Determining Risk of Hip Fracture in Older Adults with Complex Needs in New Zealand: a national population time-to-event study

Rebecca Katherine Abey-Nesbit

A thesis submitted for the degree of

Doctor of Philosophy

at the University of Otago, Christchurch,

New Zealand

20 December 2019

Abstract

Hip fractures are one of the most common and debilitating injuries in older adults. Older adults who sustain a hip fracture are more likely to have increased mortality and morbidity with reduced quality of life. This, combined with slow recovery times, can lead to a need for entry to aged care facilities.

Considerable work has been undertaken to investigate risk factors for hip fracture in the wider clinical research. This study built on that work and aims to identify risk factors for hip fracture in older adults with complex needs in the New Zealand context, based on questions from the interRAI home care (interRAI-HC) assessment. The interRAI-HC assessment is a standardised comprehensive clinical assessment typically given to people aged 65 years and older to assess areas of need that each person has. From the determined risk factors, a hip fracture risk score was developed to identify individuals who are more likely to sustain a hip fracture in the two years following their assessment.

Two sets of interRAI-HC data were used in this study. The initial dataset (September 2012 to June 2015) was randomly split into two datasets. Two-thirds of the data was used to explore risk factors for hip fracture and to develop a risk score. A competing risk regression was used to determine which variables were significantly associated with hip fracture and were to be included in the hip fracture risk scores. The remaining one-third of the initial dataset was used to perform cross-validation of the developed scores, evaluating how well the scores predicted hip fracture events not used in the creation of the scores. Separate scores for males and females were created due to their different risk profiles. The predictive power of each score was assessed using Receiver Operator Characteristic (ROC) curves and their associated area under the curve (AUC) at various candidate thresholds. The scores developed were further validated with the second, more recent, set of interRAI-HC assessments (November 2015 to June 2018).

Factors associated with hip fracture for the whole interRAI-HC assessment cohort were age, sex, ethnicity, falls, mental function varies, wandering, body mass index (BMI), tobacco use, Parkinson's disease, and dyspnoea (shortness of breath). For males, the risk factors associated with hip fracture were age, Parkinson's disease, and dyspnoea. For females, the factors associated with hip fracture were age, ethnicity, wandering, BMI, tobacco use, and dyspnoea. The male's score had an AUC of 0.586 (95% CI: 0.548 to 0.625), and the female's score had an AUC of 0.615 (95% CI: 0.593 to 0.637). When retesting using the more recent dataset, the

male's score had an AUC of 0.611 (95% CI: 0.594 to 0.629) and the female's score had an AUC of 0.624 (95% CI: 0.612 to 0.636).

The scores developed here were modestly predictive of hip fracture risk for a New Zealand interRAI-HC cohort. The results of this thesis provide a good foundation for the development of a more sensitive and specific hip fracture prediction model. With further development, the score could have clinical use for individuals who complete interRAI-HC assessments.

Acknowledgements (Preface)

Prior to beginning full time PhD study with the Department of Medicine in June 2016, I studied a Bachelor of Science majoring in statistics and philosophy. I completed a year of honours research in philosophy before pursuing a master's degree in statistics. After I completed my master's degree, I began working with the Canterbury District Health Board as a data analyst before joining two National Science Challenge Projects exploring clinical data. I had never analysed clinical data before, and I was interested in learning more about clinical data analysis techniques. I was also interested in leading my own projects in the future.

The work presented in this thesis shows how I undertook the literature review to identify a gap in the literature, chose the method of analysis, spent time preparing the datasets for analysis, analysing the data, and presenting the results. As I am not a clinician, I received advice from my supervisors on the clinical interpretation of my results. There are many other people who also offered advice, whether it be on the clinical interpretation of results, or how to maintain motivation, or how to create specific graphs in R, I would like to thank each one of them.

I would like to thank my supervisors who have all provided me with incredible support and feedback. Firstly, Dr Hamish Jamieson for offering me the opportunity to do a PhD in the first place, and for his valuable feedback on all things clinical, particularly around the interRAI itself. Thank you to Professor Tim Wilkinson who provided clinical feedback and helped me with the structure and formatting of the thesis. Professor Philip Schluter has given me excellent feedback on the statistical aspects of this thesis and helped immensely with polishing the manuscript.

I would also like to thank Dr John Thwaites for all his help and clinical knowledge around risk factors for hip fracture. Additionally, thank you to Dr Sarah Berry from Harvard University whose initial research was the inspiration for this thesis, and who provided me with excellent clinical feedback and knowledge during my PhD thesis.

I would also like to thank my Burwood colleagues for listening to my ideas and offering different insights into various problems. Specifically, Debra Morgan for all her help with database searches, Associate Professor John Pickering who helped me to create excellent graphs in R, and Ulrich Bergler and Dr Susan Gee for their motivational encouragement.

I would also like to acknowledge the interRAI assessors across New Zealand, without whom there would be no interRAI data for me to have completed this thesis. Your work is greatly

appreciated. I was fortunate enough to take part in a two-day interRAI-HC computer training programme where I learned how the assessments were conducted, and how the information collected was input into the computer. This training course was incredibly valuable, and it gave me a deeper understating of the interRAI assessment process.

Thank you to New Zealand's Technical Advisory Services for providing the interRAI assessment data and to the Ministry of Health for providing the hospital admissions and mortality datasets. I know that processing large datasets for distribution is a large and challenging task, so I thank you for your hard work in putting together and providing the data.

Finally, I would like to thank my family for all their love and support. Thank you, Mum, Dad, Sascha, Danielle, and Keira for believing in me and being my personal cheerleaders. And of course, a big thank you to my husband Richard, for being incredibly supportive through this entire journey. It would definitely have been a lot harder to accomplish this without you.

List of Abbreviations

ACC	Accident Compensation Corporation
ADL	Activities of Daily Living
ANZHFR	Australian and New Zealand Hip Fracture Registry
ANZSSFR	Australia and New Zealand Society for Sarcopenia and Frailty Research
ARC	Aged Residential Care
AUC	Area Under the Curve
BMD	Bone Mineral Density
BMI	Body Mass Index
CARE	Collaboration of Research Excellence
CART	Classification and Regression Trees
CHESS	Changes in Health, End-Stage Disease, Signs, and Symptoms Scale
CI	Confidence Interval
CIF	Cumulative Incidence Function
COP	Cut-off Point
COPD	Chronic Obstructive Pulmonary Disease
CPS	Cognitive Performance Scale
DF	Degrees of Freedom
DHB	District Health Board
FRAiL	Fracture Risk Assessment in Long term care
FRAMO	Fracture and Mortality
FRAX	Fracture Risk Assessment Tool
FRISC	Fracture and Immobilisation Score
FRT	Fall Risk Tool
GP	General Practitioner

HC	Home care
HDEC	Health and Disability Ethics Committee
HQSC	Health Quality and Safety Commission New Zealand
HR	Hazard Ratio
HRT	Hormone Replacement Therapy
ICD	International Classification of Diseases and Related Health Problems
ICD-10 AM	International Statistical Classification of Diseases, Tenth Revision, Australian Modification
interRAI	International Residential Assessment Information
IQR	Interquartile Range
LTCF	Long-term care Facility
MDS	Minimum Dataset
MET	Metabolic Equivalent Task
MoH	Ministry of Health
MS	Multiple Sclerosis
N/A	Not Applicable
NHI	National Health Index
NHLBI	National Heart, Lung, and Blood Institute
NICE	National Institute for Health Excellence
NMDS	National Minimum Dataset
NPV	Negative Predictive Value
NZ	New Zealand
NZAG	New Zealand Association of Gerontology
NZGG	New Zealand Guidelines Group
PPV	Positive Predictive Value

PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QoL	Quality of Life
RECORD	Reporting of studies Conducted using Observational Routinely collected health Data
ROC	Receiver Operator Characteristics
SFRS	Scott Fall Risk Screen
SHR	Subhazard Ratio
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
TAS	Technical Advisory Services
THIN	The Health Improvement Network
WHI	Women's Health Initiative
WHO	World Health Organization
UK	United Kingdom
US	United States

Table of Contents

List of Tables

List of Figures

Publications Arising From This Thesis

Conference Oral Presentations

Keeling, S, **Abey, R**, Keelan, K, & Macfarlane, J. Developing research capabilities. 16 September 2016. New Zealand Association of Gerontology (NZAG) Conference. Wellington, New Zealand.

Abey-Nesbit R. Risk factors for hip fractures in older people within the community. 2 May 2017. Collaboration of Research Excellence (CARE) student symposium for higher degree students conducting research in the field of ageing.

Abey-Nesbit, R. Risk factors for hip fractures in older people within the community. 15 March 2018. Burwood Academy of Independent Living Peer Group. Christchurch, New Zealand.

Abey-Nesbit R, Schluter PJ, Wilkinson T, Thwaites JH, Jamieson HA. Nutritional risk factors for hip fracture among older adults with complex needs. 7 September 2018. NZAG Conference. Auckland, New Zealand.

Abey-Nesbit R. Determining risk of hip fracture in older adults with complex needs. 10 November 2018. inSPIRe interRAI workshop. Brisbane, Australia.

Abey-Nesbit R, Schluter PJ, Wilkinson T, Thwaites JH, Berry SD, Jamieson HA. Identifying risk of hip fracture within community-dwelling older people. 24 November 2018. Australia and New Zealand Society for Sarcopenia and Frailty Research (ANZSSFR) Annual Meeting. Dunedin, New Zealand.

Publications co-authored related to interRAI while working on this thesis:

Jamieson H, **Abey-Nesbit R**, Bergler U, Keeling S, Schluter PJ, Scrase R, Lacey C. Evaluating the influence of social factors on aged residential care admission in a national home care assessment database of older adults. J Am Med Dir Assoc. Epub 2019. DOI: 10.1016/j.jamda.2019.02.005.

Burn R, Hubbard RE, Scrase RJ, **Abey-Nesbit RK**, Peel NM, Schluter PJ, Jamieson HA. A frailty index derived from a standardized comprehensive geriatric assessment predicts mortality and aged residential care admission. BMC Geriatr. 2018;18(1):319. DOI: 10.1186/s12877-018-1016-8.

Jamieson HA, Nishtala PS, Scrase R, Deely JM, **Abey-Nesbit R**, Hilmer SN, Abernethy DR, Berry SD, Mor V, Lacey CJ, Schluter PJ. Drug burden index and its association with hip fracture among older adults: a national population-based study. J Gerontol A Biol Sci Med Sci. 2018;74(7):1127-1133. DOI: 10.1093/gerona/gly176.

Jamieson HA, Gibson HM, **Abey-Nesbit R**, Ahuriri-Driscoll A, Keeling S, Schluter PJ. Profile of ethnicity, living arrangements and loneliness amongst older adults in Aotearoa New Zealand: A national cross-sectional study. Australas J Ageing. 2018;37(1):68-73. DOI: doi.org/10.1111/ajag.12496.

Jamieson HA, Nishtala PS, Scrase R, Deely JM, **Abey-Nesbit R**, Connolly MJ, Hilmer SN, Abernethy DR, Schluter PJ. Drug burden and its association with falls among older adults in New Zealand: a national population cross-sectional study. Drugs Aging. 2018;35(1):73-81. DOI: 10.1007/s40266-017-0511-5.

Jamieson HA, Schluter PJ, Pyun J, Arnold T, Scrase R, **Abey-Nesbit R**, Mor V, Deely JM, Gray L. Fecal incontinence is associated with mortality among older adults with complex needs: an observational cohort study. Am J Gastroenterol. 2017;112(9):1431. DOI: 10.1038/ajg.2017.200.

1 Introduction

The world population is ageing including that of New Zealand (1, 2), and with this comes higher numbers of age-related illnesses and injuries. With the rise in these age-related conditions, health delivery services and hospital beds are under increasing pressures and demands. In response, international organisations, such as the World Health Organization (WHO), and government agencies, such as the New Zealand Ministry of Health (MoH), have instigated and re-developed policies to better manage older people's health. A key strategy in countering these pressures and demands is around prevention.

Hip fractures are one of the most common and debilitating injuries in older adults, and can lead to premature death, disability and length recovery.

This thesis will focus on hip fractures in older people, and seeks to develop a score utilising data from a standardised comprehensive geriatric assessment tool to predict and, hopefully when implemented, reduce the associated mortality and morbidity. This introduction chapter gives an overview of hip fractures, including typical care and treatment for hip fractures in New Zealand. The second section of this chapter provides more detail on the phenomenon of ageing populations in New Zealand and the world, and the third section explores different policies about ageing and how this thesis fits within those policy aims. The fourth section details current methods of hip fracture prevention. The fifth section gives an overview of interRAI and how it used in healthcare in New Zealand and around the world. The sixth section discusses the aims and objectives of this thesis, and the seventh section then provides a brief description of each chapter of the thesis.

1.1 Hip Fractures

A hip fracture is defined as a break in the upper section of the femur. There are two types of hip fractures; intrascapular (cervical hip) fractures, and extracapsular (trochanteric) fractures (3, 4). Hip fractures are classed as osteoporotic fractures when they are caused by low bone mineral density (BMD). Osteoporotic fractures also commonly occur in the vertebra, wrist, humerus, rib, pelvis, clavicle, scapula, sternum, and tibia and fibula (3, 5).

1.1.1 Types of Hip Fracture

Clinical classification of hip fractures in New Zealand uses the International Statistical Classification of Diseases, Tenth Revision, Australian Modification (ICD-10 AM) classifications in the S72 range of specification. Table 1 lists the ICD codes and the area of fracture they represent.

Table 1 ICD-10 AM classifications for hip fracture

Area of fracture	**ICD Code**
S72.0	Fracture of head and neck of femur
S72.1	Pertrochanteric fracture
S72.2	Subtrochanteric fracture of femur
S72.3	Fracture of shaft of femur
S72.4	Fracture of lower end of femur
S72.8	Other fracture of femur
S72.9	Unspecified fracture of femur

1.1.2 Burden of Hip Fracture

Hip fractures are a debilitating injury and one of the most common injuries in older adults, particularly in those aged 80 years and older (6). Older adults who sustain a hip fracture are likely to have a reduced quality of life (QoL) after recovery. Approximately 50% of those who have a hip fracture will regain the ability to walk unaided, but with many of these people not regaining full mobility (7). Additionally, approximately 60% of people who have a hip fracture will require ongoing help with activities of daily living (ADLs) such as bathing, dressing, or toileting (8, 9).

Hip fractures have been linked to higher rates of mortality and higher rates of entry into aged residential care (ARC) facilities (10-12). In New Zealand it has been estimated that approximately 25% of adults aged 65 years and older who have hip fractures will enter ARC facilities, while another 25% will die prematurely (7). Hip fractures are rarely the single cause of premature death, but a combination of the hip fracture, age, sex, and co-morbidities have been found to be significantly associated with mortality (13). Walker *et al.* found that men had a higher rate of mortality after fracture than women, and individuals aged 85 years and older had higher rates of mortality after

fracture than those aged between 60 and 64 years (12). They also found that between 1988 and 1992 there was an 8% rate of death within 35 days of fracture, and 24% within one year of sustaining a hip fracture (12).

Additionally, studies have found that individuals who sustain a hip fracture are at an increased risk of sustaining a second subsequent fracture, compared to those who have not had a hip fracture (14, 15). A recent Australian study found that one in eleven individuals who had a hip fracture would have a second subsequent fracture (16).

