

The results indicated the presence of three main types of barriers to sports participation: structural (disorientation in a new living environment during the transition to adulthood, facilities, access to sports injury care); social (financial and time constraints); and personal (social pressures and self-image, lack of an understanding of why sporting activity matters for bone health). Adolescents and young adults need life skills to lead healthy lifestyles for the best possible PBM accrual during the transitional stages of life particularly. Support is required at those transitional stages through social, academic and health providers. The barriers to HRSA participation also included time constraints, a lack of motivation and the feelings of tiredness; these findings are similar to other reports that aimed to improve sport and active recreation opportunities (Sport New Zealand, 2018a). Continued engagement HRSA early in life leads to improved physical and psychological well-being (Collins et al., 2018), along with improved bone mass compared to those less active, especially in women (Mantovani et al., 2018). Similarly, a qualitative



study assessing the barriers and enablers to HRSA of older males and females found that communicating the benefits of incorporating enjoyable and safe osteogenic HRSA lifestyles in everyday routines is important for continued HRSA participation (Simmonds et al., 2016). Another finding from the focus group participants, consistent with existing literature was that the transition from secondary schooling to the workforce was viewed as a deterrent to HRSA participation, with additional financial constraints acquired such as accommodation and education costs along with newly acquired adult responsibilities (Martins et al., 2015).

The results indicated that enablers for sports participation included having supportive environments in social groups that improved mental well-being, having regular health checks and support structures to avoid injury, understanding the specific attributes and benefits of HRSA, supportive socio-economic structures and the affordability of university and sport facilities. Improving awareness of the benefits of HRSA on bone health is required. Educational interventions appear to be a way to reduce the burden of osteoporosis in late adulthood, and studies that consider their feasibility and effectiveness are now warranted.

### **8.3 Habitual recreational sporting activity**

#### **8.3.1 Participation in habitual recreational sporting activity**

The major exposure of interest in this thesis is HRSA. Young people in our study engaged in a large variety of sports, with participation in many of these sports having often commenced during primary school and continued throughout high school: in particular, sports such as rugby, cricket, netball, running and swimming were common.

The New Zealand secondary age review report on school perspectives on sport and recreation reported that during the primary school years HRSA participation increases, but during the teenage years HRSA participation declines in all capacities including the level of involvement and the time spent in HRSA (Sport New Zealand, 2019). The rate of adult participation in HRSA declined over a 16-year period by nearly 8% in all adults, with the greatest decline of 13.9% in HRSA occurring in the 18 to 24 year old age group. The report also indicated that the rate and pattern of HRSA decline is dependent on ethnicity, with the greatest decline (over 11%) in the Pacific group (Sport New Zealand, 2016). Furthermore, patterns established in earlier life may carry through to later life. The World Health Organization (WHO), in a global action plan on PA 2018–2030, aimed towards reductions in the level of physical inactivity of

10% by 2025 and 15% by 2030. As of 2018, one in four adults and three in four adolescents globally do not meet the global PA levels required for optimum population health (World Health Organization, 2018). The global PA levels required for adults are at least 150 minutes of MVPA or 75 minutes of vigorous PA (VPA) per week or any comparable activity and for adolescents 60 minutes of VPA is recommended (World Health Organization, 2018).

Current global PA trends indicate that the inactivity reduction of 10% target will not be met by 2025 unless there are significant upward trends in PA levels (including HRSA) (Guthold et al., 2018). Given the global implications of Covid-19 pandemic for infection prevention and control strategies like social distancing or isolation, inactivity has increased, indirectly increasing the prevalence of non-communicable diseases that may impact bone health (Modesti et al., 2020; Zheng et al., 2020).

Reassuringly, the results of the quantitative study indicated that over 80% of male and female participants reported engaging in at least weekly HRSA. New Zealand has a high rate of sports participation. A systematic review and meta-analysis of global participation in sport and leisure-time physical activities suggested those from the Western Pacific region (Australia, China, Hong Kong, Japan, New Zealand and the Philippines) were more likely to participate in lifelong physical activities (Hulteen et al., 2017). In addition, a recent New Zealand sports report suggested that 72 % adults (aged 18 years or older) participate in weekly physically active play, exercise, active recreation or sport in the past seven days with those younger aged between 15 to 17 years having an over 90% participation rate (Brocklesby & Sport New Zealand, 2019). However, similar to other reports we found that this level of recalled activity declined during adolescence (Dumith et al., 2011).

A New Zealand report from the Hillary Commission from over twenty years ago indicated that approximately two-thirds of adolescents and young adults achieved the recommended 30 minutes of moderate to vigorous physical activity (MVPA) most days of the week, and also found that males were more active than females (Walker et al., 1999), similar to other studies (Brodersen et al., 2007; Maddison et al., 2010; Sport New Zealand, 2016). The results found in this thesis may be considered as an updated report of HRSA in a New Zealand population in this age group.

The term “sport”, which is a type of organised PA that is characterised by regular training with specific rules, did not resonate with some participants in the study as they did not consider themselves “sporty”

(despite participating in high levels of PA and practicing regularly) (Hill & Azzarito, 2012); therefore they may not have classified their activity as a sport. Sport may be even viewed negatively by some people, therefore public health messages using the term “sport” may not reach the target audience to improve bone health through high impact activities and habitual levels of participation.

The 2011 Young People’s Survey (a school-based survey) also indicated that boys participated in sports more than girls and, overall, engagement in sports drops off after the teenage years. Within the school environment, HRSA can create valuable opportunities and increased competencies in young people and this momentum should be encouraged to continue beyond the school years (Palmer, 2013). It is evident that directing osteoporosis awareness and PBM accrual in the wider population requires gendered and youth-based approaches to effectively reduce future osteoporotic disease burden (Holland & Moffat, 2019).

### **8.3.2 Long-term recreational sports participation and bone health**

This thesis pinpoints the types of HRSA that may be most beneficial for bone health. Analysis of the study data after adjusting for age, weight, sex, ethnicity and BMI indicated that adolescents and young adults who participated in high impact weight-bearing sports such as rugby, soccer and running had better bone health.

Improving young people’s understanding of the types of HRSA and how they can effectively improve bone health may lead to improved PBM in young people. PA is thought to stimulate bone formation and thus improve BMD by exposing the skeleton to mechanical strain. Importantly, there is little epidemiological evidence that regular walking improves BMD substantially compared to other activities (Martyn-St James & Carroll, 2008). Mixed loading activities combined with jogging with other low-impact loading activity such as walking, stair climbing and high impact activity and resistance training with longitudinal plane (left to right positioning of exercise) consistently improve hip BMD in older people, although far fewer data exist in young adults (Martyn-St James & Carroll, 2009). The optimum type and intensity of activity for improving BMD remains unknown and it is unclear whether a specific strain needs to be exceeded, whether other aspects of impacts may also be important, or whether different effects are identifiable at different sites of the body. The term ‘physical activity’ is often used interchangeably with “exercise”: the difference between PA and exercise is that exercise is a planned repetitive fitness regime whereas PA is not planned in the same repetitive routine (Lombardi et al., 2019).

The most effective and safe recommendations for habitual life-long PA to improve bone health vary throughout the ages (Lombardi et al., 2019). A recent Korean review reported exercise guidelines for young people to increase in PBM in adolescence as a strategy to prevent osteoporosis and osteoporotic fracture in old age (Min et al., 2019). This review recommended up five to six months of vigorous physical activity (VPA) that comprised of both high impact sport or exercise, with 50 jumps per minute, for a minimum of ten minutes daily, twice a week, with a resistance exercise routine at least three times a week (Min et al., 2019). High impact activities and high intensity progressive resistance training in combination are positively associated with bone health (Beck et al., 2017).

Similar to many other studies, the results from this thesis suggest that sustained weight-bearing HRSA participation is important to bone health in adolescence and young adulthood as assessed by cQUS. These results are consistent with previously published studies that have considered cQUS as the bone outcome measure and the benefits of participation in individual sports on bone health; such studies suggested that football or dancing conferred better benefits to bone health than swimming or cycling (Vlachopoulos et al., 2018; Yung et al., 2005) and that gymnasts enjoyed better bone health compared to the controls that did not participate in these activities (Nurmi-Lawton et al., 2004).

Unexpectedly, walking was negatively associated with bone health in the present thesis. It is possible that participants not engaged in regular sports chose to report “walking” as a form a sport rather than appear inactive, while others that engaged in organised sporting activity did not include time spent walking, which in effect serves almost as a baseline activity level. In our study, the intensity of individual activities were not recorded except through the ELS score (derived from a ground reaction force test), years of sport participation and an age-weighting factor (Weeks & Beck, 2008, 2010). While the study questionnaire included questions related to participants’ increased breathing or heart rate, these would not be sufficiently and objectively quantifiable for statistical analysis in this study. Additional objective metrics such as (average) pace, speed or heart rate would help quantify the intensity of the activity more accurately and is it possible that higher intensities of the same type of exercise produce greater improvements in bone health. As this study relied on retrospective recall through the questionnaire, we were not able to objectively to quantify the intensity of the activity due the lack of availability of the appropriate validated measurement tools, but this would represent an important undertaking in future studies.

Previous studies have suggested that long-term participation in sports is beneficial through using other measures of bone health such as DXA and pQCT. The PRO-BONE longitudinal study of boys aged 12-14 years found that bone accrual was greater in footballers than swimmers and cyclists (Vlachopoulos, Barker, Ubago-Guisado, et al., 2017). That study also reported the beneficial effects of long-term osteogenic sports activity (football) and compared non-osteogenic sports such as cycling and swimming over a 12-month period (Ubago-Guisado et al., 2018) using DXA-derived BMC, bone geometry using hip structural analysis (HSA) estimates and trabecular bone score (TBS). Even through a short eight-month period, it was apparent through DXA and pQCT assessment that swimmers who participated in weight-bearing sports concurrently with swimming were likely to have better bone health than those that participated in swimming alone. This suggests that complementing swimming with weight-bearing sports activity may be beneficial to bone health status (Gomez-Bruton et al., 2017; Miller et al., 2020).

A previous study of adolescents from the Avon Longitudinal Study of Parents and Children (ALSPAC) that considered types of activity in relation to bone microarchitecture found that VPA (equivalent to jogging) was positively related to cortical bone mass, but no independent relationship was seen for moderate PA after adjusting for VPA: this highlights the importance of high impact VPA in this age group (Sayers et al., 2011). It appears that light or moderate levels of PA are not sufficient to improve skeletal development but high impact PA may improve BMD in young people. The results of our study are consistent with this conclusion.

In the Raine study, organised sport participation was documented by parents of 984 offspring at ages 5, 8, 10, 14 and 17 years and DXA-derived bone density was assessed at age 20 years (McVeigh et al., 2019). This demonstrated higher bone density among adolescents and young adults who had consistently participated in organised sports compared to those who had dropped out of playing sports (McVeigh et al., 2019). The population-based GOOD study of 1,068 young men that assessed tibial cortical bone by pQCT found that, despite stopping sporting activity during growth, bone geometry was still favourably related to previous sports participation (Nilsson et al., 2009). A later, smaller sub-study of the GOOD study compared 24 year old male resistance exercisers to soccer players and non-athletic participants, indicating that sports involving varied rapid impact movements (such as soccer) reflected positively in the bone density, geometry and microstructure compared to those young males participating in recreational resistance exercise (Nilsson et al., 2013).

Assumptions regarding the level, intensity and duration of similar sports is difficult in to assess for comparative analysis as not all measures are equivalent. Differentiating levels and intensity of PA and sport is a complex process (Lorenz et al., 2013). For example, in studies that assessed BMD by cQUS recreational long distance running had a negative impact on bone measures (Escamilla-Martínez, 2016); although two other Nigerian studies of long distance runners that found a positive improvement in cQUS measures (Laabes et al., 2008a, 2008b). This may be reflecting the intensity of the sports training rather than the qualitative properties of the different sports that were participated at a professional sporting level although these studies were also limited by the smaller sample size of the studies.

A Belgian longitudinal 27-year follow-up study of 13 year old males found positive DXA-derived associations between bone health and osteogenic impact sports participation during follow-up (Van Langendonck et al., 2003). The Swedish Northern Osteoporosis and Obesity Study of badminton and ice hockey playing males found that reduced PA was associated with bone loss, although the osteogenic effects of intensive training were maintained for at least five years (Nordström et al., 2008). In addition, results from the DXA-based 12-year longitudinal study of 17 year old active sporting career males reported long-term beneficial effects of playing badminton in youth compared to ice hockey players or the control participants (Tervo et al., 2010). Similarly, in a study of a small group of older competitive badminton players with continued long-term practice of badminton playing had higher cQUS values than the control group of active participants (Bravo-Sánchez et al., 2020). These studies indicate the importance of continued and consistent sport participation on bone health. There is cumulative evidence that weight-bearing HRSA benefits persists even after stopping this activity (Gunter et al., 2008).

### **8.3.3 Other lifestyle and medical factors relevant to bone health**

This study found that tobacco smoking was highly associated with alcohol consumption in the population, but there was no association between smoking status or alcohol consumption with bone status. This may be due to the short exposure time to these agents and/or low numbers of participants who smoked. These results are at variance with previous work that suggests early age of alcohol and smoking intake may be predictors of lower BMD in young people (Lorentzon et al., 2007; Lucas et al., 2012). Focus group participants indicated that excessive alcohol consumption and associated smoking were not as acceptable as it was in older people. These views are similar to a recent New Zealand report indicating there are multiple reasons for some of the decline in adolescent risky behaviours such as:

binge-drinking; smoking; teenage pregnancy; and crime. In particular, these changes may stem from: improved social communication; students feeling a sense of a "belonging"; lack of student part-time work leading to reduced financial independence and parental monitoring through the internet (Ball et al., 2020). It has been found that even passive smoking exposure in children, as assessed by measuring the concentrations of cotinine (a metabolite of nicotine), may induce bone loss through increased bone resorption, affecting calcium absorption, sex hormones and vitamin D (Juonala et al., 2019). The exact pathways of how tobacco smoking may affect oxidation of the biological chemical pathways; affect oestrogen levels and bone regeneration and delay bone recovery, the age of onset of smoking habit, its frequency, duration and type of tobacco and methods used warrant further longitudinal investigation on young people's PBM acquisition (Eleftheriou et al., 2013).

Specific questions on vaping and the use of e-cigarettes (and other recreational drugs) were not examined in this study, although may be relevant in this young population, where it has become a popular alternative to smoking cigarettes, particularly amongst adolescents and young adults. Further research is required in this area to determine the long-term effects on bone health, particularly given that young non-smokers may convert to vaping from smoking (McNeill et al., 2018). Many of the focus group participants reported reduced or no smoking practice, often labelling smoking as "toxic" to many health aspects including to bone health. They found that the lack of acceptability of smoking, in particular of smoking within indoor places, acted as a deterrent to smoking practices, particular to those participants who originally came from overseas (Thomson et al., 2013).

While moderate alcohol consumption of less than two units of alcohol daily has often been shown not to be detrimental to bone health, alcohol intake above this threshold appears to be associated with an increased risk of fracture (Kanis, Johansson, et al., 2005). It may be that other components of alcohol or other confounders play a role and have a protective osteogenic effect on bone health if taken in moderation. Preliminary analysis of the quantitative study indicated that about one of third of young people reported at least monthly binge drinking, many whom reported to have consumed alcohol by the age of 15 years. These findings are indicative of a need to reinforce the detrimental consequences of premature and/or heavy alcohol intake (Patel et al., 2020). A study of 18 to 20 year old college females engaged in heavy alcohol drinking found frequent heavy alcohol consumption was detrimental to vertebral BMD (LaBrie et al., 2018). While a New Zealand study of alcohol dependent 22 to 55 year old women found that the cQUS measure (BUA, SOS, T-scores and Z-scores) were poorer than the age-

matched reference control females. In this population alcohol-dependent females typically reported other risk factors for poor bone health such as smoking, low dietary calcium intake and falling; a period of alcohol detoxification appeared to result in bone turnover recovery, with beneficial effects in bone formation markers (Fuggle et al., 2018).

As the studies encompassed in this thesis all included young people, there may be an increased likelihood of participants with conditions such as period or menstrual dysfunction, female athlete's triad (a combination of low BMD, menstrual dysfunction and low energy levels) and relative energy deficiency syndrome (RED-S, that affects bone health in both females and males) (Mountjoy et al., 2018). RED-S in particular may be associated with eating disorders and high risk physical activities that may lead to poor bone health and stress injury (Ducher et al., 2011; Mountjoy et al., 2018).

Menstrual function was discussed in both the focus groups and in the online questionnaire (which included questions 16 to 22 pertaining to periods, start of periods or not, issues with periods and oral contraceptive use), as bone is affected by imbalance in reproductive hormones and menstrual function in female athletes that may affect by performance levels and intensity of the training as well as the age of menarche (Maïmoun et al., 2013; Wewege & Ward, 2018). Some focus group participants reported greater knowledge of bone health gained from prior medical experiences, including fracture. Female participants were generally more aware of their personal health and often obtained contraception at an early age of around 15, although were less aware of potential detrimental effects of oral contraceptives on bone health. Female participants were generally more aware of their personal health and often obtained contraception at an early age of around 15, although were less aware of potential detrimental effects of oral contraceptives on bone health. Hormonal contraceptives potentially negatively impact PBM accrual depending on the extent of use and age at which it was taken (Jackowski et al., 2016). In particular, early use of OCP during teenage years may impact PBM development (Trémollières, 2013). As such a greater understanding and education of the use of OCP and the alternative options is warranted.

Menstrual dysfunction includes abnormal and/or delayed bleeding patterns and are often linked with family history of ill-health, physical and mental stress, smoking, medication, low weight, excessive exercise and/or high levels of stress that may impact their bone health (Mountjoy et al., 2018). For young females, reproductive health is important as oestrogen is vital for bone development and prevention of osteoporosis. Puberty is an important time for bone accrual, requiring adequate nutrition and PA (Perez-



Lopez et al., 2010). Recognition and early intervention are required to reduce the potential negative effects on bone which may be reversible with treatment. The focus group study indicated a lack of awareness or willingness to seek appropriate healthcare in a timely manner, which requires further investigation to prevent lasting harm on overall health and for the long-term effects on bone health. The analysis of menstrual dysfunction and/or RED-S (low relative energy availability) was out of the scope of this current thesis and will be addressed in future postgraduate work.

Sedentary behaviour is different from inactivity that does not meet PA guidelines. During sedentary activity, energy expenditure is  $\leq 1.5$  metabolic equivalents of intensity. Examples of sedentary activities include screen-based activities like television watching and cell phone usage, and non-screen-based activities like reading, homework and crafts (Higgins et al., 2019). They found inconclusive evidence of a relationship between sedentary behaviour on adolescents' and young adults' bone health, in part because it is difficult to estimate activity of this type accurately without a validated accelerometry assessment. Sedentary behaviour and screen-time was recorded in the questionnaire but are not reported in this thesis, as these variables will be reported in a future collaborative study with researchers at the University of Tromsø. Participants engaged in sports may spend less time in leisure time activities (Gayman et al., 2017). The implications of insufficient exercise or load stimulus on bone health has been demonstrated in studies in astronauts, who over a six-month period in space (with zero-gravity conditions) lost BMD as shown by DXA (Cavanagh et al., 2010). Another study of astronauts from the International Space Station found that after a period of trabecular bone loss during space-flight, the skeleton does not fully recover and may even continue to decline after spaceflight (Vico et al., 2017).

The Tromsø Fit Futures Norwegian study has previously found that screen-based sedentary activity was only negatively associated with BMD levels as assessed by DXA in males (Winther et al., 2015). Other studies have suggested that time spent in sedentary activities may not be detrimental to bone health per se: although they used differing bone measurement techniques which may detect nuances of bone adaptations. For example, Tan et al. (2018) suggested that although PA influences bone strength during adolescence, high levels of sedentary behaviour do not negatively influence adolescents' bone strength as assessed by pQCT. The heterogeneity of the study design, the different methods and the activity levels of all participants recruited in the studies make direct comparisons challenging. Another systematic literature review found no association between sedentary behaviour and bone health as assessed by DXA and indicated that further work is required to understand the effect of increasing sedentary behaviours in

adolescents and young adults (Koedijk et al., 2017). Thus, VPA of sufficient osteogenic levels, variety, type, intensity, frequency and duration may counteract the potentially negative effects of sedentary time on bone health in young people.

#### **8.3.4 Vitamin D and sunlight, diet and calcium intake**

Vitamin D is important to musculoskeletal, physiological and cardiovascular health, as well as for proper immune function, maintenance of calcium and phosphate homeostasis, optimal bone health and muscle function (Nowson et al., 2012). Inadequate dietary calcium can lead to bone resorption in order to maintain blood circulating calcium levels, ultimately reducing overall bone health (Nowson et al., 2012; Wilson-Barnes et al., 2020). In addition, ethnicity plays a role in sun exposure behaviours, further details of which are discussed below.