There is also a high financial burden associated with hip fracture. For example, in the United States of America (US), hip fractures accounted for 14% of all fractures in 2005, but represented 72% of the total fracture related costs (17, 18). In 2016, there were 3,750 people admitted to hospital in New Zealand for a hip fracture arising from a fall, which cost the health system approximately $171 million (19, 20). A typical hip fracture that requires a stay in hospital of up to three weeks costs approximately $47,000 in 2019. If there are complications arising from the hip fracture which lead to the individual being released to an ARC facility after their hospital stay, the associated costs are closer to $135,000 (9).

1.1.3 Treatment and Care of Hip Fractures in New Zealand

New Zealand has District Health Boards (DHB) who are responsible for providing health care services in specific areas of the country. DHBs are organisations responsible for providing health and disability support within a specific geographic area of New Zealand. There are currently 20 DHBs in New Zealand (21) and some of them may have slightly different treatment plans for hip fracture. The New Zealand MoH has a set of guidelines outlining the standard process for hip fracture treatment. The MoH is the government advisory department that provides health information, and plans and funds public health services. The MoH also provides guidelines and monitors each of the DHBs but the DHBs can still differ in their treatment practices within those guidelines (22). Further, people admitted to hospital with a hip fracture have differing levels of fitness so their treatment plans may differ even when treated within the same DHB.

When a person has a hip fracture in New Zealand, they are typically admitted to the emergency department of a hospital. In the normal course of events, the hospital staff will work with the patient to determine what is wrong and the best course of treatment based on their findings. X-rays of the hip are performed and hospital staff may also test

the patient's blood and perform chest X-rays to check for any heart or lung problems that may affect decisions made about surgery. While these tests are being undertaken, a patient will be given painkillers, or other medications, if needed. Depending on the severity of the fracture, some patients will go straight to surgery from the emergency department, and others will be transferred to an orthopaedic ward. In the orthopaedic ward a full medical assessment will be done to determine the patient's health and how fit they are for surgery (23). Before surgery the patient will meet with an anaesthetist and surgeon to discuss any details about the operation. There will also be a nursing team who will perform checks to assess the patient's comfort, blood pressure, body temperature, and heart rate. The anaesthetist will then administer anaesthetic, and the surgery will be performed. After the surgery, the patient will be transferred to a recovery room where their condition will be assessed to ensure the patient is not suffering any ill effects from the surgery. When the patient is doing well, they are transferred to a hip fracture or orthopaedic ward. After the patient is returned to the ward post-surgery, the recovery and rehabilitation stages begin. Patients typically spend a few days or weeks in hospital for rehabilitation to regain strength. A team of specialists such as nurses, physiotherapists, occupational therapists, and social workers work with the patient to tailor a recovery plan. Part of the recovery plan will involve determining whether the patient requires extra help at home such as specialised equipment to reduce falls, further medical checks, or access to community-based exercise classes (23).

To ensure that a high standard of care is provided to anyone suffering a hip fracture, the Australian and New Zealand Hip Fracture Registry (ANZHFR) audits a number of hospitals in Australia and New Zealand using both patient level and hospital level data to assess seven focus areas to ensure a high quality of hip fracture care in hospitals (24). As part of its annual audit, in 2018 the ANZHFR gathered information on hip fracture treatment from 56 hospitals, 15 of which were in New Zealand. A total of 9,408 records on individual hip fractures (2,291 from New Zealand, 7,117 from Australia) were used for this report. Patients whose data were used for the audit were limited to individuals over 50 years of age who had fractured their hip from a minimal trauma injury (e.g., from a fall), and underwent management (either surgical or non-surgical) of the hip fracture (25).

According to the audit, approximately 50% of hospitals in New Zealand document performing a pain assessment within 30 minutes of presenting to the emergency department, and 38% of patients are receiving painkillers within the first 30 minutes of arriving or while travelling to hospital. The rate of pain management using nerve blocks has been improving in New Zealand hospitals, with 61% of hip fracture patients in 2018 receiving nerve blocks compared with 58% in 2017 and 51% in 2016. In New Zealand, 24% of patients are assessed by a geriatrician before their surgery. Approximately, 80% of patients undergo surgery within the first 48 hours of them presenting to hospital. In the cases where patients had to transfer from one hospital to another for the surgery, the average time to surgery was 54 hours. The average length of stay in the emergency department was 5 hours. The day after surgery, 87% of patients are given the opportunity to mobilise and 93% of patients have unrestricted weight-bearing immediately after surgery. Approximately 80% of patients were followed up 120 days after presentation to hospital, and of those who were followed up, 23% stated they had returned to their pre-fracture level of mobility. Approximately 74% of hip fracture patients in New Zealand underwent a falls-risk assessment during their hospital stay. Bone protection medication was prescribed to 25% of New Zealand hip fracture patients when they were discharged from hospital. Among New Zealand hip fracture patients who had a 120-day follow up, 38% were still taking bone protection medication (25).

1.1.4 Incidence of Hip Fracture

1.1.4.1 Worldwide

Hip fracture incidence rates vary worldwide. A systematic review by Kanis *et al.* grouped countries into three categories of risk: high, moderate, and low incidence (26). The categories were based on the rates of fracture per 100,000 people/year. High incidence of fracture was defined as >300 in women, or >150, or >250 for both men and women. Regions with a high incidence of fracture included Northern, South Western, and Central Europe, countries in the Middle East, and some Asian countries such as Singapore, Japan, and Korea. Moderate instance was defined as 200-300 in women, 100-150 in men, or 150-250 in men and women. Moderate risk regions included Australia, New Zealand, China, Argentina, India, and North America. Low instances were <200 in women, <100, or <150 in both men and women. Low-risk regions included South East Asia, Latin America, and Africa (26). A study conducted

in the United Kingdom based on general practice data estimated that the lifetime risk of a female sustaining a hip fracture is 11.4% and for a male it is 3.1% (27).

1.1.4.2 New Zealand

Langley *et al.* identified hip fracture incidence rates in New Zealand for individuals aged 50 years and over from 1974 to 2007. After adjusting for age, , the incidence rate per 100,000 people/year was estimated to be approximately 100 for men in 1974, increasing to 150 in 2007. Compared to males, females had a higher incidence of 400 in 1974; this rate increased to 490 in 1987 but declined thereafter to 370 in 2007 (28).

The Langley study compared incidence rates across 5-year age groups by examining the rate ratio relative to a 50-54-year-old baseline group (28). (28). For males, the rate ratio increased with increasing age to a maximum rate ratio of 12 for the 95-99-year-old age group. There were similar trends among females, with the maximum rate ratio of 10 observed for the 90-94-year-old age group (28). An earlier study on hip fracture risk among older people found that for both men and women, once they reached 90 years of age, their hip fracture risk did not increase with further ageing (29). Following from these results, Langley *et al*. estimated the incidence rates of hip fractures in 2025 among those aged 65 years and older. They used two different approaches to estimate hip fracture trends, to allow for two different possible ways the trends could continue into the future. The first scenario assumed a constant rate of hip fracture incidence from 2003 to 2025, and the second scenario, used the observed trend and assumed it would continue to 2025. The total number of hip fractures for males in 2007 was 799 and for females it was 2,250. This first scenario predicted an overall decrease in the annual number of hip fractures with an estimate of 649 fractures for males, and 1,232 hip fractures in females for the year 2025. The second scenario predicted an increase in the total number of hip fractures with an estimate of 2,439 hip fractures in males, and 4,395 estimated hip fractures in males, for the year 2025 (28).

A paper published in 1995 reported on the hip fracture incidence rates in Māori (New Zealand's indigenous ethnic group) and non-Māori people aged 60 years and older (30). Their results found that non-Māori females had the highest rate of hip fractures (827 per 100,000 people from 1989-1991), and Māori males had the lowest rate of hip fracture (197 per 100,000 people from 1989-1991) (30). When comparing the rates from 1989-1991 to previous hip fracture incidence rates from 1973-1975, Barber *et al.*

noted there was no significant increase in hip fracture rates for Māori male, but there were significant increases for non-Māori males, Māori females, and non-Māori females (30). Table 2 below, shows a comparison of the hip fracture rates for each group.

Table 2 Age standardised rates of hip fracture per 100,000 of population comparison by years

	Hip fracture rates 1973-1975 (95% CI)	**Hip fracture rates 1989-1991 (95% CI)**
Māori Male	149 (89-208)	197 (117-243)
Non-Māori Male	162 (151-173)	288 (269-295)
Māori Female	239 (147-331)	516 (355-566)
Non-Māori Female	493 (476-510)	827 (795-832)

Health Quality and Safety Care New Zealand (HQSC) collects data on falls in people aged 50 years and older (20). The data can be used to identify anyone who had a hip fracture due to a fall. The data comes from hospital inpatient and outpatient collections, the Accident Compensation Corporation (ACC), DHB shared services, and the Pharmaceutical Collection. (ACC is a New Zealand organisation which provides financial support to anyone who has suffered an accidental injury in New Zealand. The Pharmaceutical Collection is a data warehouse that contains the claim and payments information for subsidised dispensing.) The latest report was from 2016 and identifies a total of 3,750 people who were admitted to hospital for a hip fracture in that year with an average rate of 2.4 fractures per 1,000 people/year. Hip fracture rates increased with age, with 49% of fractures occurring in people aged 85 years and older (20). They found that women had higher rates of hip fracture than men, but these figures were not age adjusted. Māori are New Zealand's indigenous people and represent 16.5% of the population, and they often have differing outcomes and corresponding healthcare needs in many areas of healthcare. People who identified as European/Other ethnicity had a higher rate of hip fracture (2.8 per 1,000 people) than people who identified as one of the other three ethnicity groups specified in the study: Māori, Pacific people, and Asian (all with a rate of 0.8 per 1,000 people). The HQSC report also stated that hip fracture rates have not significantly changed since 2011 but no figures were given (20).

The ANZHFR 2018 audit across 15 different hospitals in New Zealand from 1 January 2017 to 31 December 2017 identified 2,291 people who had a hip fracture. Of those

2,291 people, 70% were female and the average age of patients was 84 years. Most hip fracture patients identified as European ethnicity (approximately 80%) with 3.6% of individuals identifying as Māori and Pacific people. Most people were living at home (72%) at the time of sustaining their hip fracture and 39% of people were identified as having dementia or impaired cognition (25).

There appears to be an increase in the absolute hip fracture incidence around the world, including in New Zealand, when not standardising for age. One possible reason for this increase in hip fracture incidence could be that people are living longer - with an increasing number of older adults, there would be an expected increase in the rate of hip fracture.

1.2 Ageing Population

The world's population is ageing (31, 32). In lower income countries, this is primarily due to lower rates of mortality in younger people, while in higher income countries, this is predominantly due to lower rates of mortality in older people (31). The ageing population has led to older adults (people aged 65 years and older) being the fastest growing age group around the world (31). It is estimated that from 2015 to 2050, the world population of people aged 60 years and older is expected to rise from 901 million to 2.1 billion (32). Additionally, the global population of people over 80 years old is expected to increase from 125 million in 2015 to 434 million in 2050. With an ageing population, there is an associated increase in risk of illnesses and greater health care requirements. The incidence of hip fracture is increasing, which leads to more people requiring health care services to treat hip fractures. Increased focus on health care now could help implement preventive measures to ensure that those who are living longer are doing so as healthy individuals. The WHO recognises the need for a greater focus on ensuring older people are not just living longer, but are living good and healthy lives (31, 33).

New Zealand's population is no exception to the global trend and is also ageing. This nation had 700,000 people aged 65 years and older in 2016; a number that is estimated to increase to around 1.32 to 1.42 million by 2043 (34). The population of those aged 85 years and older is expected to increase from 83,000 in 2016 to between 239,000 and 284,000 in 2043 (34).

These projected increases will have a major impact on the health care system as current service delivery is predicted to be unsustainable in the long-term if nothing is done. A change in delivery will be required to account for an increase in older people's health services (35). With this change in health service delivery, there may be an increase in the cost of health care; however it has been noted that if preventive measures can be implemented in time, population ageing may not lead to significantly higher expenditure (36). Different organisations around the world have developed health policies to work towards better health care plans suited for an ageing population; section 1.3 below outlines some of the policies developed. The New Zealand government have also had several agencies developing policies to ensure that older person's health is a top priority (37-39). It is important to understand the biomedical, social, and any other issues that may arise due to an ageing population so that they may be treated, and older adults can have a high QoL as they age.

1.3 Policies and Health Care Services Relating to Ageing and Hip Fractures

1.3.1 World Health Organization Ageing Strategy

In response to the ageing population and the need for changes to the current health care service delivery models, in 2016 the World Health Assembly adopted a global strategy and action plan to ensure that adults were not only living longer, but they were also living healthier lives (31, 33). The action plan has five strategic objectives. The first objective is to take action to promote healthy ageing in every country. This involves a plan to establish national frameworks, strengthen the capacities of countries to develop evidence-based policies, and to combat ageism by providing better understanding about ageing. The second objective is to develop age-friendly environments. This includes encouraging older adults to have the freedom to make their own decisions and engage more with the community and promoting action across multiple sectors to ensure an age friendly environment at all levels. The third objective is to align health systems to the needs of the older people by developing health systems for capacity and functional ability, providing access to affordable age specific clinical care, and ensuring all health professionals are trained and educated on older people's health. The fourth objective is to develop sustainable and equitable systems for long-term care, by constantly improving a long-term care system, establishing a strong workforce and supported

caregivers, and to ensure a high quality of person-centred long-term care. The final objective is to improve measurement, monitoring, and research on health ageing by having a consistent way of measuring, analysing, describing, and monitoring healthy ageing, strengthening research capacities and encouraging innovative research, and producing research around healthy ageing (33).

1.3.2 New Zealand's Ageing Strategy

New Zealand is a signatory to the WHO Global Health and Ageing Strategy and has developed policies on healthy ageing in alignment with WHO's guidelines. The MoH developed the Healthy Ageing Strategy to ensure that older people will live long, healthy lives and receive appropriate end-of-life care (39). The Healthy Ageing Strategy is informed by other health strategies such as the New Zealand Health Strategy, which was developed for all New Zealanders (37, 38), the New Zealand Disability Strategy (40), and several other New Zealand based policies relevant to healthy ageing, including Māori and Pacific health policies. The New Zealand Healthy Ageing Strategy has taken a life-course approach because ageing well begins when an individual is young and still developing, and adopting healthy habits early can lead to a healthier individual at an older age (39).

The Healthy Ageing Strategy has five key areas of focus to ensure healthy ageing for all New Zealanders. The first key area is ageing well, which is a strategy dedicated to focusing on physical and mental health throughout an individual's life, developing resilience, achieving equity among different ethnic groups, improving the physical, social, and environmental aspects of ageing, and supporting age-friendly communities. The second area of focus is acute and restorative care including accuracy of admissions, developing co-ordination between different hospital specialties, making sure hospitals are safe for all users including those with dementia, and aiding with recovery, both in hospital and out in the community. The third area of focus is on living well with long-term conditions, ensuring that clinicians and social workers have the tools to help individuals with long-term conditions as well as giving the individuals themselves the resources to be able to ensure they have the support they need. The fourth focus area is support for people with high and complex needs, ensuring a high quality of in-home services and aged care services are available, in addition to support for the families. The final focus area is respectful end-of -life care ensuring the preferences of

individuals are respected, that families also have access to support at this time, and a high standard of palliative care (39).

The Healthy Ageing Strategy is relevant to this thesis, as the research presented focuses on ageing well, and support for people with high and complex needs by developing a hip fracture risk score to assess how likely an individual is to sustain a hip fracture over a 2-year period. Individuals identified as being at an elevated risk of hip fracture may then be given extra support to try and reduce the risk of hip fracture.