Vitamin D insufficiency is common in some ethnicities (Hammad & Benajiba, 2017; Hiremath et al., 2018). Enhanced vitamin D manufacture in the skin during time spent outdoors is associated with better bone health (Elgan & Fridlund, 2006). Hence, vitamin D status is dependent in part upon the training environment for sport, specifically during the summer time, as this is the optimal time of the year to synthesise vitamin D. An Israeli study found vitamin D deficiency was common in adolescent sport participants who practiced indoor sports (dancers, basketball players and Tae Kwon Do players), possibly due to low sun exposure, and may derive limited osteogenic benefits of their PA on their bone health (Constantini et al., 2010). The same study investigators suggested that the focus should not only be young people's HRSA but also their training environment (indoor or outdoor facilities) and the season, as the level of sun exposure is greatest in the summer months (the optimal time to synthesise vitamin D<sub>3</sub> in the skin) (Constantini et al., 2010). Similarly, a recent review also suggested that an excess of indoor training time may lead to bone vitamin D insufficiency and hence poorer bone health (Wilson-Barnes et al., 2020).

In New Zealand, vitamin D levels are determined by ethnicity and seasonality, along with geographical latitude (Rockell et al., 2006). A systematic literature review of young adult swimmers found that the impact of sport on BMD were moderated by sunlight exposure (geographical latitude): that is, the higher the latitude, the smaller the differences in BMD between swimmers and participants in high impact sports (Gomez-Bruton et al., 2018). Thus benefits of some HRSA on bone health may be moderated by the level of sun exposure.

Our focus group study revealed a lack of knowledge in those of Asian and South Indian descent of the benefits of sun exposure for vitamin D purposes, despite the high occurrence of vitamin D deficiencies in individuals of such descent with darker skin pigmentation. These findings are similar to an English study that found that South Asian women compared with Caucasian women had lower vitamin D levels and sun exposure (Darling et al., 2019). Those with a darker skin pigmentation require a greater dose of sunlight (ultraviolet B radiation) than those with fairer skin pigmentation to synthesise adequate levels vitamin D through their skin for optimal bone health acquisition, and as such may warrant increased vitamin D intake (Horton-French et al., 2019).

Changing dietary and PA patterns singularly or in combination are a global factors in the increasing trend in BMI in young people, which significantly impacts general and bone health (NCD Risk Factor Collaboration, 2017).

Dietary dairy intake, vitamin D and PA together potentially enhance bone health during childhood and adolescence (Bianchi et al., 2009). Calcium intake, through consumption of dairy products, is also a factor in PBM acquisition; young children in New Zealand who avoid drinking milk are prone to fracture (Goulding et al., 2004). The PEAK25 Finnish longitudinal study reported suboptimal bone growth in early life due to calcium insufficiency that may have long-term lasting negative effects on bone health (Laitinen et al., 2005). A Japanese study recommended daily milk intake of at least 400 mL/day to improve bone mass and found a positive dose-effect relationship between milk intake and bone strength in late adolescence (Uenishi & Nakamura, 2010). The positive benefits of regular milk intake was further demonstrated in a study of 2,674 Hungarian children, which reported that cQUS bone variables were related on gender, physical activity and nutrition in 16 to 18 year old adolescents (Szmodis et al., 2016).

A systematic literature review of the impact of vegan or vegetarian diets showed that such diets led to a lower BMD than in omnivores, in addition, vegans also had higher fracture rates (Iguacel et al., 2019). However, not all studies have suggested that vegetarianism is associated with poor bone health: in the longitudinal Saskatchewan Pediatric Bone Mineral Accrual Study (PBMAS) cohort, a vegetarian diet with dark green vegetables, eggs, legumes with low-fat milk was positively associated with good bone health (Movassagh et al., 2018). Given the variety in food choice patterns among young adults indicated by participants in this study, research is warranted to pinpoint nutritional determinants of osteoporosis in young people to maximise PBM and bone health to give insight into new approaches for preventing

osteoporosis (Viljakainen, 2016).

### **8.3.5 Use of cQUS to assess bone health**

Not only is the calcaneus a highly trabecular bone, it is an easily accessible weight-bearing site with a similar high metabolic rate to the lumbar spine and femoral neck (which are traditionally used for osteoporosis diagnosis). Like the vertebral spine, it is affected by changes in conditions and ageing more so than the more rigid cortical bone. Heel ultrasound is used to assess bone structure and strength and is used worldwide for osteoporotic fracture risk assessment, although it should not be used as a diagnostic tool (Moayyeri et al., 2012). The heel ultrasound test involves no risks or harm and is a comfortable, radiation-free test that only takes a few minutes to perform (Shewale et al., 2017).

It has been shown that the correct positioning of the heel bone, especially in adolescents and young adults (Jaworski et al., 1995), is easier with the heel ultrasound tool compared to other imaging tools such as DXA, magnetic resonance imaging (MRI) and peripheral quantitative computed tomography (pQCT) (Pezzuti et al., 2017). cQUS can discriminate poor bone health in women and those with and without a history of prior fracture (Frost et al., 2002). Similarly, it has been reported that broadband ultrasound attenuation (BUA) predicts fracture risk in both men and women (Khaw et al., 2004). Other studies have shown that quantitative ultrasound densitometry is useful when assessing skeletal health status changes due to exercise in all age groups and as a research tool (Babatunde & Forsyth, 2013). Meta-analysis of cQUS by Moayyeri et al. (2012) found that validated devices can predict the risk of different fracture outcomes. The PRO-BONE study supported the use of the cQUS device as an acceptable alternative method to DXA to assess bone health in active adolescent males where DXA was not available (Torres-Costoso et al., 2018). For all those reasons, we elected to use heel ultrasound as the method of assessing bone health in the quantitative phases of this study.

In addition to the studies included in the current systematic literature review in this study, there are a number of studies that have used cQUS to understand the effect of modifiable lifestyle factors, such as PA, on bone and muscle health in 18 to 21 year old students (Hervás et al., 2018). For example, a study of British army recruits using bone assessments through DXA, cQUS and MRI examined the influence of smoking, alcohol intake and PA, and found PA and moderate alcohol intake to be beneficial to bone health, with smoking detrimental to bone health (Eleftheriou et al., 2013). In another study using cQUS in females, moderate alcohol consumption was found to be beneficial to BMD (Feskanich et al., 1999),

while another study found that prolonged recreational long distance running in mature men had a negative impact on BMD as assessed by cQUS (Escamilla-Martínez, 2016). The Norwegian Tromsø longitudinal study indicated that being underweight was negatively associated with cQUS bone parameters in adolescence (Evensen et al., 2018).

A study of college gymnasts indicated that cQUS sensitivity and specificity were comparable with DXA measures and was able to differentiate between cQUS parameters in young, competitive gymnasts compared to healthy controls who underwent regular activity (Taaffe et al., 1999). Similarly, a study assessing the effects of sedentary behaviours supports the use of cQUS in a diverse, ethnic, young population to monitor skeletal development along with other biochemical bone metabolic markers (Herrmann et al., 2015). Finally the PEAK-25 Cohort of Women study that compared the DXA-derived BMD measures found that the SOS-cQUS (the cQUS variable most equivalent to bone density) was comparable to DXA-derived BMD measures and that the BUA was sensitive and detected the lower bone microarchitecture (bone strength) (Sandström et al., 2016).

Study participants were mostly enthusiastic about the heel bone ultrasound scan testing procedure, finding it a non-daunting, non-invasive and quick. Participants' positive experience of undergoing a bone scan encouraged the sharing of osteoporosis knowledge with their family and friends, as well promoting further recruitment of participants to the study.

### **8.3.6 Young people's knowledge of PBM and the lifestyle risks to poor bone health**

Young people who participated in this study were largely well-educated (Ministry of Education, 2020), from the university and enthusiastic learners who were generally keen to maintain their health and appearance. Their knowledge of general health was very good and they were well-versed in researching online for practical solutions. In contrast, their knowledge and understanding of bone health was limited as often they did not believe that they themselves were vulnerable to osteoporosis. Our findings are similar to the findings of a recent review of the knowledge, beliefs and practices regarding osteoporosis amongst young people (such as cultural differences, the negative farming practices, cost of dairy and inconvenience of osteogenic practices) that may limit calcium intake and HRSA (Chan et al., 2018). That review suggested that a lack of knowledge and misconceptions about osteoporosis led to behaviours that might result in suboptimal PBM acquisition, as young people did not feel susceptible to osteoporosis, assuming that it was a disease of old age. Additionally, and worryingly, the same study found that young

people were disinterested in osteoporosis and considered that other diseases were comparatively of more concern for them (Chan et al., 2018). There are only a few studies that have used a qualitative approach to assess the knowledge and perceptions of osteoporosis amongst adolescents and young adults, with no available New Zealand-based data and only one Australian study (Chan et al., 2018; Liberato et al., 2013). Osteoporosis is often viewed as fracture and age dependent (Holland A & Lorbergs, 2019). We did not find such disinterest in our own study. More recently, an Australian study to identify barriers and facilitators to osteogenic exercise for young adult women found convenience, accessibility and understanding of osteoporosis preventative behaviours an effective lifestyle strategy (Lambert et al., 2020).

Our findings are similar to a Canadian study that reported an osteoporosis prevention health education programme designed for young adults, which also found that young adults were not concerned about future disease risk of osteoporosis (Holland, 2017). That Canadian study also found that to effectively engage young adults to learn about osteoporosis, information given should relate to young people's interests (such as fitness and food) using traditional methods based on health, education, community and family programmes, as well as using social media (Holland, 2017). A New Zealand web-based study of women in their twenties to forties found that, although participants considered osteoporosis to be a serious disease, they felt at low risk of osteoporosis (von Hurst & Wham, 2007). A Swedish study of young women aged 19 to 26 years used grounded theory methods and found that lifestyles changes, such as PA and smoking in relation to bone health development, were influenced by their outlook on life and their individual life circumstances, although these women also had limited knowledge of bone health (Elgan et al., 2005). Taken together, these studies suggest that knowledge of factors affecting bone health, and perception of vulnerability to fracture in later life, could be improved to reduce the personal and public health burden of fracture. Overall, females were found to be more aware of factors affecting their health: this finding is consistent with that of other studies (von Hurst & Wham, 2007).

Our study also showed that: the terms "*osteoporosis*" and "*peak bone mass*" were confused with other similar medical terminology; doctors and other healthcare professionals were viewed as trustworthy sources of health information; the need for good nutrition and exercise were necessary for good health; and young people did not know specific methods of osteoporosis prevention. Our study participants considered osteoporosis to be important but did not know enough about bone health to adopt specific behaviours to improve PBM.

Typically, as described above, our study found that young people underestimated their own vulnerability to poor bone health. Their lack of understanding that they could improve their own PBM accrual on a day to day basis while they were still young was a seldom understood concept. For example, they did not know that bones did not just stop growing upon reaching the legal age of adulthood and their bones were still able to adapt to the lifestyle behaviours or that osteoporosis was inevitable in old age. Learning programmes from an early age are necessary to give young people a greater understanding of bone biology and the factors that influence bone growth. Family history taking, encouraging intergenerational discourse and motivating family members and *whanau* (extended family) to reduce risk factors for poor bone health must be encouraged. Finally, the participants in this study were aware of the limitations of internet sourced information, and believed that validated and unbiased evidence for PBM accrual promoted by health practitioners and educators would aid better long-term bone health outcomes. Both this lack of knowledge and misconceptions about osteoporosis lead to behaviours that might result in suboptimal PBM acquisition. For example, when reducing dairy intake or sourcing milk alternatives there is a lack of knowledge of alternative sources of adequate levels calcium that may lead to suboptimal behaviours to gain optimum PBM potential. Barriers to dairy intake include the high cost of dairy, inconvenience, negative or environmental factors, climate change concerns and farming practices (including hormones and pesticide use). Cultural differences also play a role, such as the misconception that osteoporosis is simply an inevitable part of getting old, along with a general lack of understanding at a young age around preventative or proactive behaviours that can reduce the impact of poor bone health later in life.

A New Zealand study of young women aged 20 to 29 years reported a limited knowledge of the role of vitamin D in bone health; although participants understood calcium and PA was required for osteoporosis prevention, they had a limited understanding of the different sources of vitamin D and calcium; and believed that milk was calcium-rich but limited milk consumption due to its high cholesterol content (von Hurst & Wham, 2007).

Our focus group study also indicated that while adolescents and young adults were aware that heredity factors impact their own future health status, they had a limited understanding of their own personal family health history. This lack of awareness is important considering that parental (or grandparent) history of fracture is associated with increased risk of fragility fracture (Kanis, Johansson, et al., 2004).

It is important that young people have a knowledge of their own family health history given this criteria is assessed in the Fracture Risk Assessment Tool (FRAX) tool to calculate the 10-year risk of osteoporotic fracture (Kanis et al., 2010). An understanding of one's wider family history of disease can help to pre-empt the onset of osteoporosis through behavioural modifications, early diagnosis and the opportunity to exchange and discuss health information.

A previous systematic literature review that focused on young people's knowledge of osteoporosis and PBM identified that there were a limited number of mostly quantitative studies that used self-designed or validated questionnaires to assess bone health in young people (Chan et al., 2018). Where available the qualitative studies focused on young people's knowledge of osteoporosis, PBM, and on the barriers to attaining good bone health and/or HRSA participation (Abdelghaffar et al., 2019; Aljefree et al., 2017; Allender et al., 2006; Arahanga-Doyle et al., 2019; Bonevski et al., 2013; Cooky et al., 2016; Elsborg et al., 2019; O'Reilly et al., 2018; Pawlowski et al., 2018; Pettit, 2008). These studies considered interlinked factors that included time and money, work, chores and study loads, access to facilities, safety, competition, social interactions and expectations (in relation to friends, partners, family, peers and the community), gendered roles, fun, abilities, competition, technology, organisation structure (such as the lack of structured PA at upper school levels), environmental factors including the weather and body-centred issues (including a lack of confidence, self-awareness, weight, fitness, aesthetic appearance, menstrual dysfunction, fatigue and lack of sleep). Similarly, weather and safety factors play a role in barriers and enablers to HRSA at many stages of life (Hesketh et al., 2017).

During young adulthood, HRSA participation declines and inactivity increases dramatically, forming a critical turning point in founding life-long HRSA participation. It was found that during this time, the number of young people who have a dislike for HRSA increases for any number of reasons. The reasons for the dislike to HRSA and barriers to HRSA are included in Chapter 7 of this thesis. The qualitative study found the presence of three main types of barriers to sports participation that may affect bone health: structural, social and personal barriers. Recognising the barriers to HRSA that enable beneficial bone health lifestyles in young people and improving young people's knowledge and understanding of osteoporosis may enable policy makers and young people to increase PBM to reduce the effects of fragility fracture later in life.



The focus group study participants indicated that screen time is an important activity for a multitude of reasons, including increasing knowledge, organising their schedules and communicating their engagement in recreational sporting activities. The latter can take place through activity tracking mobile applications that record progress and milestones related to health data. Therefore, understanding the types of screen time behaviours should be considered when promoting the benefits of HRSA to optimise PBM accrual in young people.

Our study also indicated that fatigue and requiring more sleep were common traits: studies have indicated that sleep quality and overall energy balance may be important considerations in acquiring optimal PBM (Elgan & Fridlund, 2006). As the underlying causes of higher than usual sedentary behaviours such as fatigue and irregular sleep patterns require further investigation, young people should be encouraged to seek appropriate healthcare to ensure optimal health status, which ultimately may affect bone health.

Along with relevant and engaging educational interventions to understand PBM accrual, participants suggested tertiary education providers can provide opportunities to incorporate behavioural modifications in the study environments and workplaces to decrease sedentary behaviours and increase HRSA participation, improving both overall health and PBM potential.

## **8.4 Current knowledge, strengths and limitations**

### **8.4.1 Strengths**

The studies described in this thesis have a number of strengths; these are discussed in turn below.

#### **8.4.1.1 Sample size**

Firstly, for the quantitative study, the sample size was larger than many previous studies of cQUS and HRSA, with information on relevant confounders collected by an online questionnaire. Although the generalisability of this study may be considered limited to the student population centred around one university, the participants came from different backgrounds and a range of locations within New Zealand and internationally, ensuring a wide ethnic mix; reflecting much of the population of the Wellington region (Statistics New Zealand, 2013, 2018). However, some ethnic groups were not sufficiently represented to allow relationships between individual ethnicities and bone health to be reported. The sample size calculation indicated the study had sufficient power to discern differences between gender. This cross-sectional study did not restrict study participant recruitment except for age.

The overall sample numbers for the quantitative study included 920 participants aged 16 to 35 years for which data were available.

In the original preliminary analysis, participants aged 16 to 35 years (n=920) were included in the descriptive statistics. The multiple regression models removed participants from the analysis with missing values. That is, an observation was excluded if the value for one predictor was missing. Therefore, it was a pragmatic decision to only include participants with complete data (for the predictors in the final analysis model). The descriptive statistics were then updated for the individuals included in the final analysis (for consistency) and reported in the submitted manuscript (n=452) in Chapter 5.

For the qualitative study, participants were based on a convenience sample from the larger cohort of the quantitative study.

#### **8.4.1.2 Study recruitment**

The strengths of this study include the participants' wide ethnic diversity and age range. Participant recruitment was inclusive in that any person was able to be recruited into the study provided they met the age inclusion criteria of 16 to 35 years inclusively. This gave all people an opportunity to be involved in the bone health study with access to bone health information, including those with a health disability or impairment. Participant recruitment through the university, two girls' secondary schools and sport complexes was dependent on the investigators obtaining regulatory approval.

In this study, we began by recruiting young people aged 16 to 35 years old largely from a university setting, which may have impacted the generalisability of the results. In New Zealand, tertiary education is accessed by a large sector of society (Ministry of Education, 2020). However, in an attempt to enable the results to be more generalisable to young people as a whole, we also recruited non-university young people through clubs, fitness centres, secondary schools and social networks. Non-students from clubs and fitness centres typically reflect those individuals who are still active at a recreational level.

There were no health exclusion criteria in this study. Most participants recruited in this study were found to be in a healthy weight range for their age, gender and ethnicity. Participants provided health information indicating current medication and supplement intake. Co-morbidities were reported in the survey, albeit no participants reported a concurrent medical condition that might materially affect bone

health. Medical conditions reported in the questionnaire by the participants were reviewed by a specialist medical expert in the field of bone health.

There were no health exclusion criteria in participant recruitment in the study. However, a pregnant female and an immobile participant with existing paralysis were excluded from the analysis, as these are known factors affecting calcaneal bone health. In the systematic literature review, studies of sports participation at national or international levels were excluded.

Although many young women reported use of the oral contraceptive pill (OCP), no other individuals reported use of other oral medications that might impact bone health. It is possible that some individuals were using steroids or other drugs but did not declare their use: as such, we were unable to assess this accurately in this study. Also, participants with a history of asthma might report lower PA levels; however, no clear pattern emerged regarding this, as it is likely instances of asthma were well controlled with inhaled therapies.

The quantitative study was conducted primarily at Victoria University of Wellington in the Wellington region in New Zealand, *Aotearoa* (a country with a population of approximately five million). Wellington, New Zealand's capital city, comprises a relatively young, culturally diverse population of less than half a million people. A quarter of this population was born overseas. Reassuringly, the demographic information provided by study participants indicated that the ethnic distribution of this study mostly reflected the ethnic distribution of the general population of the Wellington region, consistent with the latest available statistics that records Wellington's population (European 77%, Māori 13%, Pacific peoples 8%, Asian 10.5%, Middle Eastern, Latin American or African (MELAA) 1.5% and other ethnicities 1.8% (Statistics New Zealand, 2013)). For the purposes of this thesis, detailed sub-group analysis was not possible due to the small sample size of the sub-groups. As a result, classification of participants' ethnicity was either divided between three categories ("European," "Māori and Pacific " and "Others") for the preliminary analyses or two groups ("European" and "Others" who were neither European, Māori nor Pacific peoples) for the final analyses. This classification mostly reflects New Zealand's ethnicity health demographics (Statistics New Zealand, 2013). Typically in New Zealand, South Asian ethnic groups and Māori and Pacific peoples children have relatively higher fracture rates than other ethnic groups (Delshad et al., 2020). These findings are tempered with the potential effects of lifestyle associations such as sports participation, socio-economic differences, locality and fracture

history (Lynch et al., 2019; Moon et al., 2016); and the ethnicity health disparities in New Zealand (Durie, 2000). Sport participation for Māori and Pacific peoples is received positively as strong part of New Zealand's cultural and national identities, with high levels of sport participation and proficiency at all age levels that have a broad spectrum beneficial community effect socially and professionally (Sport New Zealand, 2017). Cultural identity was seen as a driver of HRSA particularly for males when playing rugby; incorporating culturally relevant methods to improve bone health and PBM accrual is important lifestyle requirement (Benbenek & Garwick, 2012).

The qualitative and quantitative perspectives of the research permitted a better understanding of the research objectives (Creswell, 2014; Creswell et al., 2004)

#### **8.4.1.3 Sex of the study populations**

We achieved sufficient participation rates in males and females, for both quantitative and qualitative aspects of this thesis. As some sex differences were observed in relationships of lifestyle factors with cQUS in the quantitative study, further work is required to determine whether these are real differences and what the biological explanation may be. Previous studies have suggested that sexual dimorphism may operate in the relationships seen (Holland A & Lorbergs, 2019; Zymbal et al., 2017). While the focus groups highlighted that osteoporosis was generally perceived to be a female condition, participation in the focus groups was incentivised through a *koha* gift of a grocery voucher which allowed good recruitment across both males and females.

Osteoporosis affects males as well as females. However, as it is often associated with ageing in older females, males may be less aware of the condition and are less likely to be diagnosed or undergo screening for osteoporosis (Alswat, 2017). Studies have indicated that young males achieve PBM later than females, particularly in trabecular bones such as the spinal area, independent of nutrition or levels of PA (Avdagic et al., 2012). Bone size is greater in males than females at the end of puberty (Bonjour et al., 2009). The HRSA behaviours of males and females are dependent on many factors including age, health (disabilities and chronic diseases), socio-economic position and marginalisation of certain groups within the population. For example, a New Zealand study found that within elite school settings, young women have many more opportunities for sports participation (Burrows & McCormack, 2011). Young people residing in high deprivation areas experience less HRSA opportunities and consequent lower HRSA participation (Brocklesby & Sport New Zealand, 2019; Palmer, 2013). While gender was not

viewed as a barrier to HRSA in the study focus groups, it is important to note that gender stereotypes persist in sports, with males typically spending more time participating in HRSA than females in New Zealand (Brocklesby & Sport New Zealand, 2019). Strategies to achieving gender equality in all areas of society in New Zealand, including a collective bargaining agreement and pay equity, can promote improved HRSA engagement and PBM acquisition in young females (Sport New Zealand, 2018b).

#### **8.4.1.4 Use of mixed methods**

Mixed methods research is a combination of quantitative and qualitative methods that helps to provide a better understanding of the research topic, to provide a more holistic and trustworthy picture of this study on the association of HRSA on bone health (Creswell, 2014; Creswell et al., 2004; Schoonenboom & Johnson, 2017).

Mixed methods research is defined as follows (Johnson et al., 2007, p. 123):

*“Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e. g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration.”*

It was evident from the results of the systematic literature review that there was a dearth of quality studies that used heel ultrasound as the bone health measure to assess non-elite sporting activities in young people. The current systematic literature review in this thesis specifically addressed studies that assessed the impact of specific non-elite sports using cQUS as the bone measure (this differs from previous systematic literature reviews that used DXA, pQCT, HSA and so forth) and focused on PA or impact or non-impact sports or elite sports at a professional level (Hind & Burrows, 2007; Nikander, Sievänen, et al., 2010; Tan et al., 2014; Zulfarina et al., 2016). Therefore, it was logical to focus on heel ultrasound as the outcome of the quantitative study as the systematic literature confirmed that there was an evidence gap in its utilisation. Further, due to the practical nature of study methodology used, the quantitative study provided large amounts of cQUS data and information pertaining to young people’s lifestyle through the questionnaire. The qualitative study provided informative literature, including field notes, and insight in young people’s lack of understanding of osteoporosis and PBM, as well as indicating the

decline in sporting activities during the later teens and beyond. It also provided valuable contributions and contextual information about young people's lifestyles and provided the participants for the focus group discussions. During the heel ultrasound testing procedure, some participants also spoke of similar concepts and ideas of their bone health knowledge and their lifestyle habits. The evidence provided by the quantitative study indicated there was a need to understand what young people understand about PBM, the risk of osteoporotic fracture and how lifestyle factors impact PBM.

The mixed methods approach captured participants' perceptions of their sporting behaviours and other lifestyle factors influencing their bone health, through both quantitative questionnaires and qualitative analysis: a key strength of the study. The mixed methods approach was appropriate to the subject area and highlighted the strengths of both quantitative and qualitative methodologies. The integration of the studies provided robustness and strengthened the overall conclusions of this thesis.

#### **8.4.1.5 Triangulation**

Triangulation is used in qualitative research strategies to test the validity of the information provided by participants, through the use of mixed methods to obtain data from a variety of sources (Heale & Forbes, 2013). Together, our results provide insight on how specific HRSA affects bone health in young people and how young people understand lifestyle factors that influence their PBM acquisition.

Within the qualitative data obtained from the nine focus group interviews held, field notes and responses to the open-end probe questions listed in the Appendix, and the objective independent observations from the different investigators, were triangulated and synthesised to provide confirmation of the findings and different perspectives of the views of the participants in the qualitative study (Carter et al., 2014).

By using the mixed methods approach to the thesis, it was possible to obtain informative concepts from different angles (Turner et al., 2017). The triangulation approach supports and tests the validity of the study by using different methods and sources to inform the data collected. For example, there was coherence between answers to questions 56 and 63 in the online questionnaire (*Why do you participate in sports or exercise*; and *What factors affect your ability to participate*) and the focus group discussion (as recorded in the field notes and the reflexive diary). This helped to authenticate the data and shows that the concepts that emerge are consistent, demonstrating the trustworthiness of the studies undertaken in this thesis (Patton, 1999).

#### 8.4.1.6 Assessment tools

The tools used in this thesis are: systematic literature review, study protocol and quality assurance of the heel measures undertaken. The questionnaire, trustworthiness and robustness of the study are discussed below.

Registration of the systematic literature review protocol in Prospero helped promote transparency and rigour in selection of the studies reviewed. The unique registration number of the study tracks the impact and any citation of the review. The permanent public record of the planned method and the protocol amendments used to improve the systematic literature review methodology helped avoid any potential duplication (Centre for Reviews and Dissemination, 2009). The systematic literature review helped to identify, evaluate and summarise the findings of all relevant studies in young people engaged in specific HRSA. It helped to understand the impact on HRSA on the cQUS measures, the lack of knowledge on this topic and the heterogeneity of the type of literature available. Additionally, the approach taken helped the candidate understand the background literature to the thesis and informed the direction of future work undertaken for the subsequent quantitative study.

The quantitative study was undertaken in a way to ensure validity of the bone health measures taken. The same ultrasound machine was used throughout the study by the same trained operator with guidance from the manufacturers to ensure correct servicing of the machine. A daily quality assurance calibration check was performed on the machine before use using the manufacturer's standardised phantom. The short-term *in vivo* precision of cQUS measures from triplicate scans in 15 participants and the coefficient of variation for bone mass measurements SI, SOS and BUA were acceptable and within the manufacturer's pre-set specifications (GE Medical Systems Lunar, 2010).

Information on potential confounding factors was collected by a questionnaire. Self-report and adjustments for important confounders such as age, BMI, height, puberty timing, PA, alcohol consumption and smoking were included in all preliminary analyses. To assess the lifestyle factors of the study participants, several modified validated sporting activity questionnaires were incorporated into the on-line questionnaire which were adapted for the New Zealand population (Clark et al., 2012; Deere et al., 2016; Kowalski et al., 2004; Weeks & Beck, 2008).

Young people's knowledge of PBM and lifestyles was assessed through focus group work. The qualitative nature of the focus groups are able to capture young people's perceptions. Trustworthiness adds robustness to the study findings. Trustworthiness in a qualitative study may be judged by its credibility, transferability, dependability and confirmability (Loh, 2013). Data was sourced from a range of participants from the university campus who came from different backgrounds (a range of locations within New Zealand and internationally with a wide age range of 17 to 33 years). Participants from the focus group also participated in the quantitative study. During the focus group discussions, participants were encouraged to talk freely; the interviewer's interactions were minimised after the initial introductions to the group. Encouraging participants' to lead the discussions in a relaxed environment permitted objective experiences of participants to be revealed. This approach helped validate the findings from participants, ensuring the participants thoughts and ideas were captured in the data, giving credibility to the data obtained. Following the discussion groups, ideas and themes were summarised. The reflexive diary, which formed the basis of the preliminary analysis after each focus group meeting, included discussions held between the investigators, permitting continuous comparison and consensus on the emerging themes as the data was consistently interpreted independently by the investigators.

The study protocol and rich description recorded in the reflexive diary of the iterative research process permits transferability of the methods used to other contexts such as the planned future qualitative research with a younger school-aged population. For dependability of the research process, an appraisal of the research protocol was conducted by an external party and other qualified researchers in the field. The emergent themes were auditable in NVivo, the software program used for managing the data, and continuously compared to develop the emerging themes. The debriefing sessions held with the study facilitators highlighted any ideas to be further addressed, including any keywords, themes or patterns and relationships identified from the focus groups and were recorded in the reflexive diary to objectively confirm that the findings and interpretations were true to the participants' views. During the NVivo manual coding process, emergent themes were discussed with other researchers to reduce researcher coding bias, adding robustness to the resulting themes. A greater understanding of different software applications available for qualitative research, such as NVivo and Leximancer (Sotiriadou et al., 2014), give the potential to add further rigour in the reporting of the findings; these will be considered in future qualitative research undertakings. In addition, future qualitative studies may be further enhanced in their integrity, transparency, and trustworthiness by following guidelines such as APA journal article reporting



standards for qualitative primary, qualitative meta-analytic and mixed methods research (Bantry-White et al., 2019; Levitt et al., 2018).

### **8.4.2 Limitations**

There were a number of limitations to the studies performed in this thesis.

#### **8.4.2.1 Generalisability**

Achieving as representative a sample as possible with regard to ethnicity is important when considering the relationships between HRSA and bone health. As noted in section 8.4.1.2, the ethnic diversity of the study population was mostly reflected in the local population demographics of Wellington (Statistics New Zealand, 2013), there was an insufficient sample size to permit an adequate, in-depth sub-analysis based on ethnicity. The detailed analysis based on an important covariate ethnicity was limited to European and others which included a broad spectrum of ethnicities; detailed group analysis based on ethnicity may have incurred type 2 errors due to inadequate power to detect significant differences. The Hillary Commission found that Māori and those of European descent were more likely to meet the recommended MVPA compared to other ethnicities and that levels of PA declined in the 16 to 17 year old age group (Brocklesby & Sport New Zealand, 2019; Walker et al., 1999). Future studies with purposeful sampling of participants to permit ethnic diversity with young people from a range of social settings in specific age groups would be useful.

Limitations in the qualitative study include lack of generalisability to other populations due to the potential recruitment bias from participants with prior knowledge from the main quantitative study. In this way participants in the qualitative study may have been potentially be less representative of the general population due to possessing a better understanding of health knowledge than those who did not participate.

Despite being relevant in this population, the study did not include those with mobility disabilities and those identifying as gender diverse: health research is typically inadequate in these areas (Clark et al., 2014; Graham et al., 2011; Shannon et al., 2019). Despite incentivising recruitment through a *koha* (gift of a grocery voucher) which permitted good levels of recruitment, students who chose to participate for the qualitative study were mostly females of European descent: this may reflect the gender bias found

for osteoporosis and health topics. Incentivisation through a small *koha* may be considered a form of coercion but was permitted by the ethical committee as is common in these studies.

As there were no exclusion criteria in place except for the age, participants who competed at a national or international level in sport may inadvertently have been included, while those with higher reported levels of activity or inactivity were also included. For example, it may be debatable whether a participant who performed 27-hours a week of exercise, who was included in an article within our systematic literature review, can still be considered to be participating at a recreational sporting level. In particular, for activities that require endurance in terms of time, volume, duration and intensity or frequencies, the number of required variables that need to be included in the questionnaire to capture this information would be considerable. For example, in New Zealand recreational cricket participation is common and involving many hours over the weekend and includes practice sessions during the week, with varying levels of intensity and activity. Multiple factors need to be considered when categorising elite and non-elite-athletes (Lorenz et al., 2013). Conventionally, athletes in higher divisions or those competing internationally may be considered elite but the level of sport, type, intensity, frequency, duration, strength, power, endurance and agility all have a relationship and impact on bone health.

As we relied on recall of historic sports participation, future longitudinal studies with validated measures of activity are required. Prior experience with the quantitative study may lead to recall of factors relating to osteoporosis, but it was clear that the term PBM was not a familiar term to the qualitative study participants. Some agreed that they had never heard of PBM or osteoporosis before being introduced to the main study. Some participants changed some thought processes and behaviours (incorporating more osteogenic lifestyles such as reduced alcohol consumption, increased recreational sports, changes in diet and questioning their medication and use of oral contraceptives) in relation to their own and family's bone health since undergoing the bone scan.

As lifestyle information was obtained in the quantitative study by self-completed questionnaires rather than physical examination, and we were not able to confirm the responses given, this raises the possibility of recall bias. Use of an objective, validated accelerometer as supportive evidence would have been beneficial to the study. Participants' responses may have had an element of social desirability; putting themselves as they would like to be seen or how others would like them to be seen. Studies indicated that young people typically overestimated time spent engaged in PA (Boon et al., 2010): this is confirmed

within the French BOUGE fitness study that found that over 82.9% of adolescents overestimated self-rated PA level (Vanhelst et al., 2017).

Since this study is a subset of a larger observational study, it is possible that selection bias operated in favour of healthier lifestyles compared to less healthy individuals, although many participants joined the study as they were curious about their own bone health data and the information provided. We were unable to provide in-depth separate analyses for each sport group as there may be overlap in sport participation and training frequency. This was a possible explanation for the unexpected observation that walking was negatively associated with bone health. We hypothesised that this finding reflected the fact that more active participants may have omitted reference to walking. It is possible that participants not engaged in regular sports chose to report “walking” as a form of a sport rather than to appear inactive, while others that engaged in organised sporting activity did not include time spent walking as a sport activity, which in effect serves almost as a baseline activity level.

#### **8.4.2.2 Accuracy in assessment tools**

This study was limited by not being able to assess the specific intensity of different types of physical work or recreational activities (such as walking, dancing, yoga or the various types of resistance exercise) and work-based activities, although options to include these activities were available in the questionnaire. Participants were invited to include other information and PA relevant to their bone health, with opportunities to discuss work-based activities in the focus groups and enter relevant information in the text box entry in the questionnaire also specifically housework and gardening was included. This indicates the importance of the intensity of the activity that affects bone health as our participants classify as sport or PA or work-based activities such as paid work, gardening or/housework or chores uniquely.

There is a need to clarify what exactly comprises “sport” and “exercise”, as some activities may be categorised in either group depending on their application. The terms “recreational sporting activity”, “exercise” and “PA” are often used interchangeably at times by participants which leads to confusion. Some participants may consider sport as some form of competition, however, some reported activities would generally not be considered competitive such as yoga or Pilates and recreational walking. Furthermore, some activities could be either competitive or non-competitive such as running, walking, dance and resistance exercise. Factors such as time spent inactive or in education, time and type of paid work activity and socio-economic status of the participants were not assessed accurately, although these

factors may affect the level and time spent in habitual PA (Ahrens et al., 2020). Defining and measuring any form of PA or sedentary behaviour is not simple (Higgins et al., 2019) and our study was completed without access to a validated accelerometer. Defining PA and measuring levels, frequency, intensity and duration of HRSA, competitive, non-competitive, physical leisure activity, inactivity, screen time and work-based activity are important variables which ideally are measured objectively. For example, an accelerometer that records continuous accelerometer data (such as a Fitbit) to capture intensity or magnitude of activity, as well as questionnaires that assessed all levels of activity and inactivity, were not feasible in a large population study, primarily due to restricted finances (Tully et al., 2014). Objective assessment of the comparator participants is important, such as a meta-analysis that defined control participants as sham exercisers who engaged in “habitual recreational activity known not to affect bone” (Nikander, Sievänen, et al., 2010).

Although the importance of sunlight exposure, vitamin D and vitamin K intake for bone strength has been recognised, it was not feasible to explore their effects within the scope of the present study. Specific nutrient intake was not included in the study, such as protein, fats, other key vitamins and trace elements such as iron, magnesium, phosphorus, potassium, that are required for healthy nutrition. Due to the limited resources, it was a pragmatic decision to explore only the calcium intake in the quantitative study in order to adequately investigate the other nutritional components affecting bone health.

In the present study, calcium intake was assessed through a recall of food weekly intake assessment. We found the daily calcium intake on average ( $623.94 \pm \text{SD } 611.53 \text{ mg}$ ) was lower than the daily recommended intake and there was no association with HRSA in our analysis. A similar albeit smaller New Zealand study of 54 healthy young females aged 18 to 26 years found no significant relationship between the dietary intake of calcium of a median of 784 mg daily with DXA and cQUS measures (Schraders et al., 2019).

We reported the age of puberty through recall for the onset of menarche and appearance of facial hair in males which is subjective and limited by recall bias. Females follow a dissimilar maturation process to males, so using the age of menarche in females and the initial development of facial hair in males as a proxy for the age of onset of puberty and pubertal development status was not ideal (Bonjour et al., 2009). Other studies have assessed pubertal development more accurately using peak height velocity and found the timing critical to any effect of osteogenic sports, with two years prior to and one year after peak

height velocity being optimal (Ubago-Guisado et al., 2018). Facial hair development has been reported as a marker of gonadal hormones (Emmanuel & Bokor, 2020; Petersen et al., 1988). We note that while self-reported secondary sexual characteristics are a more common way to assess contemporaneous progression through puberty (Beccuti & Ghizzoni, 2000; Mendle et al., 2019), correlation with physical examination can be modest (Baird et al., 2017). We sought to identify outliers in regard to pubertal progression only, as this could have impacted bone development.

In this thesis, past HRSA using age-weightings were incorporated into the algorithm in the bone-specific PA questionnaire to recognise the greater osteogenic effects of exercise during growth as opposed to exercise after skeletal maturity, therefore the weighting did not specifically differentiate between those aged 16 to 17 years old compared to those in their thirties (Weeks & Beck, 2008, 2010).

#### **8.4.2.3 Missing data**

Within the systematic literature review the limitations of the bone health studies have been reported previously, in addition to the heterogeneity of the studies undertaken in the review it was found that exercise intensity was not clearly reported in most of the cited studies (Mentzel et al., 2005; Nurmi-Lawton et al., 2004; Vlachopoulos et al., 2018; Yung et al., 2005). Only two of the studies in the systematic literature review suggested that it was possible that the intensity of different PA patterns partly explained their findings and that the intensity of motion activities in soccer ranged from walking to running (Gomez-Bruton et al., 2015; Madic et al., 2010).

The main limitation of the quantitative study was the number of participants with missing data, as participants had the option to choose not to complete the study at any stage. Due to the nature of the quantitative study that included young adolescents the level of involvement in the study remained at the discretion of the participants. In particular, the study questionnaire was long and participants may not have completed the questionnaire for any number of reasons such as having lost interest or being distracted by other pursuits, or simply not wishing to declare potential relevant information such as using performance enhancing anabolic steroids or other drugs, or health issues (known or unknown): as such, we were unable to assess this accurately in this study.

Participants' data were excluded from multiple regression analysis models if values were missing. That is, for any observation where the value for one predictor was missing, the regression model would

exclude all information from that particular participant. Therefore, only participants with complete data sets for the relevant predictors were included in our final analysis. Data manipulations of the full data sets were considered for statistical analysis, whereby imputations for missing values in the data would be generated. However, this was not deemed necessary or appropriate given the reasonable sample size available, permitting sufficient power for multiple regression analyses.

#### **8.4.2.4 Unmeasured variables**

While adjustment was made for several important confounders, this does not exclude the effect of unmeasured variables, some of which are discussed below.

In the quantitative study, while 104 different sports were considered, initial analyses considered the top twenty sports reported and only significant correlations of the top ten most commonly participated sports were considered in the multiple regression analyses. Therefore, some sports were excluded in the final analysis due to lack of popularity as opposed to their effect on cQUS measures. In addition, some HRSA were considered in the analyses. While resistance exercise was recognised as a popular activity and considered in the regression analyses, we were not able to discern the effect of resistance exercise in this sample of individuals. For example, 28.6% of young people in the study participated in resistance exercise for an average period of 4.84 years, for a duration of 1 to 14 years. This may be due to the relatively low ELS score of 0.51 for resistance activity in the selected algorithm (based GRF and osteogenic index), compared to a weight-bearing activity focused on the impact on trabecular and trabecular bone such as gymnastics which is scored as 100 by the same algorithm (Weeks & Beck, 2008). Resistance exercise has been shown to stimulate osteogenic effects (bone accretion) including bone and muscle mass maintenance, particularly when cortical bone tissues are exposed to mechanical loading in excess of regular daily living activities (Hong & Kim, 2018). That review suggested that the bone measure QCT differentiates between cortical and trabecular bone tissue that is different to DXA, therefore the bone measure and bone site used is important when assessing the effects of any activity (Hong & Kim, 2018). We were not able to measure exact levels of HRSA duration, levels, intensity and frequency of participation of all specific individual sports reported in the questionnaire. Important potential confounders, including other types of activity, training load intensity and biological maturation and health status, are not easy to assess in cross-sectional studies with large numbers of participants. As such, further work is required to elucidate the effects of specific individual HRSA.

In this study, while we recognise that there are variations in gender identities and sexual orientations, we were not able to adjust for all gender types. Therefore, in this quantitative study, gender was categorised biologically from a heteronormative perspective and did not differentiate those individuals identifying as gender diverse (transgender and gender non-conforming individuals). As such, the ISCD statement recommends that DXA is used for BMD testing with additional history and parameters to be recorded for those with such diversity (International Society for Clinical Densitometry, 2019).

## **8.5 Conclusion**

The narrative systematic literature review performed indicated that much of the literature currently available focused on older people or elite sports and used ionising radiation methods of bone health assessment. Only six studies met the inclusion criteria for the systematic literature review, and their heterogeneous methodologies, with various cQUS devices used along with small sample sizes, made it difficult to dissect gender differences. All six studies reported osteogenic effects at the heel site of weight-bearing habitual levels of high impact sports, such as soccer (particularly in males) compared to non-weight-bearing sports such as swimming and cycling.