1.3.3 Osteoporosis New Zealand Strategic Plan 2017-2020

Osteoporosis is a major risk factor for fracture. Osteoporosis New Zealand is an organisation that was founded in 1999 with the goal of increasing both public and government awareness of osteoporosis (41). Since then, Osteoporosis New Zealand has expanded their goals to include improving the lives of anyone who has osteoporosis, and to prevent fractures caused by osteoporosis (42). In 2012, Osteoporosis New Zealand published Bone Care 2020, a document which outlines why there is a need to implement a systematic approach to hip fracture care and prevention in New Zealand (43). The first objective is to develop a hip fracture registry to improve outcomes and the quality of care delivered after a hip fracture. The second objective is to prevent second hip fractures by providing adequate care services for patients who are in hospital with a hip fracture. The third objective is to prevent first hip fractures by working with general practitioners (GPs) to assess an individual's risk of hip fracture. The fourth objective is to deliver consistent public health messages about how to maintain a healthy lifestyle and reduce the risk of fractures (7).

The Osteoporosis New Zealand Strategic Plan was developed in 2016, following on from the guidelines established in Bone Care 2020. The Strategic Plan expanded upon the objectives outlined in Bone Care 2020 to establish six objectives targeted at different population groups and awareness programmes were developed for each objective, to educate the public about osteoporosis and related injuries(7). Table 3 below, outlines the objectives, their target groups, and the corresponding programmes.

Table 3 Osteoporosis New Zealand Strategic Plan objectives and their corresponding programmes

Target Group	Objectives	Programmes
Hip fracture patients	Improve outcomes and quality of care by developing a hip fracture registry	Develop the New Zealand Hip Fracture Registry
Other fracture patients	Treat the first fracture and provide access to fracture liaison services to reduce the risk of a second fracture	Push each DHB to adopt fracture liaison services
People at risk of first fracture	GPs to assess fracture risk of patients in their practice	Develop first Fracture Prevention Programmes
Adults age 65 years and older	Deliver messages about health to the public about maintaining physical fitness	Public awareness campaigns
Adults aged 19-64 years	Deliver public health messages about adopting a healthy lifestyle	Public awareness campaigns
Children up to age 18 years	Deliver public health messages about achieving healthy bone mass	Public awareness campaigns

Since the publication of the strategic plan, a hip fracture registry has been developed in conjunction with the ANZHFR and the HQSC (https://www.hipfracture.co.nz) (25). Fracture liaison services have been implemented in DHBs, and a study was published in 2016 about the experiences of the Waitemata DHB employing fracture liaison services (44). Additionally, in 2017 the ANZHFR published the Clinical Guidance on the Diagnosis and Management of Osteoporosis in New Zealand, which is a tool developed to guide clinicians in the prevention and treatment of osteoporotic fractures (45). The third objective of the Osteoporosis New Zealand strategic plan is directly related to the aims of this thesis, which include assessing the fracture risk of patients, while the guidelines have been developed for use with GPs in their practice, this thesis aims to assess the hip fracture risk of all community-dwelling older adults who undergo an interRAI-home care (HC) assessment in New Zealand. More information on the interRAI-HC assessment can be found in sections 1.5 and 3.2.1.

1.4 Hip Fracture Prevention

1.4.1 Prevention

Hip fractures are serious injuries and focus on prevention is a top priority for many health providers around the world (46, 47). Common hip fracture prevention strategies include reducing the risk of falls in the home, increasing daily exercise, management of health and medication, and maintaining bone health (46). Hip protection devices are also sometimes used as a preventive measure. They can be either a plastic case or soft padding that covers an individual's hip to reduce the chance of a hip fracture resulting from a fall (47).

There are currently no active programmes in New Zealand specifically aimed at reducing hip fractures (43). In some instances where orthogeriatric care is available, patients who are hospitalised with a hip fracture will be provided with osteoporosis medications to help prevent a second fracture (43). Osteoporosis New Zealand are currently developing a First Fracture Prevention Programme. While there are no active programmes focused on hip fractures specifically, there is a falls prevention programme, Reducing Harm from Falls. This programme was developed in 2012, and updated in 2017, with the aim of reducing the number of falls and fall-related injuries in the population, including hip fracture. The programme has several toolkits and guidelines available online for clinicians to access (9). The focus of the programme is on education across ten topics, including the impact of falls, assessing risk of falls, ensuring safe environments, medications, and improving strength and balance (48).

1.4.2 Risk Factors for Hip Fracture

Research has been carried out to identify risk factors for hip fracture. This is done so that targeted prevention programmes can be developed to reduce a person's risk of hip fracture. Falls are the most common risk factor associated with hip fracture, and other risk factors for hip fracture include osteoporosis, gender, and older age (15). A detailed discussion of risk factors for hip fracture can be found in Chapter Two.

1.4.3 Prediction Models

There have been many prediction models developed to identify individuals who have an elevated risk of hip fracture so that interventions may be put in place to reduce the risk of fractures. The prediction models incorporate multiple risk factors associated with hip fracture or falls. Often, the prediction models will give a result based on the

number of risk factors a person has; the more risk factors an individual has, the more likely they are to be at a high risk of fracture. An example of such a prediction model is the Garvan fracture risk calculator, which is one of the more commonly used hip fracture prediction scores. Items included in the Garvan fracture risk calculator are sex, age, fractures since the age of 50 years, and falls in the last 12 months, with an option to include a BMD measurement (49). Other prediction tools that have been developed are the FRAX (50), Qfracture (51), and Van Staa (52).

Chapter Two contains a detailed discussion of different hip fracture prediction models, including the variables used and how well they predict hip fracture risk.

1.5 InterRAI as a Health Care Service

In conjunction with the New Zealand Ageing Strategy, the New Zealand Guidelines Group (NZGG) developed guidelines for clinical assessment processes for older people. The NZGG is an organisation established to aid in the promotion of effective health and disability services. The purpose of the guidelines was to deliver recommendations for appropriate and effective assessment processes for identifying social, personal, functional, and clinical needs of older people (53). Older people in New Zealand generally refers to individuals aged 65 years and older as this is the retirement age of many New Zealanders. In addition to the guidelines, the NZGG performed an audit of current assessment processes and found there was a disparity between the expectations for assessments and the way that assessments were conducted. It was decided by the NZGG that the use of a comprehensive evidence-based and standardised assessment tool would be a way to ensure the assessment processes matched the needs outlined by the NZGG (53). A review of potential assessment tools was conducted, which included four comprehensive tools, six overview tools, and two screening tools. The interRAI Home Care tool (interRAI-HC) was among those explored and was rated highly (54). In 2004, five DHBs piloted the interRAI-HC (55). The pilot programme was considered a success, and it was decided that interRAI-HC would be rolled out on a national level. Since 2012, it has been mandated for all individuals aged 65 years and older requiring publicly-funded health care services, including publicly-funded ARC. To enter a publicly-funded ARC, all adults must undergo an interRAI-HC assessment (56). From 2015 it was also mandated that everyone in an aged care facility would receive the

interRAI long-term care facility (interRAI-LTCF) assessment every six months, or if their health changes significantly before that time, to ensure the healthcare needs of the residents are assessed on a regular basis (57).

InterRAI is an international group dedicated to providing comprehensive clinical assessments across multiple areas of health. There are over 20 different interRAI assessments in use around the world with focuses ranging from new-born babies, to mental health, to assessments for older people, and to people under palliative care. In New Zealand, the interRAI assessments currently in use are the contact (CA), community health (CHA), home care (HC), long-term care (LTCF), and palliative care (PC) assessments. Each assessment contains a set of core items, shared across different assessments and a set of unique questions for use with specific assessments. For example, the LTCF assessment has questions about the type of activities a resident is involved in.

The CA is a simple screening tool used to assess the severity of an individual's needs, and whether they require a more comprehensive needs assessment such as the HC. The CA consists of core questions and in some cases expands to include extra questions based on an individual's answers. For example, if an individual has cognitive issues their assessment will include extra questions to determine the severity of any cognitive impairment they may have.

The CHA is designed for use in the community, and like the CA can incorporates question branching to include extra questions if needed, for example there is an assisted living addition available for the CHA to be included when an individual is in an assisted living facility.

The HC is a comprehensive clinical assessment tool designed to evaluate the health needs of community-dwelling individuals. The LTCF is a comprehensive assessment designed for use in aged care facilities as a way of assessing the strengths and needs of an individual. The PC is an assessment of the strengths, needs, and preferences of older adults requiring palliative care (58).

A summary of the assessment types can be found in Table 4. The LTCF and HC assessments are mandated in New Zealand for anyone seeking publicly funded health services. More information on how interRAI assessments are conducted (specifically - the HC assessment) can be found in chapter three. Large numbers of assessments are

undertaken each year in New Zealand and can be linked with other health data using a unique identifier given to each individual. More information on how the data is linked can be found in 3.2.

Table 4 Summary of interRAI assessments used in New Zealand

Assessment	Target demographic
CA	Non-complex community dwelling individuals
CHA	Anyone in community with a specific care need
HC	Complex community-dwelling individuals
LTCF	People living in aged care residential care facilities
PC	People requiring palliative care

1.6 Aim and Objectives

The aim of this research was to develop a hip fracture prediction tool to be used for individuals who undergo an interRAI-HC assessment in New Zealand, as discussed in the interRAI as a health care services section above. The first objective was to identify risk factors associated with hip fracture. The second objective was to use the risk factors identified to develop a prediction score.

1.7 Thesis Structure

The remainder of this thesis has been structured using eight chapters together with supplementary materials at its conclusion. **Chapter One** has given a brief overview of hip fractures and how they impact older adults. There was also a brief explanation of how there is likely to be an increase in hip fractures due to an ageing population. The aim of this thesis was described. The **second chapter** provides an in-depth exploration and critique of the literature on hip fracture risk and provides a discussion on how this thesis can improve upon current studies of hip fracture risks in older people. The literature review also describes the gap in the literature that this thesis aims to fill. The **third chapter** explains the methodology. The chapter provides the justification for using a competing risk regression model for analysis and provides an explanation of how the hip fracture score will be developed. **Chapter Four** provides a brief overview of the dataset used for analysis. This chapter includes information on the data tidying process and basic descriptive statistics such as the mean age of the cohort, and

frequency of hip fractures within the dataset. The **fifth chapter** reports on analysis following on from the results of the score replication section in chapter three to build a competing risk regression model, based on the previous results and additional questions from the home care assessment. **Chapter Six** uses the results of the preceding two chapters to construct a hip fracture risk score. Scores calculated are then broken into two groups indicating low and high risk of fracture. This chapter goes into depth on the creation and optimisation of a hip fracture risk score that can be used to determine who is at an elevated risk of sustaining hip fractures. In **Chapter Seven**, the score is externally validated using a more recent version of the interRAI-HC dataset. It is a repeat analysis of the previous chapter to see how well the model predicts hip fracture risk for an external cohort. The final chapter (**Chapter Eight**) is an overview, and details strengths and weaknesses of various parts of the study. This chapter also provides a discussion of the practical applications of the score developed.

2 Literature Review

2.1 Introduction

There is a large array of literature pertaining to hip fractures, including incidence of hip fracture, risk factors associated with hip fracture, outcomes after hip fracture, and effective methods for treatment and recovery after hip fracture.

This chapter explores the literature in relation to the research goals of this thesis. Firstly, an examination of the literature around hip fracture risk will aid in identifying potential risk factors to include in analysis. Secondly, an exploration of the literature around hip fracture risk scores will help to identify methods and variables used to predict hip fracture risk in people. Finally, a breakdown of possible methods for use in clinical prediction models will provide insight into potential statistical methods to apply when developing a hip fracture risk score. A small section at the end of the chapter provides insight into how this thesis fits into the current body of knowledge regarding hip fracture risk, and the gap this research will fill.

2.2 Methods

Literature was systematically searched for across the Ovid Medline, and Google Scholar databases. The initial Ovid Medline search included articles from 1946 to 2019, but a later search only included articles from 2009 onwards to identify papers published within the last 10 years. The Google Scholar search was narrowed down to publications from 2009 to 2019. The literature searches were conducted in three parts. The first part was a search for literature on known risk factors for hip fracture. Key search terms used for this section were (*hip fracture* OR *femur fracture*) AND (*older adults* OR *elderly)* AND (*risk factors)*. The second search was used to identify fracture scores and indexes relating to hip fracture. Key words used for this search were (*hip fracture* OR *femur fracture* OR *osteoporotic fracture)* AND (*older adults* OR *elderly),* AND (*risk score* OR *prediction model* OR *Risk Assessment).* Inclusion criteria for identifying relevant studies were: (i) studies including "older adults" as the cohort of interest (most studies included age 65 years and older as "older adults" but some early papers identified individuals 50 years and older as "older adults"); (ii) studies exploring potential risk factors for hip fracture; (iii) studies developing prediction models for hip fracture; and (iv) published in the English language. Relevance was evaluated based on the title and

abstract of all studies found in the database. The third and final search conducted was to identify statistical methods that may be used to develop prediction models. The statistical methods were identified from the methods of the papers identified in the first two searches. Additional information about each of the methods was found in statistical textbooks. References within each article of interest were also examined to identify further articles of interest for each of the three parts. Peer-reviewed journal articles, including systematic reviews were included, editorials and grey literature were excluded.

Alerts for the key term *risk factors for hip fracture* were set up on Google Scholar in March 2019 and manual literature searches were conducted periodically from June 2016 to September 2019 to identify any newly published papers that might have been of significance. All records of interest were collected in EndNote X9.2. Figure 1 below outlines the article selection criteria following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (59)

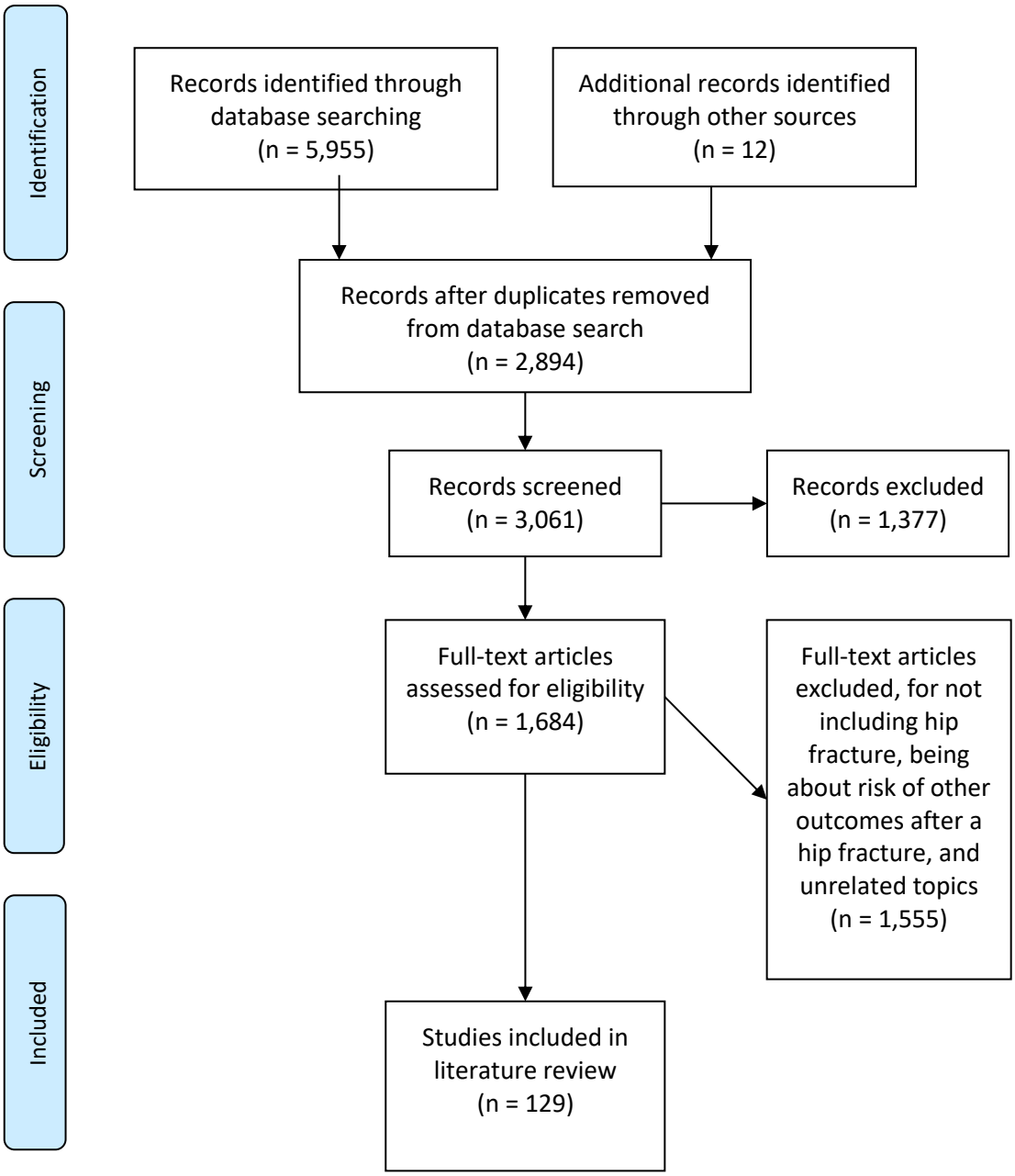

Figure 1 Flow diagram detailing selection criteria for literature review

2.3 Risk Factors for Hip Fracture

Risk factors for hip fracture have been studied extensively. Risk factors can cover a wide variety of domains, such as falls, fractures, bone strength, age, sex, ethnicity, cognition, body mass index (BMI), environment, lifestyle factors, co-morbidities, medicine, and exercise. Each type of risk factor listed can be associated with hip fracture, but they can also interact with each other.

Falls are the biggest cause of osteoporotic fractures and there are several reasons why an individual may fall (60). Environment can affect falls risk; for example, living in a house with poor lighting, loose carpets, or small pieces of furniture, which can be tripping hazards, can lead to an increase in the number of falls (61). Cognition can also impact falls, as people with cognitive impairments such as dementia are more likely to be on medications that make them dizzy or lead to postural instability (62). Some medications can cause dizziness, which can lead to an increase in falls; for example, benzodiazepines are associated with falls (63). There are many other medical conditions that can more directly lead to falls, such as diabetes mellitus, which may cause an individual to experience dizziness (60). Exercise is associated with falls where those who are more physically fit are less likely to fall (64). This could be due to stronger muscles, better balance, and faster reflexes (64).

Lifestyle factors such as smoking cigarettes and alcohol abuse have been linked to reduced bone mass, which increases the risk of fracture (61). Additionally, alcohol consumption has been found to be associated with an increase in falls risk in women; this is most likely from males and females having different alcohol metabolisms where females may be more susceptible to impaired cognition and physical functioning (65). BMI has been linked to fractures; those who have a low BMI are more likely to have a hip fracture than people with higher BMI (66). This is possibly due to those with lower BMI having less tissue surrounding the bones and when a fall occurs, a smaller individual is likely to have less cushioning from a fall and be more likely to fracture their bones (67).

There are several associations between bone health and other risk factors for hip fracture. Age and sex are both correlated with bone health (60). Females tend to be at a greater risk of osteoporosis than males, particularly after menopause (60, 68). For both males and females, the older a person gets, the weaker their bones tend to be (68). There can also be differences in bone structure and bone density across different ethnic groups as found by Chin *et al.* amongst premenopausal women of Polynesian, Asian, and European descent (69). Use of some medications such as corticosteroids can reduce bone mineral density (BMD) (70). Regular exercise can increase bone mass which can help prevent bone fracture in older adults (71).

Different ethnic groups have different BMI distributions in their populations. This results from musculature varying across ethnic groups and the apparent variances in the body fat composition in the populations of different ethnic groups (72, 73). Figure 2 below is a conceptual framework derived from the literature to help the reader understand how the literature fits together. The list below is not a comprehensive list of all the risk factors associated with hip fracture, but it does capture the main domains. There are other factors that likely contribute to hip fracture that are both unknown and known.

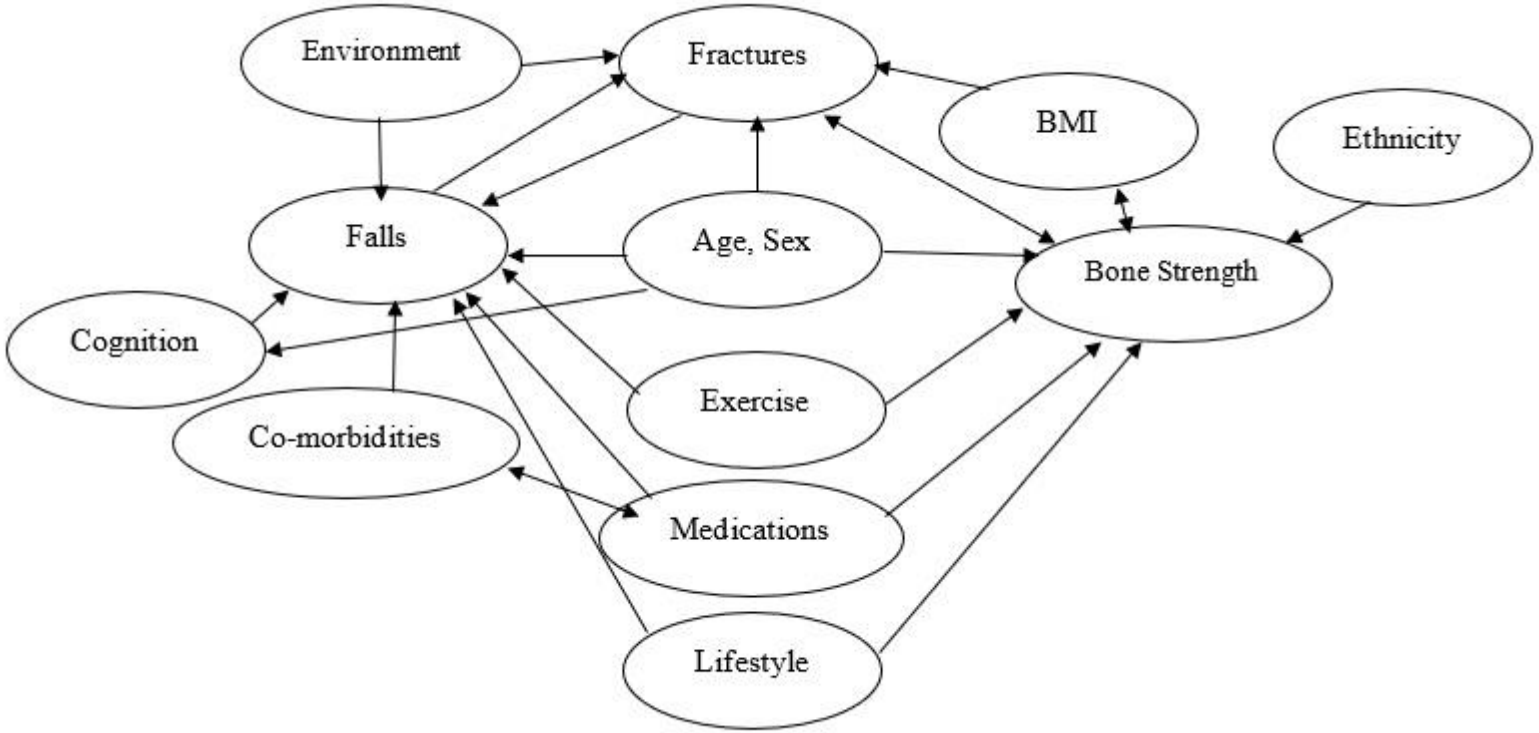

Figure 2 Diagram of factors relating to hip fracture and how they relate to each other

2.3.1 Falls

The biggest risk factor for hip fracture identified in the literature is falls (60, 74-78). Early research indicated that approximately 90% of hip fractures were caused by falling (79). Issues that can lead to falls include balance problems, dizziness, and vision problems (60). Several of the kinds of risk factors for hip fracture are related to falls as shown in Figure 2.

2.3.2 Fractures

Fractures can themselves contribute to hip fracture risk. Many studies have shown that having a hip fracture or another type of osteoporotic fracture can increase the chance of sustaining a subsequent fracture (16). After an individual sustains a vertebral fracture, their risk of sustaining a hip fracture increases by a factor of 2.5 compared to those who have not had a vertebral fracture (61). Similarly, when an individual has already suffered a hip fracture, the risk of a subsequent hip fracture increases by a factor of 2.3 compared to those who have not had a hip fracture (61). A new hip fracture can occur on either side of the body so there is a chance that an individual could sustain two or more hip fractures in a lifetime. According to research conducted by Shroder *et al.*, the risk of sustaining a third hip fracture is approximately 8.6 per 1,000 men and 9.8 per 1,000 women, per year (80).

2.3.3 Bone Strength

Reduced bone strength due to low BMD and osteoporosis are other contributing factors to hip fracture (61, 81). Osteoporosis is a disease where the bone becomes more fragile due to deterioration of bone tissue, and this can increase the chance of a fracture (3). Researchers exploring the effect of BMD on hip fracture risk found there was a strong relationship between BMD and hip fracture (61, 82). Wainwright *et al*. conducted a study to identify risk factors for hip fracture in women over 65 years old without osteoporosis and found lower BMD in the hip was associated with hip fractures (83). Bone shape can also be associated with hip fracture risk (61). An individual with a long hip axis is more likely to have a hip fracture than someone with a short hip axis (61).

2.3.4 Age and Sex

Demographic factors such as age and sex can also be related to hip fracture. Females tend to have a higher age adjusted risk of hip fracture, particularly as they are more likely to suffer from osteoporosis, diminished bone density, and other complications post-menopause (61, 68, 84, 85). Male-specific studies reported that males who sustain a hip fracture were generally younger than females (86, 87). This is possibly because females tend to live longer and may have hip fractures at an older age (88). Females on the other hand tended to have lower BMD, be older in age, and have higher rates of osteoporosis (61).

All of the hip fracture studies reviewed found that older individuals have a higher chance of sustaining a hip fracture than younger individuals (60, 61, 75). It is estimated that worldwide, hip fracture incidence rates will rise by 1%-3% per year due to the ageing population (89, 90). Ageing is associated with reduced BMD due to changing bone structure and therefore increases the risk of hip fracture (91). Older people also have reduced muscle mass and impaired reflexes, which may make them more likely to fall and sustain a fracture (61).

2.3.5 Ethnicity

Ethnic differences have been found to influence hip fracture risk. Studies have shown that white or European individuals tend to be at a higher risk of fracture than a number of different ethnic groups (61, 69). An early study by Chin *et al.* identified Asian people as having shorter femoral necks and they postulated this may be a reason why Asian people tend to have a lower rate of hip fracture than that of Europeans (69). Their results also found that Polynesian people have longer femoral necks than those of European people, but Polynesians still have lower rates of hip fracture than Europeans. Chin *et al*. suggests that Polynesians may have higher BMD that may contribute to them having fewer hip fractures (69). Hamdy *et al.* noted that white and Hispanic Americans had similar fracture risk to each other while black and Asian individuals tended to have a reduced risk of hip fracture (61). The updated Qfracture study conducted by Hippisley-Cox *et al.* found that ethnicity was related to hip fracture in both males and females (92). Specifically, those who identified as white were at an elevated risk of fracture compared to other ethnic groups such as Indian, Pakistani, Bangladeshi, Chinese, other Asian, black African, and black Caribbean (92). Ethnic differences were also found to be associated with hip fracture risk in studies conducted by Berry *et al.* which found that white race was associated with an increased hip fracture risk (76).

In New Zealand, hip fracture rates are higher in European/other ethnic groups than in Māori, Asian, and Pacific people (20). The age-standardised hip fracture rates per 1,000 people aged 50 years and older in New Zealand were 0.8 for Māori, Pacific people, and Asians, and 2.8 for European/other people (20). An earlier study examining hip fracture rates in New Zealand found that Māori males had the lowest number of fractures compared to female Māori and male/female non-Māori (30).

2.3.6 Cognition

Cognition, or more specifically cognitive impairment, has been found to be associated with fracture risk (75, 76, 93). Wandering is a trait often associated with impaired cognition, and it has been found to increase the risk of hip fracture, particularly in older people living in aged care facilities (76, 94). In addition to wandering, the Berry *et al.* study examining hip fracture

in aged care facilities found that people who were easily distracted were likely to have a hip fracture, and for each increase of 1 point on the cognitive performance scale (CPS), an individual's risk of fracture increased by approximately 3% (76). The CPS is a measure used at the end of an interRAI assessment to evaluate a person's level of cognition, with a score ranging from 0 (intact) to 6 (very severe impairment) (95). A German study comparing the risk of hip fracture in people with dementia versus those without dementia found that people who had a diagnosis of dementia were at an increased risk of hip fracture (96). Bohlken *et al.* also found that people with dementia who lived in aged care homes were more likely to have a hip fracture than those who lived at home (96). Two recent studies looking at risk of subsequent hip fracture after an initial fracture found that people with dementia were more likely to sustain a second hip fracture, and they were also more likely to die within 30 days of the initial fracture (16, 97).

2.3.7 BMI

BMI is a measure calculated from an individual's body mass divided by the square of the body height, expressed as kg/m^2 and is used as a general rule to categorise people into groups: underweight (BMI <18.5), normal (18.5 > BMI > 30), overweight (30 > BMI >34.9) , and obese (BMI >35) (98). BMI is related to hip fracture risk in two ways. People who are underweight tend to have a higher risk of hip fracture than those in the higher BMI categories (66, 68, 76, 99, 100). Bean *et al.* examined 50 women with hip fractures and found that those with lower body mass seemed more likely to be at risk of fracture; when skeletal size (the size of the bones in a person's body) was considered, body mass was not associated with hip fracture risk (101). Their findings suggest that skeletal size or muscle weakness (a lack of muscle strength), and not body mass, may be the reason for hip fracture, although their sample size was very small so further study around skeletal size would be useful for confirming these findings (101).

Several studies have also noted that many people who are overweight have a reduced risk of hip fracture (99, 102). People with higher BMI tend to have a higher body fat percentage and this extra padding around the hip area could protect an individual from fractures after a fall (67). Another suggestion posited by Hla *et al.* is that an increased strain on the bones from the increased weight can help to increase the BMD, therefore the person is less likely to fracture their hip (103). Women with higher BMI tend to have greater levels of adipose tissue; when this is the case, the body can produce more endogenous oestrogens that can help to preserve BMD (104).

2.3.8 Environment

People with different living arrangements have also been found to have differing risk profiles. Chen *et al*. identified there was a difference in risk profiles between community-dwelling and institutionalised older people (105). Each group of individuals had different risk profiles as they were subject to different environments and had differing health needs (51, 75, 105, 106). One study from New Zealand examined the difference in hip fracture rates between community-dwelling and institutionalised older people and found that individuals living in institutions such as aged care facilities were at a higher risk of hip fracture than those living at home (29). Additionally, Hippisley-Cox *et al.* found, that for males, living in care facilities was a significant risk factor for hip fracture (92). Wilson *et al.* found that the type of residence was associated with hip fracture risk; their study noted that people living in mobile homes were at an increased risk of hip fracture compared to individuals living in a house, duplex, or town house (93). However, this could be related to factors associated with living in a mobile home, such as more tripping hazards.