The systematic literature review was followed by a quantitative study, which indicated that past HRSA, current PA and other lifestyle factors were associated with measures of bone health. The results appeared to suggest that adolescents and young adults who participated in weight-bearing sports (such as rugby, soccer and running) enjoyed better bone health. These cross-sectional findings should be ideally followed up further with longitudinal investigations using cQUS in young people from the general population. The effects of life-long HRSA training on bone health needs additional investigation over a period of time.

Due to the observational nature of the study, we cannot infer a cause-and-effect relationship between HRSA and the levels of bone parameters. However, the review of prior literature and observations suggest an association between higher observed calcaneal BMD and some types of long-term HRSA such as rugby, soccer and running. Future studies should aim for a standardised, validated reporting of specific HRSA duration, frequency, and intensity levels on bone outcome measures to understand specific effects of particular HRSA.

There has been little research assessing the knowledge of young people for osteoporosis and the osteogenic lifestyle factors that permit PBM acquisition during adolescence and young adulthood. The

qualitative aspect of this study highlighted a lack of knowledge about bone health and PBM. Adolescents' and young adults' limited understanding of bone health and PBM acquisition hinders their ability to modify their lifestyles to improve their PBM potential. A greater understanding of the consequences of the modifiable lifestyle factors, such as participation in HRSA, may help reduce risk of osteoporotic fracture later in life and encourage improved overall health outcomes. Young people enjoy HRSA participation and may be further motivated by social support networks, but in transitioning to adulthood often face barriers to continuing to proactively engage in HRSA, leading to a decline in HRSA participation. There is an interest in bone health and its determinants in young people and educational interventions are now warranted to support young people to reach their PBM potential through lifestyle factors such as continued HRSA.

Finally, within the constraints mentioned above, the results of this research indicate that specific long-term HRSA are associated with increased bone density in young people, as measured by heel ultrasound. Further, lifelong engagement in osteogenic HRSA can be seen as a modifiable lifestyle factor to improve PBM acquisition and reduce osteoporotic fracture later in life. Engaging young people to develop initiatives to understand and overcome the misconceptions, improving their knowledge of PBM acquisition and osteoporosis, reducing the barriers to HRSA engagement for improved PBM is essential in reducing the burden of osteoporotic fracture later in life.

## **8.6 Future research recommendations for future practice or policy**

Much of the previous research on osteoporosis and PBM determinants has focused on participants in their forties and older. Such studies have reported that healthcare and education providers missed opportunities to educate society on the risks of osteoporosis, demonstrated by the lack of osteoporosis knowledge and poor ability to recall such risks by participants (Kasper et al., 1994). As a society, there is a need to accelerate these efforts to prevent osteoporosis. Future studies require methods not only of improving and retaining knowledge of osteoporosis, but also to facilitate the incorporation of regular beneficial osteogenic lifestyles. Modifications in the study and workplaces to incorporate to increase everyday HRSA and reduce inactive behaviours would be beneficial. Support for lifestyle behaviours such as increasing and maintaining osteogenic HRSA levels and adequate nutrition during the transitional periods of life to build healthy bones and improve overall health outcomes is required. Further work to understand the viewpoints of young children and adolescents requires a multi-phased methodology using techniques modified to suit a younger age group.



Sports participation during adolescence involving high-impact loading (such as gymnastics, martial arts practices like judo, karate, or jump-start sports such as volleyball), odd-impact loading (such as running, football, basketball, racquet games, step-aerobics and skating) or repetitive low impact sports should be encouraged from an early age to improve bone health. Low impact sports such as swimming, other water-based sports and cycling should be complemented with other weight-bearing activities to achieve optimum PBM.

University students, high school students and non-students from clubs and fitness centres typically reflect the perspectives of individuals who are still recreationally active. In this group of individuals who are yet to acquire maximum PBM, the impact of changing lifestyles such as the effect of changes in HRSA are of importance to the risk of fragility fracture in later life. The university age group of participants may be of special interest, as they represent a population who are often very active and whose HRSA participation with specific sports training history are either current or relatively recent. This permits ease of recall of events and activities engaged.

Of special note, this study was undertaken before the global COVID-19 pandemic emerged in early 2020. Future work requires innovative, safe methods to explore the impact on PBM and future risk of osteoporotic fracture; strategies such as incorporating HRSA may be used to mitigate the additional burden.

## **8.7 Future research to be undertaken**

The study findings described in this thesis give further direction and recommendations for future bone health research in young people. It will be particularly important to continue the qualitative focus group work with 11 to 18 year old school aged children. A small amendment to the current national ethics study (HDEC 18/CEN/18) has been undertaken and school authorities have already agreed to continue to assist and support the study.

A collaborative analysis between this study with a comparable study in Norway (the Tromsø study) will be undertaken to consider relationships between screen time and bone health. Further analysis of our study's rich data set will explore relationships between reported outdoor sun-exposure sports on bone

health. The data extracted as part of the systematic literature review in this study will be used to perform a second systematic literature review of relationships between elite sporting activities and bone health.

Finally, this work underpins a future PhD studentship, that will include a systematic literature review of interventions to improve bone health knowledge in college-aged students and a subsequent intervention study to improve knowledge and initiate behavioural changes.

## **8.8 Plans of dissemination**

The results of this thesis will be published in local and international journals as well as through conference attendance.

The systematic literature review was published in *Frontiers Physiology* in January 2020 (the protocol was registered with the International Prospective Register of Systematic Reviews under registration number CRD42018080101). The results of the quantitative study of the young adults have been accepted by the *Physician and Sports Medicine* (Taylor & Francis), pending re-review following the reviewers' comments. In addition, the qualitative paper that considers barriers and enablers to engaging in HRSA in young adulthood has been published in the *Journal of Osteoporosis and Physical Activity*, and the qualitative paper that considers knowledge of peak bone mass and its determinants has been submitted for publication in a special edition of *OBM Geriatrics, Osteoporosis in the Elderly*, as a position piece.

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## 10 Appendix

### 10.1 Abstract: IOF World Congress – Krakow

#### **Alcohol intake and bone health in New Zealand young adults: reason for concern?**

**Hansa Patel, Lisa Woods, Paul Teesdale Spittle, Elaine Dennison.**

**Victoria University of Wellington, New Zealand**

#### **Objective**

Peak bone mass (PBM) is a major determinant of risk of fragility fracture. Many lifestyle factors may be important to attain PBM. While excessive alcohol consumption is considered a risk factor for poor bone health in later life, fewer data are available regarding its prevalence, and association with bone health around the time of PBM acquisition. We considered these issues in a New Zealand student population.

#### **Material and Methods**

A lifestyle questionnaire was administered to 337 young adults. This detailed: age; height; weight; ethnicity; cigarette smoking; alcohol history; sporting physical activity. Heel ultrasound was performed using an Achilles ultrasonometer to provide estimates of Stiffness Index, broadband ultrasound attenuation and speed of sound to assess bone health.

#### **Results**

Of the 337 participants (124 males; 213 females), the mean age was 23.6 (SD 4.4) and 22.8 (SD 4.3) years, the mean BMI was 24.5 (SD 8.6) and 24.1 (SD 4.7) in males and females respectively. Represented ethnicities were Caucasian (62.9%), Māori/Pacific peoples (8.9%), and other ethnicities (28.2%). Three quarters of the sample reported regular weekly physical activity. More males (20.3%) than females (9.5%) were current smokers; 291 (92.1%) of participants reported drinking alcohol, with a mean weekly alcohol consumption of 6.1 (SD 4.3) and 4.8 (SD 3.2) units in males and females respectively, though 4.2% males and 4.8% females drank more than the recommended number of units weekly. Of this group 31.3% reported binge drinking (consumption of more than 6 drinks at one time) at least monthly. Reports of exposure to alcohol under the legal age of alcohol consumption were common (80% by 18 years). Individuals consuming more than the recommended units of alcohol per week were more likely to smoke ( $p < 0.001$ ). Clear associations between alcohol intake and heel ultrasound were not observed.

#### **Conclusion**

These data highlight the high rate of binge and underage drinking in young people. Further work in a larger study is now underway to understand the impact of these factors on bone health.

## 10.2 IOF Conference abstract poster presented in Poland

# Alcohol intake and bone health in New Zealand young adults: reason for concern?

## Background

Peak bone mass (PBM) is a major determinant of risk of fragility fracture. Many lifestyle factors may be important to attain PBM, including alcohol consumption. However, while excessive alcohol consumption is considered a risk factor for poor bone health in later life, fewer data are available regarding its prevalence, and association with bone health around the time of PBM acquisition. We considered these issues in a New Zealand student population.



Figure One: GE Healthcare Achilles ultrasonometer

## Methods

We recruited 337 New Zealand students and young adults. A lifestyle questionnaire was administered, that detailed: age; height; weight; ethnicity; cigarette smoking; alcohol consumption; sporting physical activity. Heel ultrasound was performed using an Achilles ultrasonometer to provide estimates of stiffness index, broadband ultrasound attenuation and speed of sound to assess bone health. Both heels were measured, and an average of the two readings taken.

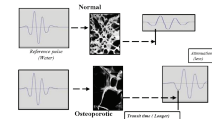


Figure two: Varying attenuation for normal vs. osteoporotic heel bone (as calcia)

## Results

Of the 337 participants (124 males; 213 females), Represented ethnicities were Caucasian (62.9%), Māori/Pacific peoples (8.9%), and other ethnicities (28.2%). 291 (92.1%) of participants reported drinking alcohol, with a mean weekly alcohol consumption of 6.1 (SD 4.3) and 4.8 (SD 3.2) units in males and females respectively, though 4.2% males and 4.8% females drank more than the recommended number of units weekly. Of this group 31.3% reported binge drinking (consumption of more than 6 drinks at one time) at least monthly. Reports of exposure to alcohol under the legal age of alcohol consumption were common (80% by 18 years).

Individuals consuming more than the recommended units of alcohol per week were more likely to smoke ( $p < 0.001$ ). Significant associations between alcohol intake and heel ultrasound bone parameters were not observed in this sample.

	Males	Females
Weekly alcohol intake (units)	6.1 (SD 4.3)	4.8 (SD 3.2)
Age	23.6 (SD 4.4)	22.8 (SD 4.3)
BMI (kg/m <sup>2</sup> )	24.5 (SD 8.6)	24.1 (SD 4.7)
Population	124	213
Current smoker (%)	20.3	9.5
Overall (%)		
- Regular weekly physical activity		75
- Reported monthly binge drinking		31.3
- Alcohol consumption		92.1
Reported exposure to alcohol before age 18 (%)		80

Figure three: Study group demographics



Figure four: Youth drinking

## Conclusion

These data highlight the high rate of binge and underage drinking in young people, which may be associated with other lifestyle factors that impact bone health negatively. Further work in a larger study is now underway to understand the impact of these factors on peak bone mass.

H. Patel, L. Woods, P. Teesdale-Spittle, E. Dennison

UNIVERSITY OF VICTORIA  
VICTORIA  
UNIVERSITY OF WELLINGTON



## 10.3 Abstract: IOF Australia Regionals – 7th Asia-Pacific Osteoporosis Conference

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### BONE HEALTH IN NEW ZEALAND YOUNG ADULTS: CAUSE FOR CONCERN?

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#### Objective

Peak bone mass (PBM) is a major determinant of the risk of fragility fracture. While many lifestyle factors may be important to attain PBM, little research exists regarding the lifestyle choices of young adults around the time of PBM acquisition. In this study we consider these issues: reporting excessive alcohol consumption, sporting physical activity and their relationship to bone health in a cohort of New Zealand young adults.

#### Material and Methods

A lifestyle questionnaire was administered to 474 young adults. This detailed age, height, weight, ethnicity, smoking, alcohol history and sporting physical activity. Heel ultrasound was performed using an Achilles ultrasonometer to provide estimates of Stiffness Index, broadband ultrasound attenuation and speed of sound in order to assess bone health.

#### Results

There were 169 male (median age=21, IQR=5; mean BMI=24.5kg/m<sup>2</sup>±7.6) and 305 female (median age=22, IQR=7; mean BMI=24.2kg/m<sup>2</sup>±5.6) participants recruited. Ethnicities represented were Caucasian (67.6%), Māori/Pacific (9.5%), and other (22.8%). Over 80% of males and females reported at least weekly sporting physical activity. More males (21.7%) than females (10.3%) were current smokers; 431 (92.1%) of participants reported drinking alcohol, with a mean weekly alcohol consumption of 6.3 (SD=4.6) and 4.9 (SD=3.2) units in males and females respectively, though 6.1% males and 6.3% females drank more than the recommended number of units weekly.

In this group of 16 to 35 year olds, 35.3% reported binge drinking (consumption greater than 6 drinks at one time) at least monthly, 50% reported drinking alcohol by the age of 15, and 83.6% reported alcohol exposure before the New Zealand legal alcohol purchasing age of eighteen. Individuals consuming more than the recommended units of alcohol per week were more likely to smoke ( $p<0.001$ ).

Clear associations between alcohol intake and heel ultrasound bone measures were not observed. Male participants who had participated in habitual sporting activity had higher heel mean stiffness index ( $p<0.005$ ). There was no statistically significant association between sporting activity and bone density amongst female participants.

#### Conclusion

These data highlight the high rate of binge and underage drinking in young people, with potential long-term impact on bone health.

## 10.4 IOF Conference abstract poster presented in Sydney

### 84 | BONE HEALTH IN NEW ZEALAND YOUNG ADULTS: CAUSE FOR CONCERN?

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<sup>1</sup>Victoria University of Wellington, Wellington, New Zealand

#### Objective

Peak bone mass (PBM) is a major determinant of the risk of fragility fracture. While many lifestyle factors may be important to attain PBM, little research exists regarding the lifestyle choices of young adults around the time of PBM acquisition. In this study we consider these issues: reporting excessive alcohol consumption, sporting physical activity and their relationship to bone health in a cohort of New Zealand young adults.

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A lifestyle questionnaire was administered to 474 young adults. This detailed age, height, weight, ethnicity, smoking, alcohol history and sporting physical activity. Heel ultrasound was performed using an Achilles ultrasonometer to provide estimates of Stiffness Index, broadband ultrasound attenuation and speed of sound in order to assess bone health.

#### Results

There were 169 male (median age=21, IQR=5; mean BMI=24.5kg/m<sup>2</sup>±7.6) and 305 female (median age=22, IQR=7; mean BMI=24.2kg/m<sup>2</sup>±5.6) participants recruited. Ethnicities represented were Caucasian (67.6%), Māori/Pacific (9.5%), and other (22.8%). Over 80% of males and females reported at least weekly sporting physical activity. More males (21.7%) than females (10.3%) were current smokers; 431 (92.1%) of participants reported drinking alcohol, with a mean weekly alcohol consumption of 6.3 (SD=4.6) and 4.9 (SD=3.2) units in males and females respectively, though 6.1% males and 6.3% females drank more than the recommended number of units weekly.


In this group of 16 to 35 year olds, 35.3% reported binge drinking (consumption greater than 6 drinks at one time) at least monthly, 50% reported drinking alcohol by the age of 15, and 83.6% reported alcohol exposure before the New Zealand legal alcohol purchasing age of eighteen. Individuals consuming more than the recommended units of alcohol per week were more likely to smoke ( $p<0.001$ ).

Clear associations between alcohol intake and heel ultrasound bone measures were not observed. Male participants who had participated in habitual sporting activity had higher heel mean stiffness index ( $p<0.005$ ). There was no statistically significant association between sporting activity and bone density amongst female participants.

#### Conclusion

These data highlight the high rate of binge and underage drinking in young people, with potential long-term impact on bone health.

## 10.5 Quantitative study participant information poster



TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI  
**VICTORIA**  
UNIVERSITY OF WELLINGTON

### Factsheet: Sporting Activity and Bone Health in New Zealand Adolescents and Young Adults

Hansa Patel: PhD Candidate, School of Biological Sciences  
Hansa.Patel@vuw.ac.nz

Supervisory Team:  
Professor Elaine Dennison and Associate Professor Paul Teesdale Spittle  
Approval from VUW Human Ethics Committee (ref: # 023752) and HDEC 18/CEN/18

#### Introduction

**What is Osteoporosis?**

- A skeletal disorder
- Decreased bone strength (reduced bone quantity and quality)
- A major world-wide public health problem – increased risk of fragility fractures

**Why study habitual physical activity and sporting activity in this age group?**

- Physical activity is an important contributor to peak bone mass
- Muscle contraction and gravity are the two primary mechanical forces applied to bone
- Bone density positively increases in response to physical loading and mechanical stress
- Typical – physical activity levels decline in our adolescents (Figure One)
- Far fewer data in this age group; this is the focus for this study

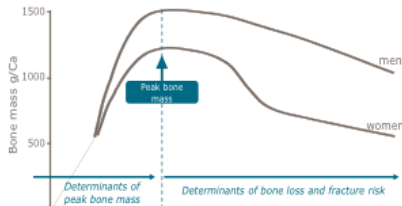


Figure One: Bone mass acquisition through the life course

#### What next?

- Online questionnaire of the predictor variables:
  - Sporting physical activity – type, level, intensity, frequency
  - Sporting physical performed indoors or outdoors as a proxy for sun-exposure and vitamin D levels
  - Screen time
  - Dietary calcium and vitamin D intake
  - BMI
  - Age
  - Other known risk factors (alcohol/smoking).
- Please read the two pamphlets provided regarding your bone health

#### How does the study work?

- The Achilles QUS Systems (background) are bone ultrasonometers that use high frequency sound waves (ultrasound, Figure Two) to evaluate bone status in the heel bone (the os calcis)
- The heel is easy to access, has very little soft overlying soft tissue, has a relatively uniform size and structure and is a highly trabecular, weight bearing site with very high metabolic activity/bone turnover, like the hip and spine.
- The machine calculates SOS and BUA, and combines them to form a clinical measure called the Stiffness Index (SI)
- SI is influenced by the elastic properties of the os calcis, which in turn is heavily dependent on the quantity and structure of bone mineral. Stiffness Index is not the same as mechanical stiffness
- Generally, BUA is related strongly to Bone Mineral Content (BMC) and weakly to connective tissue. Likewise, SOS is related strongly to BMC and weakly to bone micro-architecture.
- Therefore, the linear combination representing SI is a better indicator of bone structure than either SOS or BUA alone. Both SOS and BUA tend to increase as bone mineral density (BMD) increases. BUA and SOS have roughly equal numerical contributions to SI over the range of human values.
- The initial mean Caucasian female young normal reference was set to be equal to a Stiffness Index of 100. See Figure Three for a general guide to evaluating your T-score.

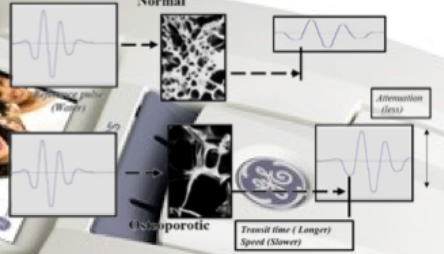


Figure Two: Varying attenuation for normal vs. osteoporotic heel bone (os calcis)

#### Definitions

<b>Bone strength</b>	The ability to resist fracture.
<b>Osteoporosis</b>	Low bone mass and micro-architectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture. According to the World Health Organisation, osteoporosis is indicated by a bone mineral density which is 2.5 standard deviations below the peak bone mass expected in normal healthy young women. (World Health Organisation).
<b>Bone density</b>	Is measured by Dual Energy X-ray Absorptiometry (DEXA), which uses radiation to determine bone density.
<b>QUS</b>	Quantitative Ultra Sound (sound waves, rather than x-rays), which provides information about the strength of bone (structure, elasticity) which is important for determining fracture risk. QUS is used for screening and identifying those at risk for fracture, but not as a diagnostic test. QUS cannot be used for clinical care purpose for bone mass assessment in men or children or pre-menopausal women.
<b>Z score</b>	Age matched score.
<b>T Score</b>	Compared to the average 25 year old female.
<b>-1 and above</b>	Bone density is considered normal.
<b>Between -1 and -2.5</b>	Is a sign of osteopenia, a condition in which bone density is below normal and may lead to osteoporosis.
<b>-2.5 and below</b>	Indicates osteoporosis.
<b>SI</b>	Stiffness index (composite of two component variables SOS and BUA).
<b>ID</b>	Identification number.
<b>BUA</b>	Broadband Ultrasound Attenuation - measure of bone quality.
<b>SOS</b>	Speed of Sound - measure of bone quality.
<b>% Age matched</b>	Percentage as compared to those in your age group.
<b>% Young adult</b>	Percentage as compared to the average young adult.

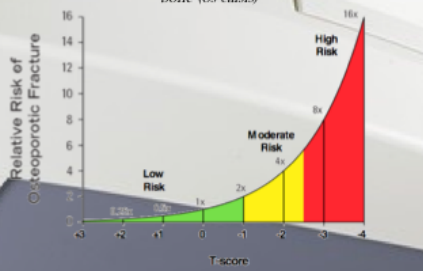


Figure Three: T-scores for Stiffness Index Risk Curve

Dennison, E.M., N.C. Harvey, and C. Cooper, Programming of osteoporosis and impact on osteoporosis risk. Clin Obstet Gynecol, 2013. 56(3): p. 549-55.