An individual's home environment may be hazardous and can lead to hip fracture. Hazardous environments can include items such as clutter around the house, no hand holds in bathrooms, loose rugs, no stair rails, poor lighting, and uneven outdoor pathways on the property (78, 107). A New Zealand study of falls risk examined reasons for falls resulting in hip fractures among 780 people. They found that 84.4% of the falls happened in the home and 13.1% happened away from home. Approximately 25% of the falls that occurred in the home had some form of object contribution (108). A case-control study conducted by Clemson *et al.* found nine specific hazards were associated with an increased risk of hip fracture; these were: doormats, floor mats in areas of high use such as hallways, internal stairs, seating, poor bedroom lighting, bathtubs, bathmats, and toilets (109).

Socioeconomic factors have also been attributed to hip fracture risk. A Swedish study noted that employment, household income, and type of housing were associated with risk factor for postmenopausal women aged 50-81 years old (110). A study from the UK on risk factors for hip fracture found, that for males, the level of deprivation was associated with hip fracture risk, where those who were most deprived had a higher incidence of hip fracture (111). Additional studies have also noted that people who have a lower income level had a higher risk of hip fracture (112, 113).

2.3.9 Lifestyle Factors

Lifestyle factors such as smoking and alcohol consumption can affect a person's risk of hip fracture. Many studies have shown that smoking tobacco can increase an individual's risk of

hip fracture (75, 86, 114). Tobacco use can lead to a decrease in BMD (115, 116). Additionally, smokers tend to have inadequate dietary intake, particularly in terms of calcium and vitamin D, which are essential for healthy bones (61).

Alcohol use has also been found to be associated with hip fracture risk (61, 117). One study found that alcohol consumption was associated with an increase in falls among women (65). Alcohol can also affect the BMD and lead to weaker bones, particularly in heavy drinkers (115, 118). Alcohol can also interact with medications leaving an individual with reduced cognitive function, thereby increasing their risk of falls (61).

2.3.10 Co-Morbidities

A variety of health conditions have been linked to an increased risk of hip fracture. Chronic obstructive pulmonary disorder (COPD) and Parkinson's disease are two particular diseases that have been linked to an increased risk of hip fracture (16, 61, 119-121). A 2010 study by Dam *et al.* found older men with COPD or asthma were likely to have lower BMD than people who did not have either disease (119). It has been noted in other studies that individuals who have asthma, particularly those who are treated with corticosteroids, are at an increased risk of osteoporosis and fractures related to osteoporosis (122-124). People with Parkinson's disease tend to be unsteady on their feet, which may lead to an increase in falls risk. Individuals with rheumatoid arthritis have also been found to be at risk of hip fracture (125-127). However individuals with osteoarthritis were less likely to have a hip fracture due to limited mobility (75, 76). Diabetes has also been associated with hip fracture risk (16, 76). Postural hypotension, stroke, Alzheimer's disease, and arrhythmias may increase the risk of falls, which can, in turn, increase the risk for hip fracture (60, 128).

Liang *et al.* conducted a meta-analysis of 13 studies to explore whether there was an association between cardiovascular disease and heart failure (129). The results showed there was a positive association between cardiovascular disease and hip fracture (129). Cancer patients have also been found to have an increased risk of hip fracture (60, 130). Edwards *et al.* identified that most older cancer patients had osteoporosis or low bone mass, which put them at a high risk of having a hip fracture (130). Their study included multiple types of cancer including breast, lung, and gastrointestinal cancers. Chen *et al.* found the risk of falls and fractures increased in postmenopausal women after they received a breast cancer diagnosis (131). A Swedish study found that older men undergoing androgen deprivation therapy for the treatment of prostate cancer developed osteoporosis and were at a high risk of sustaining a hip fracture compared to patients who were not undergoing androgen deprivation therapy for cancer treatment, and also compared to those who had no diagnosis of cancer

(132). A Danish study also found an increased risk of hip fracture among men with a diagnosis of prostate cancer and also among those who were undergoing androgen deprivation therapy (87).

2.3.11 Medications

Medications such as the use of corticosteroids have been identified as a risk factor for hip fracture (51, 81, 92, 102, 133-135). Taking corticosteroids can lead to a reduced BMD which increases an individual's risk of hip fracture (70). Corticosteroids are commonly used to treat symptoms of COPD and asthma (136). Several studies have shown that corticosteroid use is a risk factor for hip fracture among people with COPD (137, 138). Additional studies have found psychotropic medications and medications for cardiovascular issues have been noted to be associated with an increased falls risk (139).

Loop diuretics such as furosemide can increase the chance of hip fracture, particularly in men, as loop diuretics can increase urinary excretion of calcium, which leads to reduced BMD (140). However, this mechanism could also be due to confounding co-morbidities and/or hypotension (140).

Both the FRS and FRAiL studies explored whether medications had an impact on hip fracture risk for interRAI-LTCF cohorts; both studies found that the medications they explored were not significantly associated with hip fracture risk (76, 94).

To date, there have been two studies identifying specific medications that were associated with an increased risk of fracture among older New Zealanders (141, 142). The first, by Jamieson *et al.*, determined there was a significant relationship between hip fracture risk and drug burden index drugs (sedative and anticholinergic medications) (141). In the second study, Nishtala *et al.* identified there was an increased risk of hip fracture associated with use of the sleeping pill Zopiclone (142).

2.3.12 Exercise

Physical activity has been linked with hip fracture risk (68, 86, 102, 143-150). Some studies have found that those who participate more in physical activity are less likely to sustain a hip fracture than those who do little to no physical activity (68, 86, 143, 144). A comparison of different levels of physical performance in older men found that those who had poor physical performance were more likely to sustain a hip fracture than those who were more physically fit (146). Their findings showed that men who had poor physical performance in at least three tasks were approximately 3 times (Hazard Ratio (HR) :3.14, 95% CI: 1.46, 6.73) more likely to sustain a hip fracture than men who had higher physical performance capacity (146). A

Swedish study examined the effect of different levels of physical activity on hip fracture risk and found there was no association between hip fractures and the amount of time spent on work-related physical activity or total physical activity. However, time spent on general household activities and leisure-time physical activity may decrease an adult's risk of hip fracture (145). Particularly, people who spent less than one hour per week performing household activities had an 85% higher risk (HR: 1.85, 95% CI: 1.01,3.38) of hip fracture than people who spent ≥6 hours per week on the same activities (145). Trimpou *et al.* also identified that engaging in leisure-time activities had a reduced risk of hip fracture than those who did not engage in any leisure-time activities (HR: 0.83, 95% CI: 0.71, 0.97)(150). They also found that work related activities were not associated with hip fracture (150). Høidrup *et al.* identified that women who were moderately physically active for 2-4 hours per week had a decreased risk in hip fracture (HR: 0.72, 95% CI: 0.59, 0.89) (144).

Some studies showed that implementing exercise programmes had a reduced impact on hip fracture risk. A Finnish study explored whether combined resistance and balance-jumping training for older adults had a lasting impact on reducing falls and fracture rates (149). Their study found that over five years of follow-up, those who participated in the exercise training had 51% less falls (Relative Risk (RR): 0.49, 95% CI: 0.25,0.98) and 74% less fractures (RR: 0.26, 95% CI: 0.07, 0.97) than those who did not participate in the exercise programme (149). Additionally, a study conducted by Nikander *et al.* found that odd-impact exercises (soccer and squash) could be good for increasing the strength of the femoral neck which could reduce the risk of hip fracture (147). Nordström *et al.* also noted that individuals who participated in odd-impact exercises (ice-hockey and soccer) had stronger femoral necks in later life than those who did not compete in such sports (148). Regular exercise can increase bone strength by placing stress on the bones which helps stimulate bone strength and reduce the risk of fractures (151, 152). Additionally, exercise can help to improve balance leading to a reduction in falls and fall-related fractures (151, 153).

Additionally, exercise in early life is important for reaching peak bone mass (154-157). Andreoli *et al.* conducted a study to explore the long-term effects of BMD in postmenopausal ex-athletes (158). Their study found there was minimal difference between the BMD in ex-athletes and younger athletes, suggesting the benefits of physical activity performed in youth are maintained in later life (158). A meta-analysis by Karlsson *et al.* showed that exercise during an individual's formative years has long-term benefits for skeletal strength, which can help reduce the risk of fractures in later life (159).

2.4 Fracture Scores and Indexes

There are many risk factors associated with hip fracture as explored in the previous section. It is also important to note that there is a cumulative effect when one or more of the risk factors associated with hip fracture is found in an individual (160). For example, someone who has one risk factor such as low BMI would be less likely to have a hip fracture than an individual who has multiple risk factors such as low BMI, history of falls, older age, and osteoporosis. Researchers have made use of the cumulative nature of risk factors to develop models to identify individuals who may be at an elevated risk of hip fracture such as the FRAX and Garvan scores (49, 50). Many of the risk factor models are applied in a clinical setting to aid with hip fracture prevention. Once an individual's risk of hip fracture has been calculated, the assessors can implement prevention practices to help reduce a person's risk of fracture for those at high or medium risk.

This section explores 11 different risk scores developed between 2001 and 2017, for use in predicting hip fractures, and explains why they were developed, the methods used to develop the score, and the risk factors used in each prediction tool.

2.4.1 FRAX

One of the most well-known tools for assessing hip fracture risk is the FRAX (Fracture risk assessment tool) score, developed by the researchers at the University of Sheffield in 2008 (50, 161). The FRAX score was developed using Poisson regression. Hip fracture incidence data was taken from a study by Singer *et al.* (162); however, the study did not make clear how this data was applied to the total cohort. Items included in the FRAX score are age, sex, weight, height, previous fracture, a parent fracturing a hip, being a current smoker, using glucocorticoids, rheumatoid arthritis, osteoporosis, alcohol consumption, and femoral neck BMD (50). The FRAX score is used to determine the ten-year probability of hip fracture and other major osteoporotic fractures such as a spinal fracture (50, 161).

Criticisms of the FRAX score include that it is for a general cohort of men and women aged 40 years and older and may be too general to help people in specific age groups or situations such as those requiring home help. It could be a good screening tool to identify people who have some risk of hip fracture within the next ten years, but a more targeted score could be better for providing insight into health care and prevention programs for an individual with more specific health needs, such as those aged 65 years and older. Additional information, such as the cohort size, were not reported so it is unclear how much statistical power the model had.

2.4.2 Garvan

The bone fracture risk calculator, more commonly known as the Garvan tool, was developed in 2007 as a tool for predicting the 5- and 10-year risk of hip fracture in primary care settings (49). The Garvan was developed using a cohort of 1,028 females, and 740 males aged 60 years and older living in the city of Dubbo, Australia. Within the cohort there were 127 (6.5%) people who sustained a hip fracture, and 96 (4.9%) of these were sustained by females (49).

Cox proportional hazards models were used to assess the risk factors for hip fracture, and a nomogram was created to predict hip fracture risk. A nomogram is a graphical way of presenting data. In this instance, the nomogram consists of separate lines for each item used to calculate hip fracture risk. Each line is a scale that corresponds to a certain number of points (163). The first item in the Garvan tool is age in years and a vertical line is drawn from the age of a person being assessed to the corresponding number of points to determine how many points that person receives for that specific risk factor. For example, a female aged 87 years old would receive a total of 20 points. This process is repeated for each item to obtain the number of points that correspond to those items. Once this has been done for all items in the tool, the points are added together and a vertical line is drawn from the total number of points to two scales at the bottom of the nomogram indicating the 5- and 10-year risk of hip fracture for the individual being evaluated. The items included in the Garvan tool are age, BMD T-scores (which is a measure of bone density), previous fracture, and any falls in the last 12 months. Nomograms were developed separately for males and females.

The Area Under the Curve (AUC) for the Garvan model was 0.85 for both males and females, indicating the model has strong predictability (164). An AUC of 0.5 means there is an approximately 50% chance the test will accurately identify whether an individual is positive or negative and an AUC of 1 means the score perfectly identifies who is positive and who is negative (165). An internal validation was also conducted using a bootstrapping method where 1,000 sub-samples of 150 individuals of the whole sample were resampled with replacement, and analysed to see how well the Garvan tool can predict fracture in a different sample. The AUC for the Receiver Operator Characteristics curve (ROC) for the female model was 0.7 and for males it was 0.65 (49).

The Garvan score was developed with a small sample size compared to other fracture scores, and it was specific to one city in Australia, which suggests it may not be generalisable to a worldwide population as each population may have differences that mean some risk factors are more prevalent than others in those specific countries. The Garvan uses BMD that requires

the individual to undergo a clinical test to determine; this may be hard to do for every patient. There are a variety of risk factors; several that have been commonly found in the literature suggesting the score may capture people who may be overlooked if just one or two risk factors were tested for.

The nomogram method of calculation seems cumbersome given that the score could be easily calculated by developing a computer calculation where the required numbers are input into a calculation tool and the associated 5- and 10-year risk of hip fracture is returned once the input is completed. The Garvan Institute website now has an online tool (not mentioned in the original paper) using the same algorithm for calculating the 5- and 10-year risk, which will make it easier for clinicians to use (https://www.garvan.org.au/promotions/bone-fracture-risk/calculator/).

2.4.3 QFracture

The QFracture scores were two scores developed in 2009 to estimate the 10-year risk of hip fracture and the 10-year risk of osteoporotic fracture (vertebral, distal radius (wrist), and hip fractures) in GP practice patients in England and Wales. The age of participants ranged from 30 to 85 years. The study cohort was separated into a derivation and a validation dataset. The derivation dataset consisted of 1,183,663 females and 1,174,232 males, and the validation cohort consisted of 642,153 females and 633,764 males. In the derivation cohort, there were 24,350 (2.1%) osteoporotic fractures and 9,302 (0.39%) hip fractures in females, and 7,934 (0.34%) osteoporotic fractures and 5,424 (0.23%) hip fractures in males.

Cox proportional hazards models were used to identify risk factors associated with hip fracture and osteoporotic fractures. Separate risk profiles were identified for males and females. The significant risk factors associated with osteoporotic fractures in females were use of hormone replacement therapy (HRT), smoking status, alcohol use, parental history of osteoporosis, rheumatoid arthritis, cardiovascular disease, type 2 diabetes, asthma, tricyclic antidepressants, corticosteroid use, history of falls, menopause symptoms, age, chronic liver disease, gastrointestinal malabsorption, BMI, and endocrine disorders. When exploring these variables in relation to hip fracture, use of HRT, menopausal symptoms, parental history of osteoporosis, malabsorption, and other endocrine disorders were not associated with hip fracture (51).

Significant factors associated with both osteoporotic fracture and hip fracture alone were age, BMI, smoking status, alcohol use, rheumatoid arthritis, cardiovascular disease, type 2 diabetes, asthma, use of tricyclic antidepressants, history of falls, liver disease, and

corticosteroid use. All variables associated with fracture were included in the final models for prediction. When validating the QFracture scores, it was found the hip fracture score performed better than the osteoporotic fracture scores in both males and females. The AUC for osteoporotic fracture scores was 0.788 (95% CI: 0.786, 0.790) in females, and 0.688 (95% CI: 0.684, 0.692) in males. The AUC from the ROC for the hip fracture scores was 0.890 (95% CI: 0.889, 0.892) in females and 0.856 (95% CI: 0.851, 0.860) in males (51).

There is a large cohort for both the derivation and validation samples, suggesting there is likely to be better statistical power and precision in estimates. All the items used in the QFracture score are easy to determine from asking the patient and do not require complicated clinical tests to calculate. The age range used for developing the QFracture score was 30-85 years, which gives an estimate of fracture for a wider age range. This model may not be good at predicting the risk of fracture in people aged older than 85 years.