EXPIII LU:44018 Rev 4 (QUS Systems - bone ultrasonometers - Achilles EXPIII Operator's Manual)

World Health Organisation

## 10.6 Māori consultation



### **Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults: Māori Consultation**

#### **Working Title of Research PhD Thesis**

A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults.

#### **About the study**

The study focuses on the relationship between sporting physical activity and corresponding bone loading profiles on bone health in teenagers and young adults in connection with osteoporosis: which is typified by decreased bone strength with an increased risk of fragility fractures (often of the hip, wrist and spine) and of consequent illnesses linked to insufficient mobility and physical activity (Cole et al, 200). Consequently, osteoporosis places a wide social and financial health burden on individuals and society.

Bone mass typically increases during late adolescence, peaking in an individual's twenties and thirties, and decreasing from the age of 45 in both men and women. Women experience an accelerated period of bone loss perimenopausally (Berard et al 1997). Lifestyle factors contribute to the acquisition of optimal bone peak mass and to an individual's risk of osteoporosis. Most of the literature focuses on older adults, with corresponding data on young adults typically limited to retrospective recall. This study fills the significant knowledge gap regarding the bone health and the different bone loading profiles physical activity of teenagers and young adults in NZ. Tan et al 2014 systematic review reports that the period around puberty are times to enhance bone strength through physical activity and the associated healthy behaviours early in life.

This is particularly valuable, given the increased time allotted to indoor activities and 'screen time' by young people to understanding factors contributing to their bone health. This increased inactivity in young people is compounded by the removal of compulsory physical education at senior levels in New Zealand secondary schools.

A finding of a statistically significant increase in bone density in those engaging in physical activity would help make the case for the promotion of regular physical activity policies nationally and internationally to improve the quality of life.

#### **Overall project details for the PhD**

The overall project details for the PhD are as follows:

1. An updated systematic review of relationships between physical (and specifically sporting) activity with bone mass in adolescence.

2. Study of association between physical/sporting activity with heel ultrasound scan in two New Zealand-based populations. Heel ultrasound is recognised and feasible methodology to assess bone structure and strength in this study population:
  - a. Firstly university students and alumni (approximately 500-1000 participants age 11-35) and
  - b. Secondly, secondary school students of mean age 16 years (approximately 250 participants age 11-18).
3. Qualitative focus study work of attitudes to risk factors for poor bone health in the above populations (the type of physical activity and duration, time spent indoors/outdoors, sun exposure, screen time, dietary intake, alcohol intake and measuring the vitamin D levels in the subset).

This is an observational study which will obtain data through questionnaires via a Qualtrics survey tool with an intuitive interface with point and click functionality on an iPad/laptop allowing instant data entry. This will have the ability to export the data confidentially into SPSS for statistical analysis.

The questionnaire details age, personal and family history of fracture, cigarette smoking, alcohol history (duration and level of drinking, type of alcohol consumed), physical activity including duration and types of sport undertaken regularly, including whether this activity is performed indoors/ outdoors (as a proxy for sun exposure and vitamin D levels), screen time, dietary calcium, past medical history (to elicit information on possible other secondary causes of osteoporosis e.g. insulin dependent diabetes, hyperthyroidism), drug history and reproductive history. Height and weight will be recorded. Heel ultrasound will also be performed in this group, using the available GE Achilles+ heel ultrasound machine to obtain measures of bone quality (heel BMD, broadband ultrasound attenuation and speed of sound). Ultra sound results will be generated and directly transferred to the statistical software SPSS (or equivalent for statistical analysis) prevent human transfer error.

Further details may be found in the study protocol and other relevant documentation in the HDEC 18/CEN/18 application.

### **Māori Consultation**

Māori consultation is important when proposing to conduct any health research in New Zealand. This unique consultation process helps protect Māori, the indigenous tangata whenua (the people of the land Aotearoa), by reflecting the principles of the Treaty of Waitangi, the founding document of New Zealand and recognising Māori as Treaty partners with the Crown.

The study may benefit Māori through participation in the study at all levels, to improve Māori health, by discussing with Māori relevant issues helps to ensure the validity of the study design (tika) using Te ara tika and to help reflect Treaty of Waitangi principles. Those outside the scientific community have be invited to provide knowledge and input throughout the study to ensure a variety of Māori culture (manaakitanga) is valued.

Indigenous people of many countries have negative connotations of the term research therefore any study should aim to sensitively to approach those involved in the study. Ongoing discussions ensure mana (justice and equity) is preserved and that Māori can access all the benefits of the research through gaining more knowledge and through safeguarding Māori cultural concepts and

values (e.g. Discussing personal cultural considerations, support from whanau to permit a way of being in safe environment, using their traditional knowledge and language identifying sporting physical activities like Ki-o-rahi which uses a small round ball called a 'ki').

This may aid long-term Māori health outcomes by providing safe pathways for whanau to promote conversations about the triggers of reduced bone health and to improve levels of sporting physical activity.

Local leaders have expressed interest in the study, forging Whakapapa (relationships) and trust by having discussions based on shared common goals to improve health. This is strengthened as the author can empathise with participants and through her personal connection with rickets (weakening of bones in children) through an older sibling; this experience will add value to participants understanding and awareness of reduced bone health status.

Initial informal consultation with the VUW Māori Studies Department and leaders in the local education institutions helped to recognise the triggers of reduced bone health to reduce disparities in Māori and ethnic communities. Continuation of the consultation process will nurture the community relationship with Māori and although, there are no apparent specific ethical issues for this non-invasive study formal Māori consultation has been sought. VUW ethic approval has been granted for participants aged 16 to 35 (under reference # 023752).

Therefore various members of the Māori community and those currently involved with Māori health have been invited to give feedback on the study through discussion and in a summary table of relevant points and to provide on-going consultation for the study. Please see attached tables for each member.

These members include:

1. Professor Meegan Hall (Ngāti Ranginui, Ngāti Tūwharetoa) is the Assistant Vice-Chancellor (Mātauranga Māori) at Victoria University of Wellington. She provides strategic academic leadership to increase awareness and grow engagement with mātauranga Māori across the University in learning, teaching and research. She has a PhD in Māori studies, a BA in History and an LLB degree.
2. Tania Nell Chong (Ngā Wairiki Ngāti Apa/ Ngāi Tahu) mother of three children from Lower Hutt.
3. Tawai Frost (Ngāti Porou) kuia and teacher of Te Reo Maori at Sacred Heart College, Lower Hutt.
4. Bruno Marques, a researcher establishing a holistic perspective with respect to health and well-being for indigenous Māori, the relationship they have with the land, shapes the ways in which the cultural, spiritual, emotional, physical and social well-being.

## Viewpoints

The various viewpoints reflected upon include the following:

1. Random sampling so participants will not be targeted based on their ethnicity, sex, disability or religious or spiritual beliefs. This will ensure that there is no unfair burden imposed on any groups to ensure a fair distribution of the benefits and burdens of participation in the study. In this way, the study will contribute to reducing inequalities in

health outcomes between different populations, and particularly between Māori, Pacific peoples and other New Zealanders by promoting conversations about the triggers of reduced bone health and to improve levels of sporting physical activity across all communities within the age range of the study.

2. Both Māori and non-Māori students will be invited to participate in the study and given specific cultural respect as required. They will be informed that they may bring a support person along to the study and have the presence of a recognised supervising adult present during the study.
3. Māori participants and all participants have control over the level of engagement in the study, and may opt out answering any questions without giving reason.
4. If found during the dissemination of results/finding in relation to Māori in particular will be communicated to ensure results are handled sensitively and respectfully and relevant parties informed promptly.
5. This PhD study will encourage children and families to learn about one's health and well-being which is an important aspect of education Māori and Pacific children in particular. The school already supports Kapa Haka which encourages Māori student participation and also welcomes students of other ethnic backgrounds. Kapa Haka fosters a whanau concept to care and support each other, to help develop confidence and self-esteem within the students through song and dance. The study will help to empower children to make healthier lifestyle choices through awareness and sharing that information with their families to help and support the communities they engage in and to help to reduce the health inequalities present.

### **Personal Background**

My background is that I am currently enrolled in the PhD course in Clinical Research and my study topic is in Bone Health and Sporting Physical Activity in Adolescents and Young Adults.

I have completed the Post Grad Diploma in Clinical Research at Victoria. This included a paper on Maori Consultation in the CLNR 402: Ethics and Research in Special Populations as Applied to Clinical Research course with Dr Barry Smith and Dr Hilary Stace. I have attached my assignment to completed for Dr Barry Smith. I thoroughly enjoyed the ethics paper and although my research focuses on the quantitative aspects of bone health, there is a qualitative component which I am looking forward to going into in depth.

The diploma focused on my study 'A randomised controlled trial of the change in vitamin D levels in breast milk after regular, daily exposure to sunlight versus standard exposure to sunlight in Māori, Pacific Island and other ethnic populations with pigmented skin living in the Wellington region.'

Background readings include: Professor Leonie Pihama's work about colonisation is something I can relate to my own family background as an Indian born in England and having lived in a number of countries over the years makes me empathetic and values the cultural framework that binds families and communities together. Linda Smith's work on 'Research' as being a negative term leading to distrust seems understandable given New Zealand and other colonised countries history.

This lead to an interesting discussion at work where I volunteer at the Citizens Advice Bureau about societies valuing our elders (or the lack of) and health disparities within different communities and the history of individuals which makes them who they are now.

My other past history includes Treaty of Waitangi courses as part of work related training and through the Playcentre Training which I completed when my five children were younger. I also help my husband in his no-cost paediatric clinic and am in daily contact with new mothers daily, from all societies and this makes really aware of reaching out to the communities to ensure access to healthcare.

Thus, Māori consultation is important when conducting health research in New Zealand. This unique consultation process will help to protect the health of Māori and other communities in New Zealand.



## 10.7 Ethical approval letters

### 10.7.1 VUW ethics university students, and alumni (aged 16 – 35 years)



Phone 0-4-463 5480  
Email [susan.corbett@vuw.ac.nz](mailto:susan.corbett@vuw.ac.nz)

## MEMORANDUM

TO	Hansa Patel
COPY TO	Prof Elaine Dennison
FROM	AProf Susan Corbett, Convener, Human Ethics Committee
DATE	20 December 2016
PAGES	1
SUBJECT	<b>Ethics Approval: 23752</b> Sporting physical activity and bone health in New Zealand adolescents and young adults

Thank you for your application for ethical approval, which has now been considered by the Standing Committee of the Human Ethics Committee.

Your application has been approved from the above date and this approval continues until 1 June 2019. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Kind regards

A handwritten signature in black ink that reads 'Susan Corbett'.

Susan Corbett  
Convener, Victoria University Human Ethics Committee

## 10.7.2 Amendment to include Others



Phone 0-4-463 5480  
Email [susan.corbett@vuw.ac.nz](mailto:susan.corbett@vuw.ac.nz)

### MEMORANDUM

TO	Hansa Patel
COPY TO	Prof Elaine Dennison
FROM	AProf Susan Corbett, Convener, Human Ethics Committee
DATE	31 August 2017
PAGES	1
SUBJECT	<b>Ethics Approval: 23752</b> Sporting physical activity and bone health in New Zealand adolescents and young adults

Thank you for your request to amend your ethics approval. This has now been considered and the request granted.

Your application has approval until 1 June 2019. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Kind regards

A handwritten signature in black ink that reads "Susan Corbett". The signature is written in a cursive style with a large, stylized 'S' and 'C'.

Susan Corbett  
Convener, Victoria University Human Ethics Committee

### 10.7.3 HDEC 18/CEN/18 Quantitative study



#### Health and Disability Ethics Committees

Ministry of Health  
133 Molesworth Street  
PO Box 5013  
Wellington  
6011

0800 4 ETHICS  
hdec@moh.govt.nz

04 May 2018

Mrs Hansa Patel  
50 Arahiwi Grove  
Lower Hutt  
WELLINGTON 5010

Dear Mrs Patel

Re:	<b>Ethics ref:</b>	<b>18/CEN/18</b>
	Study title:	A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults

I am pleased to advise that this application has been approved by the Central Health and Disability Ethics Committee. This decision was made through the HDEC-Full Review pathway.

#### Conditions of HDEC approval

HDEC approval for this study is subject to the following conditions being met prior to the commencement of the study in New Zealand. It is your responsibility, and that of the study's sponsor, to ensure that these conditions are met. No further review by the Central Health and Disability Ethics Committee is required.

#### Standard conditions:

1. Before the study commences at *any* locality in New Zealand, all relevant regulatory approvals must be obtained.
2. Before the study commences at *each given* locality in New Zealand, it must be authorised by that locality in Online Forms. Locality authorisation confirms that the locality is suitable for the safe and effective conduct of the study, and that local research governance issues have been addressed.

#### Non-standard conditions:

3. Please correct the following line in the Consent form, it should use the pronoun, you and not I;  
I understand that my participation is voluntary and that I am free to withdraw from the study up to 4 weeks after the ultrasound test by contacting me, without giving any reason, but once **you** finished the survey the data cannot be withdrawn.
4. The Committee found the ACC paragraph to be a bit curt and lacking in information. Please use the ACC paragraph from the HDEC's PISCF template, in your Participant Information Sheet (the template is found at <https://ethics.health.govt.nz/> under the Quick Links section)

Non-standard conditions must be completed before commencing your study, however, they do not need to be submitted to or reviewed by HDEC.

#### 10.7.4 HDEC 18/CEN/18 Qualitative study (aged 16 – 35 years)



#### Health and Disability Ethics Committees

Ministry of Health  
133 Molesworth Street  
PO Box 5013  
Wellington  
6011

0800 4 ETHICS  
hdec@moh.govt.nz

20 July 2018

Mrs Hansa Patel  
50 Arahiwi Grove  
Lower Hutt  
WELLINGTON 5010

Dear Mrs Patel,

Re:	<b>Ethics ref:</b>	<b>18/CEN/18/AM01</b>
	Study title:	A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults

I am pleased to advise that this amendment has been approved by the Central Health and Disability Ethics Committee. This decision was made through the HDEC Expedited Review pathway.

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

A handwritten signature in black ink, appearing to read "Helen Walker".

Mrs Helen Walker  
Chairperson  
Central Health and Disability Ethics Committee

Encl: appendix A: documents submitted  
appendix B: statement of compliance and list of members

## 10.7.5 HDEC 18/CEN/18 Qualitative study (aged 16 – 35 years & others)



### Health and Disability Ethics Committees

Ministry of Health  
133 Molesworth Street  
PO Box 5013  
Wellington  
6011

0800 4 ETHICS  
hdec@moh.govt.nz

11 October 2018

Mrs Hansa Patel  
50 Arahiwi Grove  
Lower Hutt  
WELLINGTON 5010

Dear Mrs Patel,

Re:	<b>Ethics ref:</b>	<b>18/CEN/18/AM03</b>
	Study title:	A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults

I am pleased to advise that this amendment has been approved by the Central Health and Disability Ethics Committee. This decision was made through the HDEC Expedited Review pathway.

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'Helen Walker'.

Mrs Helen Walker  
Chairperson  
Central Health and Disability Ethics Committee

Encl: appendix A: documents submitted  
appendix B: statement of compliance and list of members

## 10.7.6 HDEC 18/CEN/18 Annual progress review approval 2019



Health and Disability Ethics Committees  
Ministry of Health  
133 Molesworth Street  
PO Box 5013  
Wellington  
0800 4  
ETHICS  
hdec@moh.govt.nz

23 May 2019

Mrs Hansa Patel 50  
Arahiwi Grove  
Lower Hutt  
WELLINGTON 5010

Dear Mrs Patel,

Re: Ethics ref:	18/CEN/18/AM04
Study title:	A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults

I am pleased to advise that this annual progress report has been approved, following review by the Chairperson of the Central Health and Disability Ethics Committee. Existing approval remains valid.

Your next progress report is due by 03 May 2020.

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

A handwritten signature in black ink, appearing to read "H Walker", written over a horizontal line.

Mrs Helen Walker  
Chairperson  
Central Health and Disability Ethics Committee

Encl: appendix A: documents submitted

## 10.7.7 HDEC 18/CEN/18 Annual progress review approval 2020



Health and Disability Ethics Committees  
Ministry of Health  
133 Molesworth Street  
PO Box 5013  
Wellington  
0800 4 ETHICS  
hdec@health.govt.nz

05 May 2020

Mrs Hansa Patel  
50 Arahiwi Grove  
Lower Hutt  
WELLINGTON 5010

Dear Mrs Patel,

Re:	<b>Ethics ref:</b>	<b>18/CEN/18/AM06</b>
	Study title:	A cross-sectional observational study to evaluate the relationship between habitual sporting activity and bone health in adolescents and young adults

I am pleased to advise that this annual progress report has been approved, following review by the Chairperson of the Central Health and Disability Ethics Committee on 18 April 2020. Existing approval remains valid.

Your **next progress report** is due by **03 May 2021**.

Please don't hesitate to contact the HDEC secretariat for further information. We wish you all the best for your study.

Yours sincerely,

A handwritten signature in black ink, appearing to read 'Helen Walker'.

Mrs Helen Walker  
Chairperson  
Central Health and Disability Ethics Committee

Encl: appendix A: documents submitted

## 10.8 Ethics documentation

### 10.8.1 Confidentiality agreement



## Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults Research Assistant Confidentiality Agreement

**Researcher:** Hansa Patel, PhD candidate Hansa.Patel@vuw.ac.nz

**Name of PhD supervisor:** Prof Elaine Dennison

Please  
tick in  
box

**This project has been approved by the VUW Human Ethics Committee (ref: #023752)**

- I [ ] have read the information sheet that has been sent to participants of this research project.
- I agree to treat the names of the participants and their responses as confidential.
- All electronic information will be kept in a password-protected file and all written material will be kept in a locked file.

☐☐☐

Research Assistant's

Name

Signature

Date

---

---

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Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)  
Study title: Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults  
Confidentiality Agreement Version: 2  
Dated: 7-May-18





## 10.8.2 Quantitative PIS general (aged 16 – 35 years)



### **Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults**

#### **INFORMATION SHEET FOR PARTICIPANTS**

Thank you for your interest in this project. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to take part, thank you for considering my request.

#### **Who am I?**

My name is Hansa Patel. I am a Doctoral student in the Clinical Research programme in the School of Biological Sciences at Victoria University of Wellington (VUW).

#### **What is the aim of the project?**

This project focuses on osteoporosis, a skeletal disorder typified by decreased bone strength due to reduced bone quantity and quality leading to an increased risk of fragility fractures (often of the hip, wrist and spine). The aim of this study is to gain knowledge of the relationship between sporting physical activity and bone health in New Zealand young adults. This project has been approved by the VUW Human Ethics Committee (ref: # 023752).

#### **How can you help?**

The information you provide will help to us to understand the relationship between sporting physical activity and bone health of young people in New Zealand. If you agree to take part, we will assess your bone health by performing a heel ultrasound test and a questionnaire. It is anticipated that the whole process of data collection will take approximately 20 to 30 minutes.

The heel ultrasound test involves no risks or harm. It is a quick, comfortable, pain-free, radiation-free test that only takes a few minutes to perform. The heel ultrasound test will be performed privately onsite at the university e.g. the library study rooms or sports complex private rooms. You will be seated comfortably, with your shoes and socks removed. Your heel will be sprayed with alcohol before it is placed on the footplate of the portable ultrasound machine. Whilst the measurement is performed, two inflated membranes filled with warm water will surround the heel of your foot. This is not uncomfortable or painful. If you were hurt in this study, which is unlikely, you would be eligible to apply for compensation from ACC like you would be if you were hurt in an accident at work or at home. You will have to lodge a claim with ACC. If your claim is accepted, you will receive funding to help with your recovery.

The questionnaire asks questions about your lifestyle, how much sporting activity you do, general health and medical history that may be relevant to your bone health. Qualtrics and VUW provide software that uses a highly confidential secure encryption system for the questionnaire. Upon agreeing to participate, I will send you a confidential link by email to the questionnaire. This can be completed at the time of your appointment for your heel ultrasound measurement, or at a different time if more convenient.

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)  
Study title: Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

Version: 2  
Dated: 8-May-18



Page 1 of 3

The questions will include details such as your age, personal and family history of fracture, cigarette smoking, alcohol history (duration and level of drinking, type of alcohol consumed), physical activity including duration and types of sport undertaken regularly, including whether this activity is performed indoors/ outdoors (as a proxy for sun exposure and vitamin D levels), screen time, dietary calcium, past medical history, what medication and/or supplements you take and questions about your periods if you are female.

### **If you accept this invitation, what are your rights as a research participant?**

You do not have to accept this invitation if you do not want to. If you do decide to participate, you have the right to ask any questions about the study at any time and the right to have a support person accompany you. You may choose not to answer any question or stop at any time, without giving a reason. You can withdraw from the study up to 4 weeks after the ultrasound test by contacting me, but once you have finished the survey the data can't be withdrawn.