2.4.4 QFracture Updated

In 2012, an updated version of the QFracture score was developed using routinely collected data from thousands of GPs across the United Kingdom (UK). The decision to update the score was based on recommendations from the National Institute for Health Excellence (NICE) (92). NICE provides guidance on health care in the UK. Suggestions included expanding the age range of patients and including ethnicity information. The scores were designed for estimating the 10-year risk of osteoporotic fracture (this time with proximal humerus fractures included) and hip fracture. Additional potential items were added to the model and more items were found to be significantly associated with fracture risk.

The data were separated into a derivation cohort (3,142,673 patients) and a validation cohort (1,583,373 patients). Within the derivation cohort there were 59,772 (1.9%) people who sustained a fracture, and within the validation cohort there were 28,685 (1.8%) people who sustained a fracture. A Cox Proportional hazards model was used to assess risk factors for fracture using the derivation cohort. Risk factors for osteoporotic fracture in females were age, BMI, ethnicity, alcohol consumption, smoking status, COPD, asthma, cancer, cardiovascular disease, dementia, epilepsy, history of falls, chronic liver disease, Parkinson's disease, rheumatoid arthritis, systemic lupus erythematosus, chronic renal disease, diabetes (type 1 and type 2), previous fracture, endocrine disorders, gastrointestinal malabsorption, antidepressant use, corticosteroids, HRT, and parental history of hip fracture, and for hip fractures the risk factors were the same as for osteoporotic fracture except for gastrointestinal malabsorption and parental history of hip fracture.

For males, the risk factors were similar to those of the females but being in a residential care facility was also significant and endocrine problems was not. All significant factors for osteoporotic fracture were also significantly associated with hip fracture except for gastrointestinal absorption. The AUC from the ROC for osteoporotic fracture in females was 0.790 (95% CI: 0.787, 0.793) and for hip fracture was 0.893 (95% CI: 0.890, 0.896). For males the AUC for osteoporotic fracture was 0.711 (95% CI: 0.703, 0.719) and for hip fractures it was 0.875 (95% CI: 0.868, 0.883) The updated Qfracture scores tested better than the original Qfracture scores, and, again, the hip fracture score had better calibration and discrimination than the osteoporotic fracture scores (92).

The original Qfracture score was created using individuals aged 30-85 years old, and the updated score considers the older adults and ranges in age from 30-100 years old. The score had a large cohort and a large derivation cohort, which allowed for more statistical power. Cross-validation was used, which allows for testing the score on a dataset that was not directly used for development. A Cox proportional hazards model was used, and a competing risks model may be a better option as it would account for deaths as a competing event. There is an online tool available for use with the QFracture Updated algorithm at http://qfracture.org.

2.4.5 FRACTURE Index

The FRACTURE Index is a clinical assessment score used to assess the 5-year risk of osteoporotic fracture in postmenopausal women developed in 2001 in the USA (84). The FRACTURE index was developed to be simple to calculate in a clinical setting by using a small number of variables. The cohort consisted of 7,782 women who were recruited across multiple health care databases such as health plan information and registered voter lists. Within the cohort there were a total of 231 (3.0%) people who sustained a hip fracture (84).

Variables included in the model are age, BMD (optional), fracture after age 50 years, maternal hip fracture after age 50 years, weight less than or equal to 57 kg (125 pounds), smoking status, and use of arms to stand up from a chair (84). There was a strong relationship between the FRACTURE index and incidence of hip fracture. The AUC from the ROC for the model was 0.714 without BMD and 0.766 with BMD (84). No confidence intervals were reported in the published paper.

The FRACTURE score is developed for a specific cohort of postmenopausal women and is good for informing the clinicians and patients about their risk of fracture, which can help in determining which preventative strategies to implement for which people to best reduce

osteoporotic fractures. The specific cohort is also a disadvantage as it means the score may not necessarily work for other people; for instance, it would not work for predicting hip fracture risk in males. The cohort were healthy individuals, and anyone with complex health care needs may have a different risk profile, therefore the score may not work as well for those people.

2.4.6 FRAMO

The Fracture and Mortality (FRAMO) Index was developed in 2004 in Sweden to predict the risk of fracture and mortality in women aged 70 years and older (166). The cohort consisted of 1,248 women recruited from rural health care areas in Sweden. Within the cohort a total number of 31 (1.2%) women sustained a hip fracture. The FRAMO Index was developed to identify women who may be at high risk of vertebral and non-vertebral (including hip) fractures so that preventive measures can be taken to lower this risk. The score was developed using a small number of questions to be easily used as part of routine clinical assessments (166).

The items included in the index were age, weight, previous fragility fracture (hip, lower arm, upper arm, or vertebrae fracture), and using arms to rise out of a chair. Both logistic regression and Cox proportional hazards models were employed to assess which variables were associated with hip fracture. The AUC of the index was 0.72 (95% CI: 0.64, 0.81) for hip fracture and 0.75 (95% CI: 0.71, 0.79) for mortality (166).

The score was specifically developed for older females and may not be generalisable to other people. There are only four items used in the score and all are easy to obtain from the individual, which makes it easy to calculate a score. The size of the cohort used for development of the score was small so it is likely that a larger cohort could have yielded a more predictive model.

2.4.7 FRISC

The Fracture and Immobilisation Score (FRISC) is a prediction model developed for adults in Japan to assess the risk of fracture and immobilisation (167). It was developed to identify risk factors in a Japanese population and to identify an individual's risk of fracture (both hip and other osteoporotic fracture). Patients were recruited while in hospital. The score was developed in 2010 using adults aged 40-79 years old. The cohort consisted of 1,787 people and 44 hip fractures occurred over a one-year period (167).

Items used in the FRISC were age, weight, BMD, prior fracture, osteoporosis, dementia, menopausal status, and back pain. Poisson regression models were used for analysis. The

FRISC was validated using data from two different areas of Japan, Miyama and Taiji, where the AUC of the FRISC was 0.727 (95% CI: 0.660, 0.794) (167).

This score was developed specifically for postmenopausal women in Japan and may not be generalisable to another audience. The sample size was small, and the score was not validated on any other datasets. The AUC was above 0.7 which suggests it is good for predicting hip fractures for the target cohort.

2.4.8 Van Staa

The Van Staa is a clinical tool developed to predict the 5-year risk of fracture (hip, vertebral, and other osteoporotic fracture) in postmenopausal women aged 50 years and older (52). The purpose of the Van Staa tool was to identify long-term risks of hip fracture in postmenopausal women. The development cohort consisted of 366,104 women living in the UK. There were a total of 6,453 (1.8%) hip fracture events. Patient information for the study was obtained from The Health Improvement Network (THIN) database of medical records from UK GP patients (52).

Items included in the Van Staa assessment are age, BMI, previous fractures, falls, smoking status, medication use, early menopause, chronic disease, and medication for the central nervous system. Risk factors were identified using Cox proportional hazards models. The AUC was 0.84 for hip fracture, 0.69 for vertebral fracture, and 0.60 for other osteoporotic fracture (52). Confidence intervals of the AUCs were not reported in the published paper.

This score was also developed specifically for postmenopausal women, and therefore may not be generalisable to a wider population. The cohort was large, which means there was high statistical power, and the score was validated with a cohort of 32,728 people.

2.4.9 WHI

The Women's Health Initiative (WHI) developed an algorithm in 2007 to predict the 5-year risk of fracture in postmenopausal women. The purpose of the study was to develop a score using multiple risk factors for hip fracture in postmenopausal women. The cohort consisted of 93,676 people living in the USA who were recruited from the WHI study exploring clinical interventions. There were a total of 1,132 (0.16%) hip fractures (102).

Items included in the WHI algorithm were age, height, weight, ethnicity, previous fracture, parental history of fracture, alcohol consumption, medication use, self-reported health, and physical activity. The prediction model was developed using Cox proportional hazards models. The AUC for the entire cohort was 0.80 (95% CI: 0.77, 0.82). Models where some

variables were excluded were also explored. The AUC for the algorithm excluding active hormone therapy was 0.80 (95% CI: 0.77, 0.83), the AUC for the model excluding active dietary intervention was 0.78 (95% CI: 0.75, 0.81), and the algorithm excluding active calcium and vitamin D had an AUC of 0.81 (95% CI: 0.78, 0.83) (102).

The WHI was developed for postmenopausal women and may not be generalisable to other populations. The algorithm was developed in a large cohort (93,676) but validated in a smaller cohort (10,750); the results of the validation cohort may not be as precise as they could be. The authors explored multiple different variations of the algorithm to test which of the scores had the highest AUC.

2.4.10 FRAiL

The Fracture Risk Assessment in Long-Term Care (FRAiL) model was developed using interRAI-LTCF data for older adults in US nursing homes in 2017. The purpose of the FRAiL study was to develop a hip fracture score for use with questions from the interRAI-LTCF assessment. The cohort consisted of 419,668 people with 299,794 females and 119,874 males. There were a total of 14,553 (3.5%) hip fractures (76).

Questions used in the FRAiL model were age, race, cognitive performance score, ADL hierarchy scale (which is a measure of a person's level of independence in performing personal hygiene activities, toilet use, locomotion, and eating), locomotion in room, bladder continence, previous fall, transfer performance, easily distracted, wandering, osteoarthritis, BMI, pressure ulcer, and diabetes. A competing risk model was used to develop the hip fracture scores. Initially, Berry *et al.* included medications in their model but removed them from the final model as they did not change the overall outcome of the score (76). Males and females had similar risk factors for hip fracture with the exception that diabetes was not statistically significant as a risk factor in males. Receiver operator characteristic (ROC) curves were created for the FRAiL model, and the area under the curve (AUC) were reported to assess how well the instrument predicts risk of fracture. The AUC reported for men was 0.67 and for women was 0.69 (76). The FRAiL model was further validated and tested for prediction of hip and other fractures in 2019 in a retrospective cohort. All items in the initial version of the FRAiL model except for easily distracted remained significant for other non-vertebral fractures (femur, pelvis, and upper arm). The AUC for the hip fracture only model was 0.68 in both males and females, and for other non-vertebral fracture the AUC was 0.65 in females and 0.66 in males (confidence intervals were not reported).

The FRAiL index was developed using a large cohort of 419,668 long-term care residents. It has also been successfully validated in three different instances showing that it is a good model for predicting hip fracture risk. The large cohort is a nationally representative sample of people living in US nursing homes receiving Medicare. It may not be generalisable outside of a US nursing home cohort. The cohort had high rates of mortality and a competing risk regression was employed to account for this where mortality was considered a competing event to hip fracture.

2.4.11 FRS

The Fracture Risk Scale (FRS) was developed using interRAI-LTCF data for 29,386 individuals living in long-term care facilities in Ontario, Canada. A total of 1,553 (5.2%) of people had a hip fracture injury. The purpose of the study was to develop a hip fracture prediction model for use with interRAI long-term care data. Their final model calculated the 1-year risk of hip fracture using eight questions from the long-term care interRAI assessment (LTC RAI-MDS version 2.0) (94).

The variables used in the FRS to assess hip fracture risk were ability to walk in a corridor, BMI, previous fracture, wandering, age, transfer performance, and previous fracture (94). Decision tree analysis was used to predict hip fracture risk. The AUC in the FRS was 0.67 for the derivation set and 0.69 for the internal validation set, indicating the model had reasonable, but not great, predictability (165). Confidence intervals were not reported in the published paper. The FRS was validated in Ontario, British Columbia, and Manitoba. Discrimination among the provincial groups was similar with Ontario having an AUC of 0.67, British Columbia having an AUC of 0.64, and Manitoba having an AUC of 0.65 (168).

This score was developed specifically for people living in long-term care facilities in Canada and may not be generalisable to people living in the community. The design of the tool makes it easy to use and could be integrated into the interRAI-LTCF instrument outcome scores and scales. However, this group is similar to that of Berry *et al*., which has a high mortality rate, and decision tree analysis does not account for death as a competing event.

2.4.12 Summary of Hip Fracture Scores

All scores reported above included age and weight as variables for assessing hip fracture. In some cases, weight was used as a part of the BMI information. Some of the scores found there were different risk profiles for male and females, and separate scores were developed for each sex. There were also some scores that were developed specifically for females, namely FRACTURE Index, FRAMO, and WHI. There were four scores that were developed for a

combined male and female cohort with sex being used as a variable in the model; in these cases all non-sex variables in the models will have the same impact on the calculated scores for males as they do for females. These models cannot capture cases where another variable may be more significant for males than females or vice versa. The FRS did not include sex as a part of the model. Four of the scores included previous fracture and six included falls information. While there are a large number of hip fracture prediction scores already developed, none have been developed for an interRAI-HC cohort, and none of the previously developed scores can be calculated using the interRAI-HC data as not all of the items are available. Table 5 outlines the known fracture scores and the items used in calculating each score.

Table 5 Items used across different fracture scores

	FRAX(50)	Garvan(169)	FRAiL(76)	FRS(94)	Qfracture(51)	Qfracture Updated(92)	FRACTURE Index(84)	FRAMO(166)	FRISC(167)	Van Staa(52)	WHI(102)
Age	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Weight	✓	✓	✓[a]	✓[a]	✓[a]	✓[a]	✓	✓	✓	✓[a]	✓
Height	✓		✓[a]	✓[a]	✓[a]	✓[a]				✓[a]	✓
Sex	✓	✓	✓		✓	✓					
Race/ Ethnicity			✓			✓					✓
BMD	✓	✓					✓		✓		
Previous fracture	✓	✓		✓		✓	✓	✓	✓	✓	✓
Parental history of fracture	✓				✓	✓	✓				✓
Falls		✓	✓	✓	✓	✓				✓	
Smoking	✓				✓	✓	✓			✓	✓
Alcohol	✓				✓	✓					
Osteoporosis	✓				✓	✓			✓		
Rheumatoid Arthritis	✓				✓	✓					
Specific medications	✓		✓		✓	✓				✓	✓
Cognitive Impairment			✓	✓							
ADL			✓								
Locomotion in room			✓								
Bladder continence			✓								
Transfer performance			✓	✓							
Easily distracted			✓								
Wandering			✓	✓							
Osteoarthritis			✓								
Pressure ulcer			✓								

	FRAX(50)	Garvan(169)	FRAiL(76)	FRS(94)	Qfracture(51)	Qfracture Updated(92)	FRACTURE Index(84)	FRAMO(166)	FRISC(167)	Van Staa(52)	WHI(102)
Diabetes			✓		✓	✓					✓
Walking in corridor				✓							
Asthma					✓	✓					
Cardiovascular disease					✓	✓					
COPD						✓					
Epilepsy						✓					
Dementia						✓			✓		
Cancer						✓					
Systemic lupus erythematosus						✓					
Parkinson’s disease						✓					
Chronic renal disease						✓					
Care or nursing home residence						✓					
Aid to get up from sitting							✓	✓			
Menopausal									✓		
Back pain									✓		
Self-reported health											✓
Early menopause										✓	
Chronic disease										✓	
Central nervous system medication										✓	
Physical activity											✓

[a]Calculated together as BMI

There were 11 scores developed across six countries: USA, UK, Canada, Japan, Sweden, and Australia between 2001 and 2017. The cohort sizes ranged from 1,248 to 1,183,663 people. Six of the developed scores employed the Cox proportional hazards method. Other statistical methods used for development were Poisson regression, logistic regression, competing risks regression, and decision trees. More information about the statistical models can be found in section 2.5. Table 6 presents a summary of each of the scores mentioned above.