### **What will happen to the information you give?**

Because the heel ultrasound measurements are still considered a research tool and are not used clinically you will not be given your individual results, but you will be given information and feedback on lifestyle measures to improve bone health. If you have any concerns and/or want more information about your bone health, please contact your own health care provider/GP.

This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be aggregated and your identity (name) will not be disclosed in any reports, presentations, or public documentation. Every attempt will be made to preserve your anonymity.

The data collected will be securely stored in such a way that only the researchers will be able to gain access to it. At the end of the project any personal information will be destroyed. Any raw data on which the results of the project depend will be retained in secure storage for ten years, after which it will be destroyed.

A summary of the results of the study will be generally available for viewing at the Victoria University of Wellington library as part of a PhD thesis, if requested a summary may be provided.

### **What will the project produce?**

The results of this research study will help us understand more about how sporting physical activity affects bone development during adolescence and young adulthood. The information from this research will be written up into my PhD thesis and this will be available for viewing at the Victoria University of Wellington library. The study will be also be the basis of several articles which will be submitted for publication in scholarly journals upon approval.

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)  
Study title: Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

Version: 2  
Dated: 8-May-18





**If you have any questions or problems, who can you contact?**

If you have any questions, either now or in the future, please feel free to contact either:

**PhD Student**

Name: Hansa Patel

Email: [Hansa.Patel@vuw.ac.nz](mailto:Hansa.Patel@vuw.ac.nz)

**Supervisor**

Name: Professor Elaine Dennison (Clinical Research)

School: Biological Sciences

Phone: +64 4 463 5339

Email: [Elaine.Dennison@vuw.ac.nz](mailto:Elaine.Dennison@vuw.ac.nz)

**Human Ethics Committee Information**

If you have any concerns about the ethical conduct of the research you may contact:

Name: Associate Professor Susan Corbett

Position: Victoria University HEC Convener

Phone: +64 4 463 5480

Email: [ethicsadmin@vuw.ac.nz](mailto:ethicsadmin@vuw.ac.nz)

For Maori support please contact:

Name: Associate Professor Meegan Hall (Ngāti Ranginui, Ngāti Tūwharetoa)

Position: Assistant Vice-Chancellor (Mātauranga Māori)

Phone: +64 4 463 5793

Email: [meegan.hall@vuw.ac.nz](mailto:meegan.hall@vuw.ac.nz)

If you want to talk to someone who isn't involved with the study, you can contact an independent health and disability advocate on:

Phone: 0800 555 050

Fax: 0800 2 SUPPORT (0800 2787 7678)

Email: [advocacy@hdc.org.nz](mailto:advocacy@hdc.org.nz)

You can also contact the health and disability ethics committee (HDEC) that approved this study on:

Phone: 0800 4 ETHICS

Email: [hdec@moh.govt.nz](mailto:hdec@moh.govt.nz)

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)

Study title: Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

Version: 2

Dated: 8-May-18



### 10.8.3 Quantitative consent form general (aged 16 – 35 years)



## Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

### WRITTEN CONSENT TO PARTICIPATE

**Researcher:** Hansa Patel, PhD candidate (Hansa.Patel@vuw.ac.nz)

**Name of PhD supervisor:** Prof Elaine Dennison

**This project has been approved by the VUW Human Ethics Committee (ref: #023752).**

Please  
tick in  
box

- I agree to have a heel ultrasound test and answer a confidential, online survey on sporting physical activity and health. I am aware that I may bring a support person along to the study. ☐
- I understand that data collected during the study may be shared with researchers in New Zealand and in other countries (that may have different privacy laws to New Zealand). I understand that researchers will not be given my name or any other information that would enable them to identify me. I understand that the results will be used for a PhD report and a summary of the results may be used in academic reports and/or presented at conferences. ☐
- I understand that data will be stored securely, and will be kept for up to ten years after study completion. ☐
- I understand that my participation is voluntary and that I am free to withdraw from the study up to 4 weeks after the ultrasound test by contacting me, without giving any reason, but once I have finished the survey the data cannot be withdrawn. ☐

Participant's Name

Date of Birth

Contact Email

Signature

Date

---

---

---

---

---

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)

Study title: Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

Consent form (general) Version: 2

Dated: 7-May-18

Page 1 of 2



OFFICE USE ONLY				
Date		Ref #	Left foot	Right foot
Name		T score		
Age		Z score		
Gender		SI		
Study #		ID		
Height		BUA		
Weight		SOS		
		% Aged matched		
		% Young adult		





## 10.8.4 Qualitative focus group recruitment flyer

### Barriers to adopting a better lifestyle for bone health later in life: focus group study

We would like to find out how young people feel about the lifestyle choices that are associated with better bone health later in life. Identifying the barriers to lifestyles that lead to better bone health is the first step towards making a positive difference to bone health in New Zealand.

We would like you to take part in an audiotaped focus group discussion lasting up to 45 minutes with approximately 4 to 10 other people aged 16 to 35 about day-to-day lifestyle factors that may influence bone health. You will receive a grocery voucher as a token of appreciation. If you are interested, please take a tear-off tab and feel free to contact us with any questions you may have about the study.



Hansa Patel  
PhD Candidate  
School of Biological Sciences  
hansa.patel@vuw.ac.nz



The discussion is voluntary, and if any questions make you feel uncomfortable, you do not have to answer them. You may leave the discussion at any time for any reason without consequence. Your privacy will be protected, and your name will not be used in any report that is published. The discussion will be kept confidential and while it cannot be assured, other participants will be asked to respect the privacy of other participants.  
This research has been approved by the VUW Human Ethics Committee (ref: 023752) and the Health and Disability Ethics Committee (HDEC) 18/CEN/18.

Lifestyle and bone health focus group study  
hansa.patel@vuw.ac.nz

Lifestyle and bone health focus group study  
hansa.patel@vuw.ac.nz

Lifestyle and bone health focus group study  
hansa.patel@vuw.ac.nz

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Lifestyle and bone health focus group study  
hansa.patel@vuw.ac.nz

## 10.8.5 Qualitative focus PIS and consent (aged 16 – 35 years)



### **Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults**

*Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study*

#### **INFORMATION SHEET FOR PARTICIPANTS AGED 16 to 35 inclusively**

***Please go through this information sheet and make sure you understand what is involved. Please contact me if you have any questions.***

Thank you for your interest in this study. Please read this information before deciding whether or not you would like to take part.

#### **What is the Research?**

- We would like to find out how young people feel about the lifestyle choices that are associated with better bone health later in life. If we can identify the barriers to adoption of a lifestyle that leads to better bone health, we can try to reduce those barriers.

#### **Why have you been asked to take part?**

- We are asking young people who have helped with a previous study of bone health where you helped us by completing a questionnaire and undergoing a heel ultrasound. At that time you gave us permission to contact you again in relation to the study.
- Even if you feel like you have nothing new to say, we would love to hear from you. Everyone's contribution will enable us to make a positive difference to bone health in New Zealand.

#### **What does the study involve?**

- We would like you to take part in a discussion with other young people about factors that impact the lifestyle choices you make now that might impact bone health later in life.
- If you participate in this study, you will be in a group of approximately 4 – 10 young people. There will be a facilitator who will ask questions and facilitate the discussion, and a note-taker to write down the ideas expressed within the group. The focus group will last about 45 minutes and will be audiotaped.

#### **Voluntary Participation**

- This discussion is *voluntary* – you do not have to take part if you do not want to.
- If any questions make you feel uncomfortable, you do not have to answer them.
- You may leave the group at any time for any reason without consequence. Please note that since data will be collected and stored in de-identified form, any data that you have provided will not be able to be withdrawn.
- However, it is okay if you do not take part in the study.

#### **Privacy**

- Your privacy will be protected.
- Your name will not be used in any report that is published.
- The discussion will be kept *strictly confidential*.
- The other young people in the group will be asked keep what we talk about private, but this cannot be assured.

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)

Sub-study title: Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study

Focus Group 16 and over Version: 1

Dated: 5-Jul-18

1



- All research data including the audio recordings and paper data will be stored in a locked file cabinet in the School of Biological Sciences main office or on a password protected computer for ten years, and then destroyed.
- This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be grouped together and your name will not be shared with anyone else.
- A summary of the results of the study will be available for viewing at the Victoria University of Wellington library as part of a PhD thesis, if requested a summary may be provided.

**Payment:** You will receive a grocery voucher as a token of appreciation for taking part in the focus group.

**Questions:** We will be happy to answer any question you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact the coordinating researcher by email [Hansa.Patel@vuw.ac.nz](mailto:Hansa.Patel@vuw.ac.nz)

**Ethical approval:** This project forms the basis of a Victoria University of Wellington (VUW) PhD studentship and has been reviewed and approved by the VUW Human Ethics Committee (ref: 023752) and the Health and Disability Ethics Committee (HDEC) 18/CEN/18.

#### Contact information:

##### Supervisor

Name: Professor Elaine Dennison (Clinical Research)  
 School: Biological Sciences  
 Phone: +64 4 463 5339  
 Email: [Elaine.Dennison@vuw.ac.nz](mailto:Elaine.Dennison@vuw.ac.nz)

##### Human Ethics Committee Information

If you have any concerns about the ethical conduct of the research you may contact:  
 Name: Dr Judith Loveridge  
 Position: VUW HEC Convener  
 Phone: +64 4 463 6028  
 Email: [hec@vuw.ac.nz](mailto:hec@vuw.ac.nz)

##### Other Support

For **Maori support** please contact:  
 Name: Associate Professor Meegan Hall (Ngāti Ranginui, Ngāti Tūwharetoa)  
 Position: Assistant Vice-Chancellor (Mātauranga Māori)  
 Phone: +64 4 463 5793  
 Email: [meegan.hall@vuw.ac.nz](mailto:meegan.hall@vuw.ac.nz)

If you want to talk to someone who isn't involved with the study, you can contact an **independent health and disability advocate** on:  
 Phone: 0800 555 050  
 Fax: 0800 2 SUPPORT (0800 2787 7678)  
 Email: [advocacy@hdc.org.nz](mailto:advocacy@hdc.org.nz)

You can also contact **HDEC** on:  
 Phone: 0800 4 ETHICS  
 Email: [hdec@moh.govt.nz](mailto:hdec@moh.govt.nz)







## Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

*Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study*

### WRITTEN CONSENT TO PARTICIPATE FOR PARTICIPANTS AGED 16 to 35 inclusively

**Researcher:** Hansa Patel, PhD candidate

**Name of PhD supervisor:** Prof Elaine Dennison

Please  
tick in  
box

**This project has been approved by the VUW Human Ethics Committee (ref: #023752) and HDEC 18/CEN/18.**

- I have been given the Participant Information Sheet and understand the information provided in it. ☐
- I understand that my participation in this study will involve me taking part in a focus group with other young people. ☐
- I consent to the audio-recording and transcribing of the focus group discussion. All data will be de-identified and stored in a locked filing cabinet or on a password protected computer. ☐
- I understand that data collected during the study may be shared with researchers in New Zealand and in other countries (that may have different privacy laws to New Zealand). I understand that researchers will not be given my name or any other information that would enable them to identify me. I understand that the results will be used for a PhD report and a summary of the results may be used in academic reports and/or presented at conferences. ☐
- I understand that data will be stored securely, and will be kept for up to ten years after study completion. ☐
- I understand that my participation is voluntary and that I can leave the group at any time for any reason without consequence. I understand any data provided will not be able to be withdrawn but will be stored in de-identified form. ☐

Participant's Name

Date of Birth

Contact Email

Signature

Date

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)  
Sub-study title: Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study  
Focus Group 16 and over Version: 1  
Dated: 5-Jul-18

3



## 10.8.6 Qualitative focus PIS and consent others (aged 16 – 35 years)



### Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

*Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study*

#### INFORMATION SHEET FOR PARTICIPANTS AGED 16 TO 35 INCLUSIVELY

***Please go through this information sheet and make sure you understand what is involved. Please contact me if you have any questions.***

Thank you for your interest in this study. Please read this information before deciding whether or not you would like to take part.

#### What is the Research?

- We would like to find out how young people feel about the lifestyle choices that are associated with better bone health later in life. If we can identify the barriers to adoption of a lifestyle that leads to better bone health, we can try to reduce those barriers.

#### Why have you been asked to take part?

- We are asking young people aged 16 to 35 from all walks of life to share with us your views in a one-off interview on different factors in day to day life which have an impact on bone health positively or negatively. The team would like to take your opinion and discuss various contributing factors such as what sorts of physical activity you engage in (jogging, cycling, sports etc.), the type of food you consume, etc.
- Even if you feel like you have nothing to say, we would love to hear from you. Everyone's contribution will enable us to make a positive difference to bone health in New Zealand.

#### What does the study involve?

- We would like you to take part in a discussion with other young people about factors that impact the lifestyle choices you make now that might impact bone health later in life.
- If you participate in this study, you will be in a group of approximately 4 – 10 young people. There will be a facilitator who will ask questions and facilitate the discussion, and a note-taker to write down the ideas expressed within the group. The focus group will last about 45 minutes and will be audiotaped.

#### Voluntary Participation

- This discussion is *voluntary* – you do not have to take part if you do not want to.
- If any questions make you feel uncomfortable, you do not have to answer them.
- You may leave the group at any time for any reason without consequence. Please note that since data will be collected and stored in de-identified form, any data that you have provided will not be able to be withdrawn.

#### Privacy

- Your privacy will be protected.
- Your name will not be used in any report that is published.
- The discussion will be kept *strictly confidential*.
- The other young people in the group will be asked keep what we talk about private, but this cannot be assured.

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)

Sub-study title: Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study

Focus Group aged 16 to 35

Version: 2

Dated: 10-Sep-18



- All research data (including the audio recordings and paper data) will be stored in a secure facility at the School of Biological Sciences, Victoria University of Wellington (**VUW**) and on a password protected computer for ten years, and then destroyed.
- This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be grouped together and your name will not be shared with anyone else.
- A summary of the results of the study will be available for viewing at the VUW library as part of a PhD thesis, if requested a summary may be provided.

**Payment:** You will receive a grocery voucher as a token of appreciation for taking part in the focus group.

**Questions:** We will be happy to answer any questions you have about this study. If you have further questions about this project or if you have a research-related problem, you may contact the coordinating researcher by email [Hansa.Patel@vuw.ac.nz](mailto:Hansa.Patel@vuw.ac.nz)

**Ethical approval:** This project forms the basis of a VUW PhD studentship and has been reviewed and approved by the VUW Human Ethics Committee (ref: 023752) and the Health and Disability Ethics Committee (HDEC) 18/CEN/18.

#### Contact information:

##### Supervisor

Name: Professor Elaine Dennison (Clinical Research)  
 School: Biological Sciences  
 Phone: +64 4 463 5339  
 Email: [Elaine.Dennison@vuw.ac.nz](mailto:Elaine.Dennison@vuw.ac.nz)

##### Human Ethics Committee Information

If you have any concerns about the ethical conduct of the research you may contact:

Name: Dr Judith Loveridge  
 Position: VUW HEC Convener  
 Phone: +64 4 463 6028  
 Email: [hec@vuw.ac.nz](mailto:hec@vuw.ac.nz)

##### Other Support

For **Maori support** please contact:

Name: Associate Professor Meegan Hall (Ngāti Ranginui, Ngāti Tūwharetoa)  
 Position: Assistant Vice-Chancellor (Mātauranga Māori)  
 Phone: +64 4 463 5793  
 Email: [meegan.hall@vuw.ac.nz](mailto:meegan.hall@vuw.ac.nz)

If you want to talk to someone who is not involved with the study, you can contact an **independent health and disability advocate** on:

Phone: 0800 555 050  
 Fax: 0800 2 SUPPORT (0800 2787 7678)  
 Email: [advocacy@hdc.org.nz](mailto:advocacy@hdc.org.nz)

You can also contact **HDEC** on:

Phone: 0800 4 ETHICS  
 Email: [hdec@moh.govt.nz](mailto:hdec@moh.govt.nz)





## Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults

*Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study*

### WRITTEN CONSENT TO PARTICIPATE FOR PARTICIPANTS AGED 16 to 35 inclusively

**Researcher:** Hansa Patel, PhD candidate

**Name of PhD supervisor:** Prof Elaine Dennison

Please  
tick in  
box

**This project has been approved by the VUW Human Ethics Committee (ref: #023752) and HDEC 18/CEN/18.**

- I have been given the Participant Information Sheet and understand the information provided in it. ☐
- I understand that my participation in this study will involve me taking part in a focus group with other young people. ☐
- I consent to the audio-recording and transcribing of the focus group discussion. All data will be de-identified and stored in a locked filing cabinet or on a password protected computer. ☐
- I understand that data collected during the study may be shared with researchers in New Zealand and in other countries (that may have different privacy laws to New Zealand). I understand that researchers will not be given my name or any other information that would enable them to identify me. I understand that the results will be used for a PhD report and a summary of the results may be used in academic reports and/or presented at conferences. ☐
- I understand that data will be stored securely, and will be kept for up to ten years after study completion. ☐
- I understand that my participation is voluntary and that I can leave the group at any time for any reason without consequence. I understand any data provided will not be able to be withdrawn but will be stored in de-identified form. ☐

Participant's Name

Date of Birth

Contact Email

Signature

Date

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752)  
Sub-study title: Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study  
Focus Group aged 16 to 35  
Version: 2  
Dated: 10-Sep-18

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## 10.8.7 Qualitative protocol (aged 16 – 35 years)



### **Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults**

*Barriers to adopting a better lifestyle for bone health later in life*

*Focus Group Sub-Study*

**Hansa Patel**

300125144

Hansa.Patel@vuw.ac.nz

021 048 3560

#### **Working Title of Research Project/Thesis:**

A cross-sectional observational study to evaluate the relationship between lifestyle, including habitual sporting activity, and bone health in adolescents and young adults.

**VUW Human Ethics Committee Approval Number:** 023752

**Health and Disability Ethics Committee:** 18/CEN/18

**Primary Supervisor:** Professor Elaine Dennison

**Secondary Supervisor:** Associate Professor Paul Teesdale-Spittle

**Administrative Supervisor:** Melanie McConnell

**Other:** Bronwyn Kivell

**PhD start date:** 1 June 2016

**Anticipated completion date:** 1 June 2019

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## ***Rationale***

It is well known that lifestyle factors influence bone health.<sup>(1-3)</sup> This qualitative study is part of a PhD thesis that will evaluate the relationship between lifestyle factors including habitual sporting activity and bone health in adolescents and young adults. As part of this, we would like to find out how people feel about the lifestyle choices that are associated with better bone health later in life. If we can identify the barriers to adoption of a lifestyle that leads to better bone health, we can try to reduce those barriers. The study will use data and information obtained from small focus groups of young people aged 16 to 35 inclusively. The results of this work will help us to understand the ideas and feelings that motivate young people to protect their bone health. The findings will help us to consider how to improve bone health in New Zealand through education campaigns designed at young people.

## ***Research questions***

1. What do adolescents and young adults understand about peak bone mass and risk of osteoporotic fracture?
2. What are the barriers that young people face in adopting lifestyles associated with better bone health and how should we try to reduce these?

## ***Introduction***

Osteoporosis is a major public health problem through its association with fragility fracture of the hip, wrist and spine.<sup>(4)</sup> Adult bone mass increases during late adolescence, reaching a peak in an individual's twenties and thirties; in both sexes, net bone loss occurs later in life after the age of 45. In addition, women experience an accelerated period of bone loss perimenopausally.<sup>(5)</sup>

The National Osteoporosis Foundation's scientific statement by Weaver et al (2016) considered lifestyle factors and bone accretion during the critical years and found the best evidence was available for the positive effects of calcium intake and physical activity.<sup>(2)</sup> Other studies such as Behringer et al (2014) indicate weight bearing activity and high calcium intake in childhood potentially act in a prophylactic manner to osteoporosis.<sup>(6)</sup> A multifactorial approach to health is required to reach maximum genetic potential. Zohrehkhoshnood et al (2016) suggests modifiable factors such as calcium, vitamin D intake and regular sport activity (rather than physical activity alone) have defined barriers. Personal impediments need to be addressed to help young people to reduce the effect of osteoporosis later in life.<sup>(7)</sup> Studies such as Wetter et al (2004) indicate that something more than physical activity may be required to improve skeletal status in young adulthood; more specifically, physical activity that is achieved with long term sporting behaviours.<sup>(8)</sup> Deere et al (2016), suggests that high impact activity such as running and jumping are more beneficial in improving hip BMD and strength than lower impact activities.<sup>(9)</sup>

A number of modifiable lifestyle factors are known to contribute to the acquisition of optimal bone peak mass and to an individual's risk of osteoporosis and hence risk of fracture. Factors such as dietary calcium intake and weight bearing physical activity affect bone health positively in the growing years, although recommended levels of physical activity and calcium intake fall short during early adolescence despite this being the opportune time to optimise bone health.<sup>(2)</sup>

The majority of the literature focuses on the relationship between physical activity and bone health in older adults, with corresponding data on young adults typically limited to retrospective recall. The proposed study fills the significant knowledge gap regarding the bone health and physical activity of adolescents and young adults; this is supported by a systematic review that reported that prepuberty and peripuberty are important times to enhance both bone strength through physical activity and the associated healthy behaviours early

Health and Disability Ethics Committee Ref: 18/CEN/18 (VUW Human Ethics Committee #023752) 2  
Sub-study title: Barriers to adopting a better lifestyle for bone health later in life – Focus Group Study

Protocol Version: 2  
Dated: 10-Sep-18

in life.<sup>(10)</sup> This is important as physical activity declines during the lifetime, particularly in adolescents.<sup>(11)</sup>

The scope of our study would be particularly valuable given the increased time allotted to indoor activities and ‘screen time’ by young people in New Zealand. The increased level of sedentary activity in young people is compounded by the removal of compulsory physical education at senior levels in New Zealand secondary schools. A study by Sport New Zealand in 2016 has shown that the rate of adult participation in sporting physical activities has declined over a 16 year period by nearly 8% in adults. In the same period, there was a nearly 14% decrease for the 18-24 age group. This study also shows the rate and pattern of sporting physical activity decline is variable for the different ethnic groups, with this decline being the greatest (over 11% ) in the Pacific group.<sup>(12)</sup> Some of this disparity could be explained by lower income and social status, though little research has been undertaken that explores the reasons for less sporting physical activity, particularly in some ethnic groups.<sup>(12)</sup>

The Ministry of Education and Sports and Recreation New Zealand advocates developing safe physical and emotional environments, including friendship groups, to help the continuation of sporting activities in the growing years.<sup>(13, 14)</sup> Studies suggest that qualitative studies may provide a better understanding of challenges and obstacles facing people participating sports and physical activity over their lifespan.<sup>(15)</sup> In addition, childhood obesity is on the rise in some parts of the world with detrimental health consequences. A review by Mughal et al (2011) indicates that obesity is harmful in the accrual of bone mass.<sup>(16)</sup> An Australian study on physical activity and sedentary behaviours suggested that high risk groups included those who rated their own health poorly, or were obese and/or smokers aged 25-44.<sup>(17)</sup>

Alcohol abuse is another contributing factor, with numerous studies of older (typically male) subjects reporting that alcoholics have radiographic and histomorphometric evidence of low bone density, and that long-term excessive alcohol consumption is an independent risk factor for bone loss.<sup>(18-20)</sup> Bone is in a constant state of bone turnover. Bone formation is effected by osteoblasts, and bone resorption by osteoclasts. In good health, the two processes are in balance, but impaired osteoblastic activity, or increased osteoclastic activity both lead to net bone loss with factors such as alcohol.<sup>(21)</sup>

Most studies have consistently shown that alcohol ingestion is associated with a reduction in bone formation, but studies assessing bone resorption have given conflicting results.<sup>(22, 23)</sup> Previously, a study was performed in premenopausal Caucasian women admitted to the alcohol detoxification unit at Kenepuru hospital, in New Zealand, by administering questionnaires and obtaining heel ultrasound measurements, in addition to looking at bone turnover in this group. Results from this baseline study were recently published.<sup>(24)</sup> It was found that alcoholic women had poorer bone health compared with controls, and that recovery of bone turnover was apparent within a few days of admission, suggesting the detrimental effect of alcohol excess might be reversible. We have also recently surveyed a student population in Wellington, New Zealand to determine the prevalence of lifestyle factors associated with poorer bone health. Of the 337 participants (124 males; 213 females), 92% reported drinking alcohol. Of those drinking alcohol, 80% reported exposure to alcohol under the legal alcohol purchasing age of 18 and 31.3% reported binge drinking (consumption of more than 6 drinks at one time) at least monthly. Those who drank more than the recommended number of alcohol units each week (4.2% of males and 4.8% of females) were more likely to smoke ( $p < 0.001$ ). In this study’s preliminary analysis, three quarters of the sample reported regular weekly physical activity, including sporting activity, and clear associations between alcohol intake and heel ultrasound were not observed in this young population.

There is a need to study the evidence around sporting physical activity in the formative years and in young people which may be used to support good bone health policies and thereby reduce the risk of osteoporosis



in later years. The special characteristics of this study uses a combination of quantitative and qualitative methods to understand the long-term sporting physical activity behaviours and experiences of young people and the impact this has on the bone health of young people in New Zealand. These novel investigative methods will provide new information relevant to the New Zealand population to help to understand the effects of their behaviours and attitudes and its inevitable implications on the overall long-term health of young people. Of special interest would be to elicit evidence for the specific types and level of sporting physical activity that may be effective in improving bone health outcomes. For example, studies have shown the bone health benefits of gymnastics early in life,<sup>(25)</sup> however swimming, although associated with some health benefits, has not been specifically recognised as improving BMD.<sup>(26)</sup>

The following focus group study is part of a PhD thesis which is using a mixed methods research approach. The first phase of the study was to perform a systematic review of relationships between habitual sporting activities and bone mass in adolescence and young adulthood. The second phase was to undertake a quantitative multi-centred Wellington study of the association between sporting activities and heel ultrasound scan in two New Zealand-based populations: Victoria University of Wellington (VUW) students/alumni and others age 16 to 35 inclusively (~500 participants); and school children of mean age 16 years (~500 participants): this quantitative study forms the foundation of the following qualitative study to find out how young people feel about the lifestyle choices that are associated with better bone health later in life (including behaviours associated with smoking, alcohol, diet, exercise and in particular sporting physical activity).

### ***Methods***

Using the foundations of the main PhD study documentation previously submitted to HDEC, a qualitative methodology will be used to gain an understanding of what influences behaviours that might improve bone health, such as sporting behaviours, to inform future intervention strategies. Studies suggest that young people are not concerned with the risk of disease later in life and instead focus on their current interests, appearances, and fitness levels, and further, that social media has a role to play in modifying young people's lifestyles.<sup>(27)</sup> We will perform focus group interviews with participants recruited from the previously held quantitative study (using heel ultrasound measurements and a survey to gain knowledge about attitudes to bone health in young people) to explore attitudes and experiences that influence the bone health in young people. The results of this work will help to understand the ideas and feelings that motivate young people to protect their bone health.

### **Ethical Considerations and Participant Recruitment**

We held discussions to understand and examine the purpose of the sub-study, the roles of the investigators (the data recorder, study lead, observer/moderator) and the ethical considerations (including Māori consultation) for the study design. We have considered the implications as per the original protocol as to how the study may affect Māori and other communities.

After obtaining approval to an extension to the current VUW Human Ethics Committee #023752 and HDEC study approval 18/CEN/18 for the quantitative phase, participants who have previously consented to being contacted by email for further study in this research area of bone health in young people will be emailed about the focus study. Eligible participants will be aged 16 to 35 inclusively of any gender. Participant information sheets detailing the study reasoning, backgrounds, methods, privacy and safety and other characteristics that their involvement in study will entail will be provided. Upon obtaining written and informed participants will be given options for the dates of the focus group sessions so they choose an interview time that suits them and to reduce group selection bias.





An option of thanking participants with *koha* (as an expression of how much importance and appreciation has been given) with the gift of a grocery voucher has been considered.

Participants will be informed that their participation is voluntary, and they will be given the option of being identified by a pseudonym of their choice for the group discussion by writing their own name tags to be worn on their clothing if they would prefer to (or not). They may also choose not to answer any questions and may exit the discussion group as their own discretion without giving any reasons and without consequence; although since data will be collected and stored in de-identified form, any data which has already been provided will not be able to be withdrawn.

### Data collection

Participants will be reminded (by email/text or other methods agreed upon) the day before the focus group. The focus group will consist of 4-10 participants with at least 4-5 focus group discussions, and will be located in the university or secondary school environments. The focus group moderators also include Dr Hayley Denison (Research Coordinator, VUW, Epidemiologist, Centre for Public Research, Massey University) who will supervise the overall focus group interview process and Dr Sana Zafar (current Masters research student, Clinical Research, VUW) who will record and transcribe the group discussions.

To ensure participant safety, moderators will be required to complete Research Assistant Confidentiality Agreement form which was submitted to HDEC previously prior to the study commencing. The focus group participants will be encouraged to discuss with each other what they understand about peak bone mass and risk of osteoporotic fracture, as well as factors (hurdles and facilitators) affecting their bone health and their sporting behaviours. The interview will be semi-structured with open-ended questions. Discussing these risk factors will help us to understand why they take certain actions, their decisions processes, and the opportunities available in the communities. The group environment will encourage thoughts and concepts to be aired in a friendly environment without fear of being judged.

The focus group interviews will be recorded with two or more recording devices located in the room in parallel to ensure the data is collected correctly. Alongside this recording, an assistant will record non-verbal communication, so those who did not contribute to the category or theme will also be acknowledged in a tabulated template. Any non-contribution or minimum contribution will add value to the data presented to record information about the level of consensus and dissension to the topic under discussion. Participants will also be given an option to write points of discussion on scribble pads to avoid missing information thought of but not discussed openly for whatever reason (e.g. to feel safe or not judged).

At the end of each focus group session, the lead interviewer will summarise the ideas that have been discussed and ask for any final feedback to ensure all ideas/opinions and experiences are recorded. After each focus session, a debriefing session with the study facilitators will occur to highlight any discussion issues to address, including any key-words, themes or patterns and relationships identified. subsequent focus group interviews will use an iterative process whereby any previous emergent themes will be followed up with open-ended probes to give further insight into the theme until all themes have reached data saturation.

### Analysis

The focus group interviews recorded will be transcribed verbatim, and then checked by listening to the voice recordings several times to ensure all data is recorded correctly. The transcription and any tabulated data, including any notes obtained from the focus group interviews, will be thematically analysed. Sections

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Dated: 10-Sep-18

of data will be assigned codes which will be compared for consistency. The assigned codes will be categorised, and NVivo (a qualitative software programme) will be used to analyse the emerging themes (which, as set out above, will be compared and assessed across the group(s) until all themes have reached data saturation). Any emerging themes may warrant analysis of subgroups such as in: age group; gender; other baseline characteristics (such as BMI and height); age of puberty/sexual maturity; ethnicity; types of sporting activity; duration and frequency; sun exposure during sporting activity; dietary restrictions; socioeconomic groups; and geography.

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### *Attachment A*

We have applied for an additional amendment to the focus group study to include other participants aged 16 to 35 who may not participated in the original quantitative study involving the heel ultrasound scan and the online survey. This is to allow for a broader scope of viewpoints from broader range of participants, typically from the university population and to increase the pool participants available for the focus group study.

The current restriction to participants is that they have previously participated in the main quantitative study. With ethical approval, verbal and written consent the study will be carried in the same manner as the original 16-35 age focus group. Additional participants may be recruited through word of mouth and through poster flyer advertisements and through the university media. This will allow others who have not already been involved in the bone health study to express their views and make them feel empowered by sharing their opinions and ideas about matters that may affect their bone health potential.

This Attachment A has been added to this protocol to record the additional changes to the study and to record the changes to participant information sheet/consent form, the addition of the poster flyer to advertise the recruitment of the participants.

Attachment B (PAF\_Form) is the formal application for the focus sub-study amendment to allow all participants aged 16 to 35 inclusively without restriction to be eligible for this focus group study.

## 10.9 Questionnaire

04/02/2018

Qualtrics Survey Software

### Introduction

#### **Sporting Physical Activity and Bone Health in New Zealand Adolescents and Young Adults Questionnaire**

My name is Hansa Patel (Survey Coordinator) and I am a Doctoral student in the Clinical Research programme in the School of Biological Sciences at Victoria University of Wellington (VUW).

This project focuses on osteoporosis, a skeletal disorder typified by decreased bone strength due to reduced bone quantity and quality with an increased risk of fragility fractures (often of the hip, wrist and spine). The aim of this study is to gain knowledge of the relationship between sporting physical activity and bone health in New Zealand adolescents and young adults.

This project has been approved by the VUW Human Ethics Committee (ref: # 023752).

Thank you for your interest in this project. Please read the information sheet before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to take part, thank you for considering my request.

Please complete this questionnaire accurately as possible. There is no right or wrong answer. All answers will be treated in the strictest of confidence and will only be viewed by the research team.

Thank you for your participation in this study on Bone Health and Sporting Physical Activity in the 11 to 35 (inclusive) age group.

If you have any queries about the questionnaire, please do not hesitate to contact the research team.

Contact Email: [hansa.patel@vuw.ac.nz](mailto:hansa.patel@vuw.ac.nz)



Q1. Are you willing to give written and verbal consent to participate in this study?

☐ Yes

☐ No

Q2. Please enter your name.

Q3. If you are a school student, please enter your assigned school identification code  
If you are not a school student, no entry is required as an unique  
ID: \${e://Field/ResponseID} will be generated. You may proceed to the next question.

These codes and IDs will be used to link your survey with your heel ultrasound  
results.

Q4. This survey is only for those aged 11 to 35 inclusive. What is your age?

Q5. Please enter your date of birth in the following format: DD/MM/YY.

Q6. What ethnicities do you identify yourself with? Please enter as many as you wish.

☐ New Zealand European

☐ English

☐ Australian

- ☐ Dutch
- ☐ Other European
- ☐ Māori
- ☐ Samoan
- ☐ Cook Islands Maori
- ☐ Tongan
- ☐ Niuean
- ☐ Tokelauan
- ☐ Fijian
- ☐ Other Pacific Peoples
- ☐ Filipino
- ☐ Chinese
- ☐ Indian
- ☐ Japanese
- ☐ Korean
- ☐ Cambodian
- ☐ Other Asian
- ☐ Middle Eastern
- ☐ Latin American
- ☐ African
- ☐ Other

### General Health

Q7. Please enter your height in centimetres. Round to the nearest centimetre.

Q8. Please enter your weight in kilograms. Round to the nearest kilogram.

Q9. Have you been diagnosed (by a doctor) for any of the following or had any longstanding illness, diseases or medical conditions for which you have sought treatment?

- ☐ No
- ☐ Coeliac disease
- ☐ Overactive thyroid gland
- ☐ Underactive thyroid gland
- ☐ Type 1 diabetes
- ☐ Asthma, bronchitis, emphysema, COPD requiring steroid
- ☐ Rheumatoid arthritis
- ☐ Cardio vascular disease (heart conditions)
- ☐ Kidney disease
- ☐ Eating disorder
- ☐ Osteoporosis
- ☐ Cancer
- ☐ Mental health conditions e.g. depression
- ☐ Other (such as sport injuries or back/joint pain, allergies, number of children, etc. or anything else that you would like to share), please list:

Q10. Please list any regular medicines used and how frequently you take them, e.g. contraception, eye drops, inhalers, hormone replacement therapy (HRT), paracetamol, aspirin.

Q11. Do you take Vitamin D supplements?

- ☐ Yes
- ☐ No
- ☐ Other

Q12. Do you take calcium supplements?

- ☐ Yes
- ☐ No
- ☐ Other

Q13. Do you take supplements other than Vitamin D and calcium?

- ☐ Yes, I take...
- ☐ No

Q14. Please explain why you take these other supplements.

## Puberty

Q15. What is your gender?

- ☐ Male
- ☐





Female



Other. If selected, please only fill out responses relevant to your experience.

Q16. How old were you when you started your periods?

Q17. Are you still having periods?



Yes



Sometimes, not regularly. Please explain briefly.



No, haven't started



No, periods have stopped due to an operation/hysterectomy, menopause, pregnancy or another health condition. Please explain briefly.

Q18.

Do you have issues due to your periods?



Yes, explain briefly



Sometimes, explain briefly



No

Q19. Have you ever taken any contraceptives like the "pill"?



Yes



No

Q20. What is the name of the contraceptive pill?

Q21. How old were you when you first took the pill?

Q22. How long have you taken the pill for (in years and months)?

Years

Months

Q23.

How old were you when you started showing facial hair?

### Lifestyle

Q24. Have you ever smoked?

☐ Yes

☐ No

Q25.

How old were you when started smoking?

Q26. How often do you smoke now?

- ☐ Never
- ☐ Sometimes, once or twice every six months
- ☐ Sometimes, once or twice every three months
- ☐ Sometimes, once or twice every month or so
- ☐ Once a week
- ☐ 2 - 3 times a week
- ☐ 4 - 6 times a week
- ☐ Daily

Q27. On an average day, when you do smoke, how many cigarettes (or their equivalents) do you smoke?

Q28. Have you ever consumed alcohol?

- ☐ Yes
- ☐ No

Q29. What age did you first consume an alcoholic drink?

Q30. How often do you have a drink containing alcohol now?

- ☐ Never
- ☐ Sometimes, once or twice every six months
- ☐ Sometimes, once or twice every three months

- ☐ Monthly or less
- ☐ 2 - 4 times a month
- ☐ 2 - 3 times a week
- ☐ 4 times or more a week

Q31. On average while drinking, how many standard units of alcohol (or equivalent measures) do you consume between Monday to Thursday (inclusive)?

Q32. On average while drinking, how many units of alcohol or equivalent measures do you consume between Friday to Sunday (inclusive)?

Q33. How often do you have six or more units of alcohol on one occasion?

- ☐ Never
- ☐ Less than monthly
- ☐ Monthly
- ☐ Weekly
- ☐ Daily or almost daily

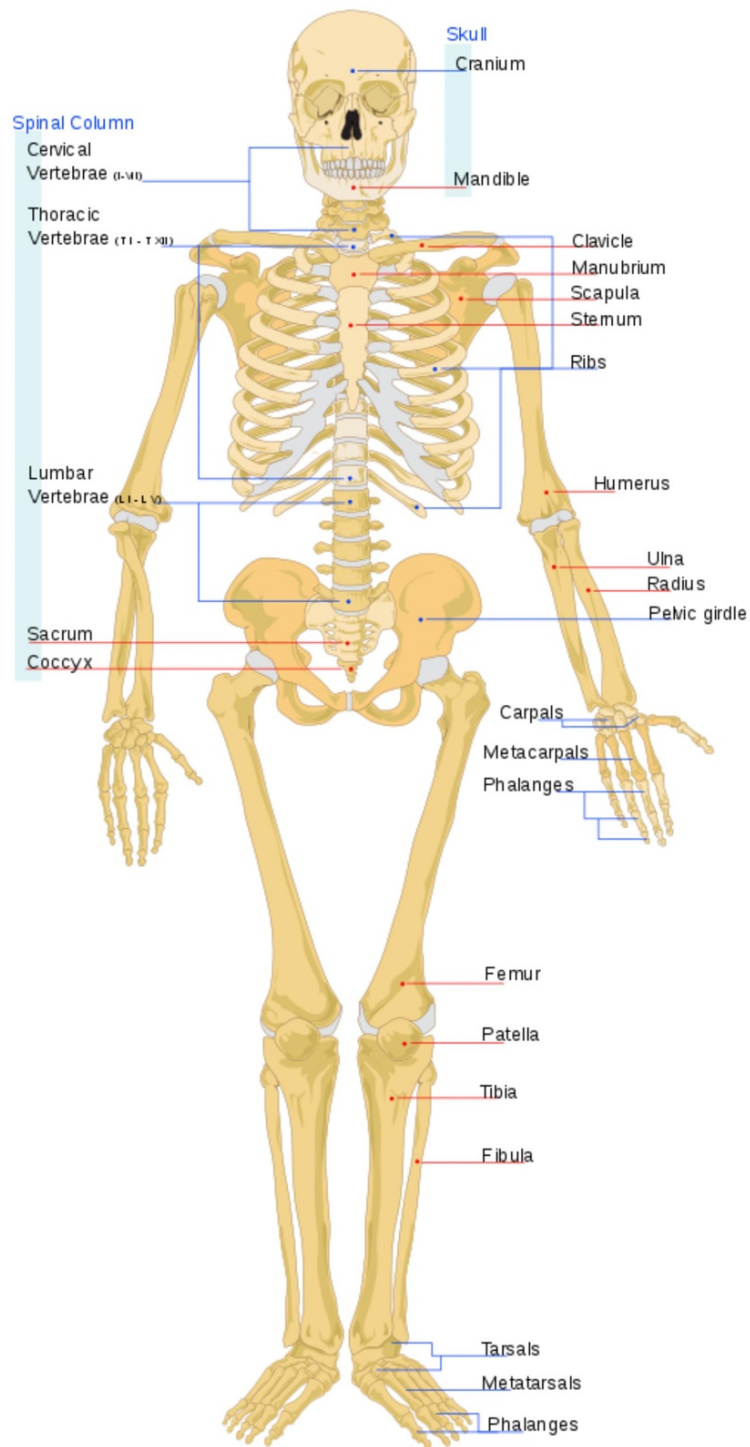
Q34. Do you drink any low alcohol beverages?

- ☐ Yes
- ☐ Sometimes
- ☐ No

**Broken Bones**

Q35. Have you ever had any broken bones? If so, please select the number of times you have broken any bone.

Q36. Please indicate on the diagram below by hovering and clicking with the mouse to indicate where you have broken your bone(s).



Q37. How old were you when broke your first bone?

Q38. Did you go to the doctor and/or hospital?

☐ Yes

☐ No

Q39. Who and where is your current General Practitioner (GP) if you have one?

Q40. Has a close relative (mother, father, brother, sister) ever broken their hip?

☐ Yes

☐ No

☐ Don't know

Q41. Approximately what age was your close relative when they broke their hip?

### Dietary Calcium

Q42. Do you have any special dietary requirements? (For example, if you are a vegetarian or have any food allergies or intolerances).

Q43. What type of milk or milk equivalent do you use?

Q44. Please think about your usual eating habits over the last year.

How much milk or milk equivalent do you use in an average day?