Table 6 Summary of hip fracture scores including year developed, country of origin, cohort size, statistical technique used, and AUC

Hip Score	Year	Country	Cohort size	Statistical Method	AUC (95% CI)
FRAX	2008	UK	Unknown	Poisson regression	Unknown
Garvan	2007	Australia	1,768	Cox proportional hazards model	0.85*
Qfracture (Females)	2009	UK	1,183,663	Cox proportional hazards model	0.890 (0.786, 0.790)
Qfracture (Males)	2009	UK	1,174,232	Cox proportional hazards model	0.856 (0.851, 0.860)
Qfracture Updated (Females)	2012	UK	1,598,294	Cox proportional hazards model	0.893 (0.890, 0.896)
Qfracture Updated (Males)	2012	UK	1,544,379	Cox proportional hazards model	0.875 (0.868, 0.883)
FRACTURE	2001	USA	7,782	Logistic regression	0.714*
FRAMO	2004	Sweden	1,248	Logistic regression	0.72 (0.64, 0.81)
FRISC	2010	Japan	1,787	Poisson regression	0.727 (0.660, 0.794)
Van Staa	2006	UK	366,104	Cox proportional hazards model	0.84*
WHI	2007	USA	93,676	Cox proportional hazards model	0.80 (0.77, 0.82)
FRAiL (Males)	2017	USA	119,874	Competing risk regression	0.692*
FRAiL (Females)	2017	USA	299,794	Competing risk regression	0.711*
FRS	2017	Canada	29,386	Decision tree	0.673*

*Confidence intervals were not reported

2.5 Statistical Models

Several different statistical techniques were identified as being used in the literature for identifying risk factors for hip fracture and developing clinical prediction models from those risk factors. This section provides an overview of five different techniques that have been commonly employed for clinical prediction modelling. While this is not an exhaustive list of possible techniques to use, it represents many of the common techniques employed. The techniques discussed are logistic regression, Cox proportional hazards, competing risk regression, decision trees, and artificial neural networks.

2.5.1 Logistic Regression

A logistic regression model is used to find the best fitting, clinically-interpretable model to describe the relationship between an outcome variable, such as death, and several predictor variables. In the case of a binary logistic regression model, the outcome variable is dichotomous, with two mutually exclusive options. There are also an ordinal and multinomial logistic regression model. For example, when looking at mortality outcomes, the two possible outcomes are dead or still alive. A logistic regression model can be applied to other clinical data in this way. For example, in a study exploring the associations between different clinical items and hip fracture, the outcome variable would be hip fracture or no hip fracture (170). There is no time component or ability to include multi-level or mixed effects variables in this model.

Logistic regression models are a simple-to-use model that can produce predictive estimates for any binary outcome. They are widely used so there is a large amount of literature detailing how to use logistic regression and describing how the model works (171). One downside of the logistic regression model is that there is no time-to-event component, and often studies identifying clinical outcomes such as hip fracture use a time-to-event analysis. The logistic regression is a simple model to use for developing a hip fracture score. However, a lot of clinical studies exploring specific effects can have competing outcomes. For example, death is a competing risk as once a person has died, they are no longer able to have a hip fracture. The logistic regression does not account for competing outcomes and it may be better to have a model that can account for competing factors. The interRAI-HC cohort has a high mortality rate, therefore for the purposes of this study, it would be better to use a model that included mortality as a competing event.

2.5.2 Cox Proportional Hazards

A Cox proportional hazards model is the most popular model for analysing survival data. Survival analysis assess time-to-event information such as death. The Cox proportional hazards model is a survival model that associates the time that passes before an event of interest (hip fracture) occurs to one or more variables that may be associated with the event, particularly in relation to the amount of time it takes for the event to occur (172). Proportional hazards models have two main components. The first component is the hazard function, which describes how the risk of event per time unit changes over time at the baseline levels of the variables of interest. A clinical example would include variables such as assigned treatment, age, sex, and any other diseases that may relate to the outcome of interest. These variables are known as confounders. The second component is the proportional hazards. The proportional hazards assumption states that variables in the model are multiplicatively related to the hazard function (173). If the proportional hazards assumption holds, it is possible to estimate the effect parameters without consideration of the hazard function (174).

The Cox proportional hazards model can be a good model to use when dealing with time-to-event survival data. Cox proportional hazards models deal with only one outcome. Sometimes clinicians want to focus on relationships, for instance, testing a certain medication and whether it reduces the risk of heart attack. For this example, a Cox proportional hazards model the outcome of interest would be whether the individual has a heart attack or not. However, there is a competing risk as subjects may die during the study period. Methods traditionally used to deal with competing risks (for example, mortality) include censoring out anyone who dies. A recent paper by Szychowski *et al.* explored risk associated with entry to ARC facilities (175). Their study compared a Cox proportional hazards model where death was censored and a Fine and Gray model of competing risks regression that account for the competing event of death rather than censoring it to see if the results were similar. The study found that competing risk events affected the probability of the event of interest. This effect can be small, but when using a competing risk regression model there will be a reduction in bias (175).

2.5.3 Competing Risk Regression

The competing risk regression developed by Fine and Gray is a time-to-event regression model with multiple outcomes. Commonly there are three outcomes: the failure event of interest (for example, hip fracture), a competing event (usually this is death), and neither the failure event of interest nor the competing event have occurred (often this outcome is called “censored”) (176, 177). However, models have been extended to now include multiple

competing risks. The competing risk can have equal or more significant clinical importance than the primary outcome, and it affects the probability of the outcome of interest (178).

Competing risk regression models are appropriate in cases where the cohort has high rates of mortality, such as in studies where the cohort is older in age (179). Their use is also beneficial for time-to-event data. For hip fracture risk, a competing risk of death should be considered for the interRAI-LTCF and HC cohorts because they have high rates of mortality. Competing risk regression models require more data than more simple models such as the logistic regression to provide meaningful results. A cohort of 5,000 people may be too small to employ competing risk regression models, particularly as there are competing events also.

2.5.4 Decision Tree

Classification and regression trees (CART) or decision trees use non-parametric methods to evaluate and divide data into subgroups based on the predictive independent variables (180). The significant variables and the order in which they should be split are determined by an underlying regression equation designed to maximise the predictive accuracy. Once the probabilities have been calculated, decision trees are created that follow different pathways to arrive at a predicted outcome for an individual, based on how they answered the questions (180). Figure 3 provides a visual example of a decision tree diagram where the answer to the first question dictates which question would be answered next. The tree diagram works as a flow chart that based on the answers to specific questions lead to a predicted outcome.

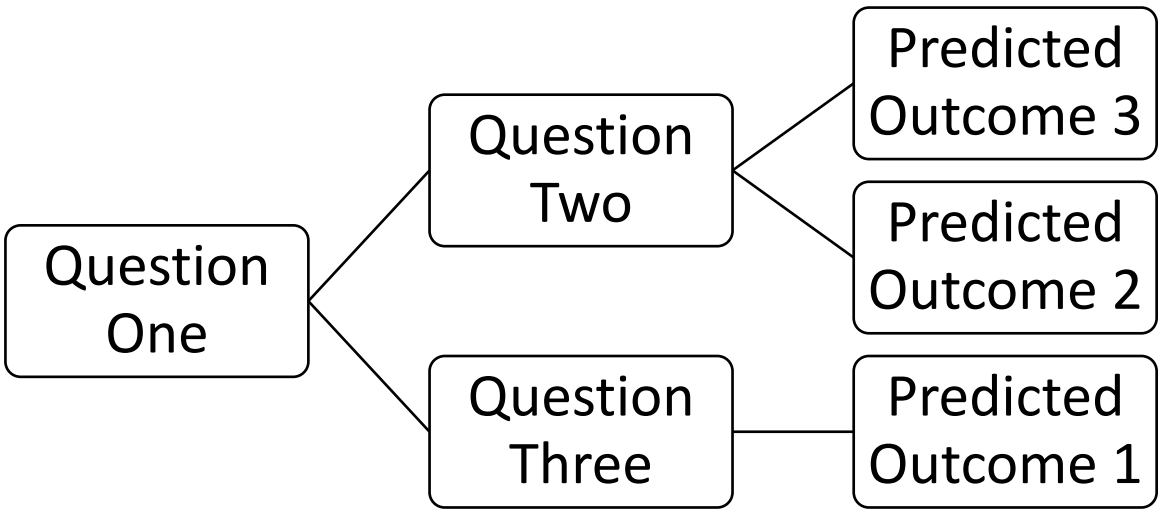

Figure 3 Example of a decision tree diagram

Decision trees provide an easily understood model that can be used easily in a clinical setting, as clinicians can follow the flow diagram produced by the tree to assess an individual's outcome. However, decision trees can be less accurate than other prediction models, particularly because the nodes on the trees do not contain enough information to reliably predict outcomes (181, 182). Tree diagrams were developed by computer scientists rather than statisticians which makes them useful for large datasets. There is no way to deal with competing events using this method, so for a cohort with high mortality, it may not be an appropriate model.

2.5.5 Artificial Neural Networks

Artificial neural networks are a type of computer system based on biological neural networks that are commonly used in artificial intelligence, including for machine learning. Machine learning involves using sets of data to train a computer system to recognise patterns and perform analysis without having to specifically program that analysis into the computer system. A neural network can be trained to model a mathematical relationship between a series of variables of interest and the corresponding output. The predictor variables and the outcomes are input into the machine, which is configured with some quantity of adjustable internal processing steps. With iterative training, the neural network can develop a mathematical model to calculate the probability of a specific outcome. Multiple sets of the data can be input during training, and the more training data the neural network receives, the more sophisticated the internal arrangement of weightings can be made. The more data input into the machine, the more accurate the outcome data (180). Artificial neural networks can model complex relationships between variables. However, the structure of the model that a particular neural network embodies is unknown. Neural networks require large amounts of data for training purposes to try to avoid problems such as overfitting. Overfitting is where the model is developed to be tailored to one limited set of data, which can lead to the model performing poorly when used on a different dataset (183).

Neural networks can require large amounts of computing power in the training stage to build an accurate prediction model. If large amounts of data and computing power are available, this allows for the modelling of more complex relationships between variables than is possible with more traditional techniques. However, in some contexts the complexity of the relationships may require more data to train a neutral network to model those relationships than is practical to gather.

2.6 Potential Clinical Implications

This thesis is novel as it is the first study internationally that uses the interRAI home care assessment to create a hip fracture risk score. The FRAiL model used competing risk regression, which is a recent technique for use in clinical analysis. Given the high rates of death in interRAI-HC and interRAI-LTCF cohorts, it is important for this study to also use competing risk regression and show more clinical researchers that it is a good statistical model to utilise when dealing with competing events in clinical cohorts.

2.7 Concluding Statement

This chapter explored the literature on risk factors for hip fracture, clinical prediction models for predicting hip fracture, and statistical techniques for developing clinical prediction models. Scores to identify those who are at risk of hip fracture are relatively common in medical settings. However, most of the clinically created risk factor scores are not suitable for those who are more frail, such as those in aged residential care facilities or still living at home but have more complex needs. The statistical technique best suited to the data is the competing risks regression model. The size of the cohort is too small for artificial neural networks to be a viable option. Time to event analysis is utilised and therefore regression models without a time component are not useful. Additionally, there is a high rate of mortality within the study cohort therefore the Cox Proportional Hazards model is not useful as it does not account for competing events. Based on a review of the literature, competing risk regression models will be used to develop a hip fracture prediction score. The next chapter provides a detailed account of the methodology and methods to be used in the rest of this thesis.

3 Methodology and Methods

The previous chapter was a survey of the literature regarding risk factors for hip fracture, hip fracture scores already developed, and statistical techniques for identifying and predicting hip fracture risk. This chapter provides a broad explanation of the methodology and methods used throughout this thesis including analytical techniques, data management, reporting methods, and ethics information. The specific methods used in each chapter will be presented in those chapters. The history of the interRAI was mentioned in section 1.5. Section 3.2.1 in this chapter provides information on how interRAI data are collected, and the format of the interRAI-HC assessment.

3.1 Analytical Techniques

3.1.1 Methods of Analysis

This study used quantitative techniques to determine risk factors associated with hip fracture and to develop a hip fracture prediction score from those risk factors. The statistical technique employed was competing risk regression, which was described in detail in the previous chapter. For the purposes of developing a prediction model, there were two interRAI-HC datasets available; one was used for the initial creation and validation of the hip fracture prediction score and the second dataset was used to externally validate the hip fracture score and support generalisability of the model (184). External validation is important for assessing the accuracy of a prediction model because most prediction models perform better on the derivation dataset (185-188).

The first dataset (original dataset) was obtained before analysis began and contained assessment records from September 2012 to June 2015 (all of the records available at the time), and the second dataset was obtained later and contained assessment records from July 2015 to January 2018. Data collected before September 2012 was of an older version of the interRAI-HC and was incomplete on a national level. When predictive models are constructed using regression analysis, the performance of the model is better on the dataset it was developed from than for any other set of data, including test sets that contain people from the same population (189). This is a well-known statistical issue, and one way to address this is cross validation: randomly splitting the dataset into two (or more) parts and use one set of data (the test cohort) to develop the model and the other set(s) (validation cohort(s)) to assess the model's performance. Using this approach, the model performance is tested on an

independent dataset with a similar cohort (189). Following this method, in order to more accurately test the predictability of the hip fracture risk score, the original dataset was randomly split into two datasets where two-thirds of the data was used as a test set to determine risk factors and construct a prediction model based on the regression analysis. The remaining one-third of the data was used to test the prediction model developed. In addition to this, the model was tested again using the second dataset from the later time period. This is conducted as a way of externally validating the data, by assessing the performance of the model with data that were not used in the initial creation and development (190). P-values of 0.05 or less defined statistical significance. Figure 4 illustrates where the data came from and how it is related.

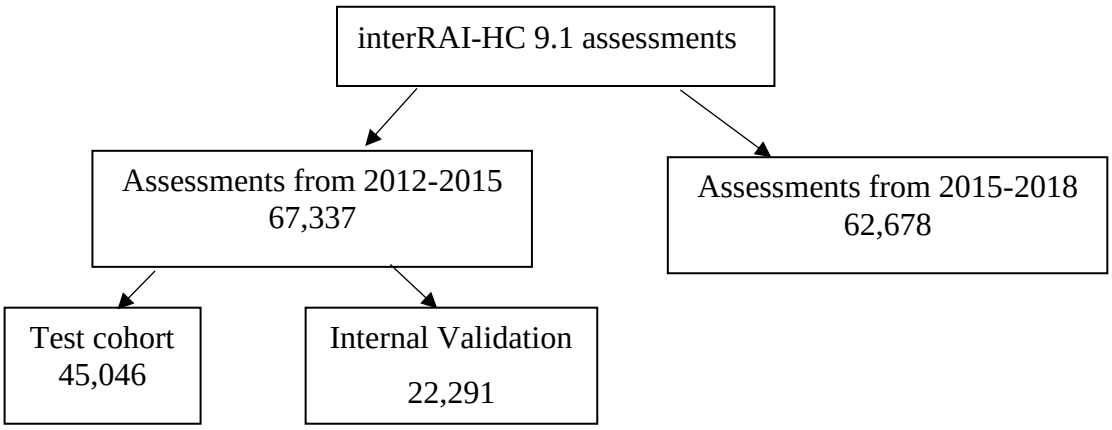

Figure 4 interRAI-HC data and how it was split for analysis

3.1.2 Target Population

The study population are people aged 65 years and older living in New Zealand who had an interRAI-HC assessment between September 2012 and June 2015. Exclusions include anyone under the age of 65 years because older person's health services in New Zealand are for those aged 65 years and older. Anyone who was listed as already living in an aged care facility were also excluded, because the focus of this study is on community-dwelling individuals. Anyone listed as having end-stage disease (less than 6 months to live) was omitted from the study because the score is for calculating the two-year risk of hip fracture and the life expectancy of the people with end-stage disease is six months. A comprehensive table outlining the exclusion criteria and the number of items removed can be found in Chapter Four, Figure 5.