Think about milk usage in tea and coffee, breakfast cereals or desserts or in cooking and how much milk is in the fridge and how much you might use on an average day.

Give your answer in millilitres (mL).

1 teaspoon ~5mL

1 cup ~250mL

1 teacup ~175mL

1 mug ~350mL

Q45.

How often and how much do you consume the products that have been listed?

All liquids are measured in teacups.

Eg, 1 cup of raw leafy vegetables

1/2 cup of other vegetables

1/2 cup of vegetable juice

Eg, if you drink one coffee a day most days of the week, enter '1' in the 6-7 days per week column

	Not Consumed	Once a month	Once a fortnight	1 to 2 days per week	3 to 5 days per week	6 to 7 d per week
Tea	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
Coffee	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>



	Not Consumed	Once a month	Once a fortnight	1 to 2 days per week	3 to 5 days per week	6 to 7 d per week
Horlicks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bournvita	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ovaltine	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Hot or cold chocolate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Complan	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Milo	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Smoothies or milk shakes (made with milk/ice cream)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Milk	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other milk-based beverages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="text"/>						
Breakfast cereal	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single slice of bread	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single slice of cheese	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single slice of cake	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single scone	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single biscuit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
A single portion of a milk-based dessert, e.g. custard, ice cream, rice pudding	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Green vegetables	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### Physical and Leisure Activity Over the Last 7 Days (Kowalski 1999 PAQ-C)

Q46.

Over the last 7 days, how often have you participated in **sporting activities**, such as sport, dance or games that make your legs feel tired or breathe harder and how long was each session.

Please enter your answer **average session time in minutes**.

For example, if you have three aerobics classes a week that each last 60 minutes, enter the number "60" under the '3 times' column.

	None	1 time	2 times	3 times	4 times	5 times	6 times	7 times or more
Aerobics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Aikido	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Aqua aerobics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Athletics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Badminton	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ballet	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Baseball	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Basketball	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Biking	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bodybuilding	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bowls	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cheerleading	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cricket	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Croquet	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cross country	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cycling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dancing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diving (platform)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dragon Boating	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Equestrian	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Football	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gardening - Light	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gardening - Heavy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Golf	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gymnastics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

[illegible]

	None	1 time	2 times	3 times	4 times	5 times	6 times	7 times or more
StairMaster - gym equipment training	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Surfing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Swimming	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
T Ball	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Table Tennis	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tag	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tai Chi/yoga/Pilates	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ten Pin	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tennis	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Track	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tramping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Triathlon	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Underwater Polo	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Volleyball	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Walking for exercise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Waterskiing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Weight Lifting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Windsurfing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Yachting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ki-o-rahi (Maori ball game)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other <input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other <input type="text"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q47. Over the last 7 days, how often were you very active (doing activity that requires you to breathe harder than you usually would)?

- ☐ Never  
☐ Hardly ever  
☐ Sometimes

- ☐ Quite often
- ☐ Always

Q48. Over the last 7 days, what did you do for most of the time during **morning tea break**, other than eat?

- ☐ Sat down (talking, reading, studying, university/school activity – not physically active)
- ☐ Stood around or walked around
- ☐ Ran or played a little bit
- ☐ Ran around and played quite a bit
- ☐ Ran and played hard most of the time

Q49. Over the last 7 days, what did you do for most of the time at **lunch break**, other than eat?

- ☐ Sat down (talking, reading, studying, university/school activity – not physically active)
- ☐ Stood around or walked around
- ☐ Ran or played a little bit
- ☐ Ran around and played quite a bit
- ☐ Ran and played hard most of the time

Q50.

Over the last 7 days, how many days **straight after classes or work** did you participate in sport or physical activity that required you to breathe harder than you usually would?

Examples of these activities include: sports, dance, playing games, martial arts, sport practice that you were very active.

- ☐ None
- ☐ 1 time

- ☐ 2 - 3 times
- ☐ 4 - 5 times
- ☐ 6 or more times

Q51. Over the last 7 days, on how many evenings did you participate in sport or physical activity that required you to breathe harder than you usually would?

- ☐ None
- ☐ 1 time
- ☐ 2 - 3 times
- ☐ 4 - 5 times
- ☐ 6 or more times

Q52. Over the **last weekend**, how times did you do sports or physical activity? For example, sports, dance, playing games, martial arts, sports practice.

- ☐ None
- ☐ 1 time
- ☐ 2 - 3 times
- ☐ 4 - 5 times
- ☐ 6 or more times

Q53. Read the following five statements and choose the answer that best describes your physical activity over the last 7 days.

- ☐ I spend most of my free time doing very little physical activity
- ☐ Sometimes I spend my free time doing 1 - 2 sports
- ☐ I often spend my free time doing 3 - 4 sports
- ☐ Quite often I spend my free time doing 5 - 6 sports
- ☐ I regularly spend my free time doing 7 or more sports

Q54. Indicate how often you did physical activity (like playing sports, games, dance, or other physical activity) for each day last week.

	None	Little Bit	Medium	Often	Very Often
Monday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Tuesday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wednesday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thursday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Friday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Saturday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sunday	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Q55. Were you sick last week or did anything to stop from doing your normal physical activities? If yes, please specify.

- ☐ Yes
- ☐ No

### Sporting and Physical Activity

Q56. Why do you do any physical activity, sport or exercise? Tick as **many** that apply

- ☐ To keep healthy
- ☐ I'm good at it
- ☐ Fun
- ☐ I like competing
- ☐ I like winning
- ☐ To socialise with friends
- ☐ To pass the time
- ☐ I have to because of school/work and/or family
- ☐ Other

Q57.

In the last 7 days, how many times does **exercise or sporting activity** make you hot or breathe hard, or gets your heart rate up (e.g. rugby, soccer, running, swimming laps, fast bicycling)?

Q58.

How long did you do **small bursts** of any physical activity for each day on **average** over the last 7 days?

That is during, last 7 days, on how many days did you walk at a brisk pace – a brisk pace is a pace at which you are breathing harder than normal. This includes walking to work or school, while getting from place to place, at home and at any activities that you did solely for recreation, sport, exercise or leisure.

Q59. How many times in the last 7 days did you walk, bike etc. to **or** from school/university/work? (For example, walking to school and back is 2 times, walking once then by car is still 1 time **or** walking to and from school Monday to Friday is 10 times)

Q60. How long does it **usually** take for you to walk, bike etc. to or from school/university/work?

Q61. How many times over the last 7 days did you go to an exercise or PE class **during the day** (e.g. at university, school, club)?



Q62. How often do you take part in sport teams or clubs **outside** of regular working hours (**before or after school or university or during the weekend**)?

Q63.

What factors affect your ability to participate in sports teams or clubs? Tick as many that apply.

- ☐ Costs too much
- ☐ Not good enough at sport
- ☐ Find boring/not interested
- ☐ Takes too much time and effort
- ☐ Friends are not into sports
- ☐ Sports I like aren't available
- ☐ Can't get there
- ☐ Feel embarrassed, self conscious, shy
- ☐ Other responsibilities
- ☐ Parents wouldn't let me
- ☐ Don't have an opinion
- ☐ I don't know
- ☐ No sports facilities nearby
- ☐ Other

Q64. Leisure Activities: After school/university/work **and** in the weekend, how long (in minutes) do you spend on average doing these activities each day in your free time?

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Leisure activities	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

<https://vuw.ca1.qualtrics.com/ControlPanel/Ajax.php?action=GetSurveyPrintPreview> 22/29

Qualtrics Survey Software

Q65. During the past 7 days, how many days were you physically active? Add up all the time you spend any kind of physical activity that increases your heart rate and makes you breathe hard some of the time.

<https://vuw.ca1.qualtrics.com/ControlPanel/Ajax.php?action=GetSurveyPrintPreview>

292

	Total Number of Minutes
Day 3	<input type="text"/>
Day 4	<input type="text"/>
Day 5	<input type="text"/>
Day 6	<input type="text"/>
Day 7	<input type="text"/>

### Past Sporting Activity History

Q66. Since you were young please tick and list the eight most common Sporting Physical Activity (SPA) you did regularly.

- ☐ SPA 1
- ☐ SPA 2
- ☐ SPA 3
- ☐ SPA 4
- ☐ SPA 5
- ☐ SPA 6
- ☐ SPA 7
- ☐ SPA 8

Q67.

Please tick all the ages between 1 - 35 you participated in various Sporting and Physical Activities (SPA) that you inserted in the previous question.

	SPA 1	SPA 2	SPA 3	SPA 4	SPA 5	SPA 6	SPA 7	SPA 8
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	SPA 1	SPA 2	SPA 3	SPA 4	SPA 5	SPA 6	SPA 7	SPA 8
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
32	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
33	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
34	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
35	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### 12 month SPA summary

Q68.

Please complete this table for all regular Sporting Physical Activity (SPA) that were performed outdoors over the past 12 months.

This will help ascertain your levels of sun exposure during these outdoor activities.

	Frequency per month (number of sessions)	Average duration of each session (minutes)
January	<input type="text"/>	<input type="text"/>
February	<input type="text"/>	<input type="text"/>
March	<input type="text"/>	<input type="text"/>
April	<input type="text"/>	<input type="text"/>
May	<input type="text"/>	<input type="text"/>
June	<input type="text"/>	<input type="text"/>
July	<input type="text"/>	<input type="text"/>
August	<input type="text"/>	<input type="text"/>
September	<input type="text"/>	<input type="text"/>
October	<input type="text"/>	<input type="text"/>
November	<input type="text"/>	<input type="text"/>
December	<input type="text"/>	<input type="text"/>

Q69. In the summer months, do you usually use sun protection? Tick as many options as you need.

- ☐ Use a sunhat?
- ☐ Use sunglasses?
- ☐ Use sun protective clothing like long sleeved clothing and/or rash vest when swimming?
- ☐ Sunscreen?
- ☐ Stay in the shade where possible?
- ☐ Avoid the sun between 10am and 4pm if possible?
- ☐ Anything else you like to say about your sun behaviour?

### Future Studies

Q70. If you wish to help in any future studies in this study topic (subject to further ethical approval) please indicate this in the questionnaire by entering a valid email address, although you are under no obligation to help and are free to change your mind to help in the future. This email address will not be used for any other purpose.

☐ Yes

☐ No

☐ Have you any comments you wish to share about your bone health?

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## 10.10 Supplementary information

### 10.10.1 Interview guide questions:

**Main two research questions** (note: participants to lead the discussions).

1. What do adolescents and young adults understand about peak bone mass and risk of osteoporotic fracture?
2. What are the barriers that young people face in adopting lifestyles associated with better bone health and how should we try to reduce this?

<b>Questions about knowledge</b>				
What do you understand about Bone health?				
What factors do you think have negative or positive impact on your bone health?				
What food do you think effects bone health?				
What about smoking?				
What about alcohol?				
<b>Questions about behaviour</b>				
What are the lifestyle factors you would choose to keep your bones strong and healthy?				
What changes did you bring in your lifestyle with the knowledge you have about bone health?				
What prompts you to stay physically active?				
How important are physical activities to you in a day to day life?				
How do you think food affects your bone? What changes did you bring in your diet to have strong bones?				
How about dairy products consumption?				
What made you start smoking? What kept you going?				
Was there anything that stopped you from smoking for any reasons?				
How happy are you with how much you drink?				
Would alcohol affect bone health?				
Have you ever sought any medical care for bone pain/ fracture?				
Final questions (may relate to knowledge or behaviour but should come at the end of the focus groups because asking them may lead to providing knowledge to participants):				
Have you ever heard about Osteoporosis/PBM?				
How do you think your bone health relates to risk of fracture later in life?				

**Additional prompts if required:** for example, costs, accessibility, time transports issues, peer pressure etc.

- a) *sense of achievement;*
- b) *pleasure/fun*

- c) fitness;*
- d) pressure to perform for family, coach/manager, peers – e.g. a cultural norm to play rugby;*
- e) risk of injury;*
- f) education;*
- g) family responsibilities;*
- h) costs;*
- i) accessibility;*
- j) transport issues;*
- k) time factor of busy lifestyles;*
- l) social media;*
- m) religious and cultural beliefs, e.g. social barriers which restrict physical activity in girls at puberty, gender differences, wearing of special clothing e.g. hijab);*
- n) fear of risks, such as fear of falling or hurting themselves;*
- o) study commitments; and*
- p) peer group behaviour.*



### 10.10.2 Qualitative study trustworthiness criteria

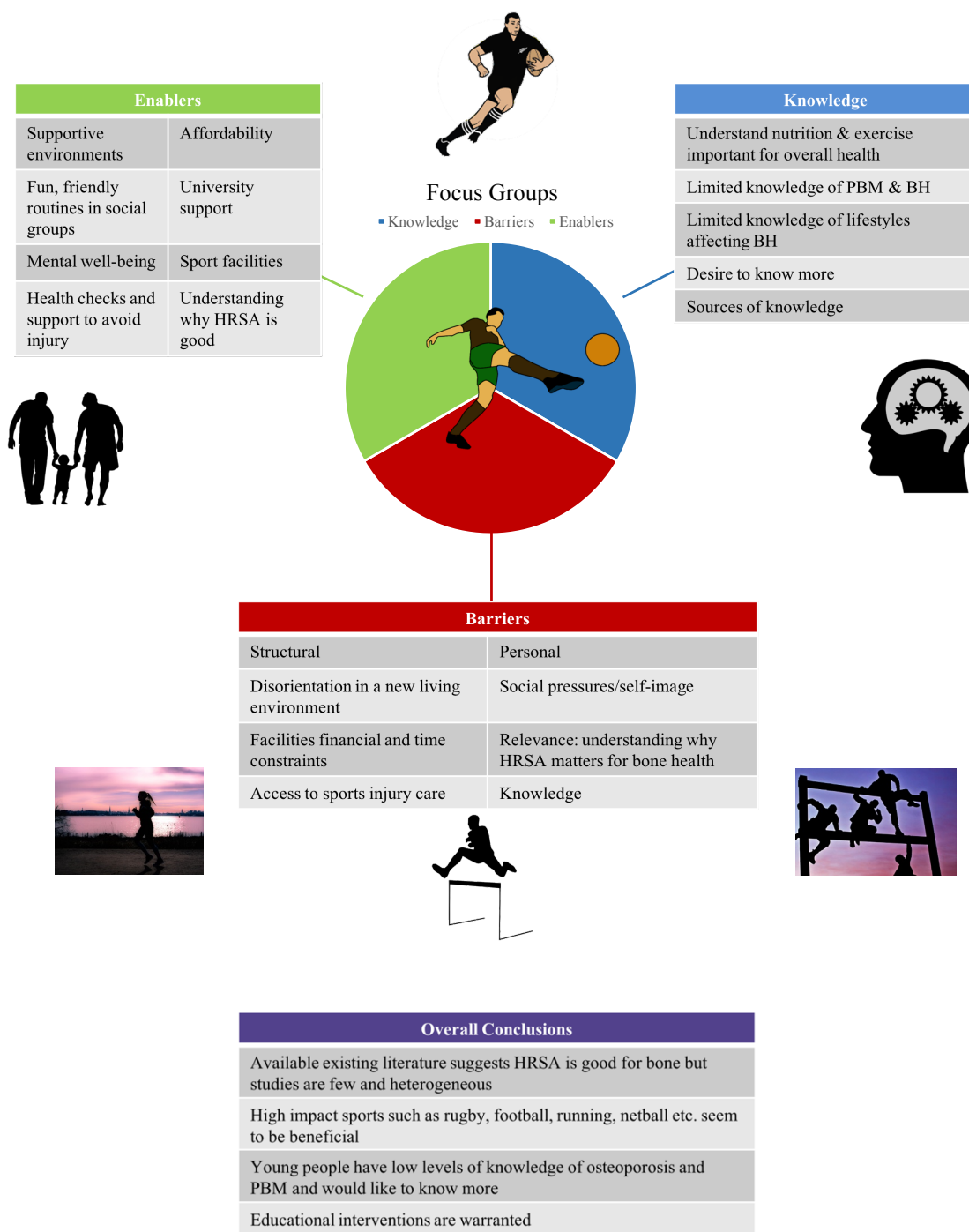
Trustworthiness summarised based on study by Loh et al. (2013).

Criteria	Techniques	Focus groups
1.Credibility (internal validity)	Prolonged engagement	Nine groups consecutively over three months
	Persistent observation	Different viewpoints from different backgrounds encouraged in a supportive environment
	Triangulation (sources, methods, investigators)	Quantitatively and qualitative sourced data, investigators recording on multiple devices & transcribing data, field notes, online questionnaire.
	Peer debriefing	Peer debriefing with investigators
	Negative case analysis	"negative case" a participant experiences differed from the main body of evidence e.g. she understood her family and community need motivation and guidance to be proactive at engaging in HRSA to better long term health including feeling stronger & healthier as her personal past sporting injuries encouraged herself and other family members to remain active.
	Referential adequacy (archiving of data)	All data stored in NVivo; initial data analysis for the knowledge and PBM topic & same data were developed for the finding on the topic of enablers & barriers HRSA for PBM acquisition.
	Member checks	Experienced team members
2.Transferability (external validity)	Thick description	Many viewpoints with engaged participants with field notes capturing non-verbal communication
3.Dependability (reliability)	Overlap methods (triangulation of methods)	Quantitative & qualitative sourced data
	Dependability audit (how data was collected; how data was kept; accuracy of data)	Peer reviewed research protocol NVivo, rechecked transcriptions, independent from transcribers.
4.Confirmability (objectivity)	Confirmability audit (findings, interpretations, supported by data)	Rechecked NVivo themes
All 4 criteria	Reflexive journal (about self & method)	Reflexive journal continuous comparisons & consensus; interpreted independently; debriefing sessions

### 10.10.3 Descriptive data for participants (n=920, aged 16 – 35 years)

Participant descriptive characteristic.	Female					Male					Total (Males and Females)				
	Mean	± SD	# Category	%	# Respondents	Mean	± SD	# Category	%	# Respondents	Mean	± SD	# Category	%	# Respondents
Age	21.07	4.32			629	23.09	4.34			291	21.71	4.42			920
European			441	70.1	629			188	64.6	291			629	68.4	920
Māori & Pacific people			85	13.5	629			28	9.6	291			113	12.3	920
Asian			55	8.7	629			26	8.9	291			81	8.8	920
Indian			29	4.6	629			36	12.4	291			65	7.1	920
Middle Eastern Latin America			9	1.4	629			7	2.4	291			16	1.7	920
African			10	1.6	629			6	2.1	291			16	1.7	920
Height (cm)	166.73	7.40			537	178.91	7.68			217	170.23	9.29			754
Weight (kg)	66.70	3.87			537	77.57	15.48			217	69.83	15.16			754
Self-reported BMI (kg/m <sup>2</sup> )	24.02	4.93			537	24.17	4.13			217	24.06	4.71			754
BUA	127.39	32.18			611	130.83	11.85			280	128.47	27.50			891
SOS	1607.19	38.74			611	1610.13	47.20			280	1608.12	41.58			891
SI	113.95	16.44			611	117.76	19.25			280	115.15	17.45			891
T-score	0.92	1.27			331										
Z-score	0.94	1.27			331										
OCP use (Yes)			291	65.2	446										
Pubertal timing (menarche/facial hair) (years)	12.72	1.48			426	14.75	2.31			193					
Never smoked			326	73.3	445			112	56.3	199			438	68	644
Have smoked			119	26.7	445			87	43.7	199			206	32	644
Cigarettes per day 0-1			44	58.7	75			30	50	60			74	54.8	135
Cigarettes per day 2-5			29	38.7	75			29	48.3	60			58	43	135
Cigarettes per day 6-10			2	2.7	75			1	1.7	60			3	2.2	135
Pack Years Smokers only	0.06	0.25			116	0.14	0.64			86	0.10	0.46			202
Yes, alcohol consumed			408	91.3	447			185	93	199			593	91.8	646
Age of starting of drinking (years)	15.39	2.38			398	15.20	3.19			183	15.33	2.66			581
Number of units for alcohol drinkers	4.53	3.44			395	6.11	4.78			180	5.02	3.97			575
Self-reported fracture			169	38.1	444			80	40.6	197			249	38.8	641
Age of first fracture (years)	10.18	5.21			168	11.96	5.40			79	10.75	5.33			247
Family fracture history (Y/N)			11	2.5	434			10	5.1	195			21	3.34	629
Dietary calcium daily (mg)	623.94	611.53			437	698.78	584.30			193	646.83	603.84			630
Modified Kowalski PA mean score	1.9878	0.56			441	2.08	0.54			190	2.02	0.56			631
Time spent in high impact weight-bearing activity each week (min)	117.39	229.60			419	117.09	216.10			182	117.30	225.43			601
Time spent in high impact weight-bearing-activity & weight-bearing activity each week (min)	468.85	467.95			419	422.20	603.89			182	454.73	512.86			601
Time spent in all activity each week (min)	494.84	479.60			419	478.05	728.85			182	489.76	566.20			601
Time spent in non-weight bearing activity each week (min)	25.99	71.70			419	55.90	181.70			182	35.03	117.19			601
Past BPAQ modified	31.54	30.68			359	38.58	25.96			158	30.62	29.32			517

## 10.11 Overall diagrammatic findings of the study





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