3.2 Data Management

This study utilises data from three different sources. These are the interRAI-HC assessment data, hospital admissions data, and mortality data. In New Zealand anyone who receives health care is assigned a national health index (NHI) number. The NHI is a unique identifier associated with a single individual that is permanently associated with them once assigned. The NHI is associated with information about that individual including their name, date of birth, address, and any health records (191). The NHI can be used to deterministically link the interRAI-HC dataset to any health datasets including mortality, hospital admissions, and pharmacy dispensing data. In this case, the NHI number was encrypted using a two-step encryption system where New Zealand's Technical Advisory Service (TAS) provided the interRAI-HC data with encrypted NHI numbers, and the MoH provided the mortality and hospital admissions data with another encrypted NHI number. The MoH holds the encryption key and it is used to provide an extra protection to participants' confidentiality. The key to linking these was provided by the MoH separately to other data. All data files from the MoH were in Microsoft Excel format. Only data relating to individuals who have consented for their data to be collected were provided for analysis, and all identifying information such as names and addresses were removed before the data was provided. Data matching was found to be highly reliable, with 0.2% of mortality records unable to be matched (192).

3.2.1 interRAI-HC Dataset

All interRAI assessments are performed by trained assessors. Every interRAI assessor is trained according to specific national level interRAI guidelines and is routinely re-tested to ensure a high standard of assessment is maintained (193). Assessors are usually nurses or social workers. In New Zealand, if a GP or hospital staff member believe that a patient requires home care services, they will refer the patient for an interRAI-HC assessment. The assessment is used to determine how much and what type of services the patient needs (194). Assessors will usually go to a person's house and sit down with them to answer questions in the assessment. The assessors also use observations, interviews with family, and clinical records to obtain as much information as possible to complete the assessment (195). Most questions within the interRAI-HC assessment are mandatory, and all data is entered electronically and collected in an interRAI-HC database managed by TAS. Once an assessment has been completed by filling in the answers to all questions, outcome scores and outcome measures are calculated and triggered for specific areas of risk. Outcome scores include clinical assessment protocols (CAPs). CAPs are triggered and highlighted to the assessor to highlight key issues an individual may be having (196). For example, the

interRAI-HC has a Falls CAP that is triggered when an individual has any number of falls documented within the assessment (197). This suggests to the assessor that a falls prevention programme may be helpful to the individual. These scales and CAPs are used to guide the assessor on areas of health care support the individual may need. Outcome measures include such things as the BMI scale and CHESS. CHESS is a measure used to predict an individual's mortality (198).

A study conducted in 2008 asked assessors across twelve countries to conduct multiple assessments across five different interRAI assessment types (199). Each assessor received the same instructions on how to conduct the assessments and kappa measures, which are a measure of inter-rater reliability, were taken to see whether different assessors answered the same questions consistently. The results showed that the reliability of all questions present in multiple assessments (including some present in the home care assessment) exceeded the conventional cut-off point for reliability testing, with most items having a mean weighted kappa of 0.80 or better. Where a kappa value ≤ 0 is interpreted as no agreement, 0.01-0.20 is slight agreement, 0.20-0.40 is fair, 0.41-0.60 is moderate, 0.61-0.80 is substantial agreement, and 0.81-1.00 is almost perfect agreement (199). Some questions were the same across all five instruments and it was noted that questions shared across interRAI instruments retained their reliability across each instrument. This included questions such as Activities of Daily Living, understanding others, standing, and incontinence (200). Reliability between assessments in New Zealand was demonstrated by Schluter *et al.* who showed that inconsistencies between repeat interRAI assessments on the same individual being assessed were low in number and missing values were also rare (192).

The interRAI-HC instrument is used under license to the MoH. It is a comprehensive clinical assessment tool consisting of 236 questions across 20 domains. Table 7 below lists the domains in use for the interRAI-HC tool.

Table 7 Domains in interRAI-HC assessment

Item
A Identification Information
B Intake and Initial History
C Cognition
D Communication and Vision
E Mood and Behaviour
F Psychosocial Well-Being
G Functional Status
H Continence
I Disease Diagnoses
J Health Conditions
K Oral and Nutritional Status
L Skin Condition
M Medications
N Treatment and Procedures
O Responsibility
P Social Supports
Q Environmental Assessment
R Discharge Potential and Overall Status
S Discharge
T Assessment Information

3.2.2 Hospital Admissions Data

The hospital admissions dataset was obtained from the National Minimum Dataset (NMDS) held by the MoH. The NMDS is a national collection of hospital discharge information for both public and private hospital care (201). The hospital admissions data has information on the accident date, discharge dates, diagnoses, hospital admission codes, and surgery dates. On admission to hospital each patient can have up to 20 different diagnoses. All diagnosis records are coded using ICD-10 AM. From the hospital admissions dataset, individuals who had a diagnosis of hip fracture in any of their up-to-20 diagnoses (ICD: S72.0, S72.1, S72.2, S72.3, S72.4, S72.8, S72.9) were extracted from the hospital admissions data.

Several patients had multiple admissions for the same hip fracture event, which was confirmed by reference to the date of accident listed. Any admission with the same accident date was counted as the same injury. Transfers between different hospital services were counted as separate admissions. For example, a patient sustaining a hip fracture may first enter the accident and emergency department of a hospital, later they may be admitted to a different hospital department such as surgery, and each of these transfers between departments is counted as a separate admission in the records. Length of hospital stay and number of admissions for the same incident were calculated. Some patients had records of a second hip fracture; where this occurred the hip fracture that took place first within the

assessment period was used in the analysis. A cut-off date of 31 October 2015 was applied to the hospital admissions data; admissions that occurred after this date were excluded even if they related to a hip fracture that occurred within the study period. The cut-off date applied of 31 October 2015 is three months prior to the end date of the available data; this date was chosen because it can often take up to three months for the data to be completed and confirmed as being accurate. The hip fracture admissions dataset was then deterministically matched with the interRAI home care assessment using the encrypted NHI number. NHI matching issues can arise when opening the data files in Microsoft Excel as some encrypted NHIs become formatted as dates automatically; additionally there can be some transcription errors, where some numbers are incorrectly typed into the database.

3.2.3 Mortality Data

Date of death information was extracted from the Mortality Collection (MORT) database provided by the MoH (202). Records for mortality were available up to 1 January 2016; to ensure mortality records for all individuals were complete, a cut-off date of 31 October 2015 was applied. The mortality records consisted of the encrypted NHI and a date of death.

3.3 Variable Recoding

Using the risk factors associated with hip fracture outlined in Figure 2 of Chapter Two (Falls, Fractures, Environment, Cognition, Health, Age, Sex, Exercise, Lifestyle, BMI, and Ethnicity), questions of interest from the interRAI-HC were identified to ensure a wide variety of health questions were being assessed as potential risk factors. Decisions about what questions to include for initial analyses were based on the apposite literature pertaining to hip fracture risk factors as discussed in the literature review and clinical advice from gerontologists, physiotherapists, and other practising clinicians. Where reasonable, for variables with categories containing less than 5% of individuals, those categories were condensed into a smaller number of broader categories. Additionally, where disease diagnoses were concerned there were four response options, namely: 0 “Not present”, 1 “Primary diagnosis/diagnoses for current stay”, 2 “Diagnosis present, receiving active treatment”, 3 “Diagnosis present, monitored but no active treatment”. These variables were collapsed into a dichotomos variable with the options “No diagnosis” (code 0) or “Diagnosis present” (codes 1-3) for each disease diagnosis.

The environment variable was created from three questions in the interRAI-HC assessment. The questions were: disrepair of the home, squalid conditions, and limited access to home or

rooms in home. Anyone who answered yes to one or more of the questions was coded as having some issue with their home environment.

BMI was transformed into categorical values based on the the National Heart, Lung, and Blood Institute (NHLBI) classifications which are underweight (BMI < 18.5), Normal (BMI 18.5-24.9), overweight (BMI 25.0-29.9), and obese (BMI ≥ 30.0)(98). Other than BMI, which can be calculated directly from height and weight data within the interRAI assessment, no outcome scores such as the CAPs were included in the analysis as they are calculated at the end of an assessment based on the answers given by the person being assessed. The final hip fracture score is designed to be similar to these outcome scores by being calculated at the end of an interRAI-HC assessment and, if triggered, the clinical assessor might then refer the patient to a hip fracture prevention program or further testing such as a bone mineral density assessment. Table 8 below outlines the questions selected for analysis, the domains within the assessment they belong to, the iCodes associated with each question, and how they were recoded.

Ethnicity groups were Māori, Pacific people, Asian, European, and other. In the New Zealand version of the interRAI-HC assessment, individuals are allowed to select up to three different ethnicities. Where an individual had multiple ethnicities listed, priority coding was applied to give them one ethnicity for analysis purposes. Priorities are coded as outlined by the MoH policy on ethnicity data protocols to ensure consistency across New Zealand studies (203).The order of priority was Māori, Pacific people, Asian, European, and other. For instance, if someone identified as European and Māori, they would be listed as Māori for analysis purposes. Pacific people included anyone who identified as Samoan, Cook Island Māori, Tongan, Niuean, Tokelauan, Fijian, Other Pacific peoples, and Pacific peoples not further defined in the interRAI-HC assessment. Asian ethnicity included people who identified as Southeast Asian, Chinese, other Asian, and Asian not further defined as listed in the interRAI-HC assessment. European included New Zealand European, other European, and European not further defined as listed in the interRAI-HC assessment.

Each question used in an interRAI assessment is given an iCode. This is a value that corresponds uniquely to that specific question. For example, in the interRAI-HC assessment, question 1 from section C is given the iCode iC1. While it is question 1 of section C in the interRAI-HC, it may appear in a different section of another assessment. If the same question is used in multiple interRAI assessments, it will have the same iCode even if it appears in different sections in these assessments. Having the iCode means the question can quickly be identified across multiple assessments if needed. This also makes it easier to identify the same

question across different versions of the same assessment tool. The questions listed below are from the interRAI Home Care Assessment Form version 9.1 New Zealand Customisation. Towards the end of 2018, a small number of assessments included in the external validation dataset were conducted using version 9.3 of the interRAI-HC assessment. None of the questions used in this study were affected by the version change.

Table 8 Variables assessed for their possible associations with hip fracture

interRAI Domain	Question	iCode	Recoding	Area from literature
A Identification Information				
	2 Gender	iA2	Male = 0 Female = 1 Unknown = Missing Indeterminate = Missing	Age, Sex
	3 Age Group (in years)	iA3	65-74 = 1 75-84 = 2 85-94 = 3 95+ = 4	Age, Sex
	13a Lives	iA12a	Alone = 1 With Others = 2,3,4,5,6,7,8	Environment
B Intake and Initial History				
	2a-2y Ethnicity	Not availabl e	Māori = 1 Pacific People = 2 Asian = 3 European = 4 Other = 5	Ethnicity
C Cognitive/Functional				
	1 Cognitive skills for daily decision making	iC1	0 = 0 Independent 1,2 = 1 Minimal Independence 3, 4 = 2 Moderate to Severe 5 = 3 No discernible conscousness, coma	Cognition
	3a Easily Distracted	iC3a	0 = 0 Not present 1,2 = 1 Present	Cognition
	3c Mental Function Varies	iC3c	0 = 0 Not present 1,2 = 1 Present	Cognition
D Communication and Vision				
	3 Hearing	iD3a	0 = 0 Adequate 1,2 = 1 Minimal to moderate 3,4 = 2 Severe to none	Co-morbidities
	4 Vision	iD4a	0 = 0 Adequate 1,2 = 1 Minimal to moderate 3,4 = 2 Severe to none	Co-morbidities
E Mood and Behaviour				
	3a Wandering	iE3a	0 = 0 Not present 1,2,3 = 1 Present	Cognition

interRAI Domain	Question	iCode	Recoding	Area from literature
G Functional Status				
	2e Walking	iG2e	0,1 = 0 Independent 2, 3 = 1 Some assistance required 4,5,6 = 2 Maximum assistance/dependent 8 = Missing	Co-morbidities
	2f Locomotion	iG2f	0,1 = 0 Independent 2,3 = 1 Some assistance 4,5,6 = 2 Maximum assistance/dependent 8 = Missing	Co-morbidities
	3a Primary mode of locomotion	iG3	0 = 0 Walking, no assistive device 1 = 1 Assisted walking 2,3 = 2 Cannot walk	Co-morbidities
	3b Timed 4 metre walk (seconds)	iG12	1 = 0-15 2 = 16-29 3 = 30+ 4= 77,88,99 = 4 Incomplete tests	Co-morbidities
	4a Total hours of exercise or physical activity	iG6a	0,1 = 0 None/Less than 1 hour 2,3 = 1 1-4 hours 4 = 2 More than 4 hours	Exercise
	4b In the last 3 days, number of days went out of the house	iG6b	0,1 = 0 None 2 = 1 1-2 days 3 = 2 3 days	Exercise
H Continence				
	1 Bladder Continence	iH1	0,1, - 1 Continent 2,3,4,5 leave as is 8 as missing	Co-morbidities
	3 Bowel Continence	iH3	0,1, - 1 Continent 2,3,4,5 leave as is 8 as missing	Co-morbidities
I Disease Diagnoses				
	1a Previous hip fracture	iI1a	0 = 0 No fracture 1,2,3 = 1 Previous hip fracture	Fractures

interRAI Domain	Question	iCode	Recoding	Area from literature
	during last 30 days			
	1b Other fracture during last 30 days	iI1b	0 = 0 No fracture 1,2,3 = 1 Had previous fracture	Fractures
	1h Parkinson's Disease	iI1h	0 = 0 Not present 1,2,3 = 1 Diagnosis present	Co-morbidities
	1j Stroke/CVA	Ii1j	0 = 0 Not present 1,2,3 = 1 Diagnosis present	Co-morbidities
	1L COPD	iI1L	0 = 0 Not present 1,2,3 = 1 Diagnosis present	Co-morbidities
J Health Conditions				
	1 Previous Fall	iJ1	0 = 0 No falls 1,2,3 = At least one fall	Falls
	3a Difficult or unable to move self to a standing position	iJ2a	0,1 = 0 Not present 2,3,4 = 1 Present	Co-morbidities
	3c Dizziness	iJ2c	0,1 = 0 Not present 2,3,4 = 1 Present	Co-morbidities
	3d Unsteady Gait	iJ2d	0,1 = 0 Not present 2,3,4 = 1 Present	Co-morbidities
	4 Dyspnoea (Shortness of Breath)	iJ3	0 = 0 None 1,2 = 1 Absent at rest 3 = 2 Present at rest	Co-morbidities
	5 Fatigue	iJ4	0 = 0 None 1,2 = 1 Minimal to moderate 3,4 = 2 Severe	Co-morbidities
	6a Frequency of pain	iJ5a	0 =0 No pain 1 =1 No pain in last 3 days 2,3 = 2 At least once in last 3 days	Co-morbidities
	6b Intensity of highest level of pain	iJ5b	0 = 0 None 1,2 = 1 Mild to moderate 3,4 = Severe to excruciating	Co-morbidities
	6c Consistency of pain	iJ5c	0,1 = 0 None to very little 2 = 1 Intermittent 3 = 2 Constant	Co-morbidities

interRAI Domain	Question	iCode	Recoding	Area from literature
	9a Smokes tobacco daily	iJ8a	0 = 0 Non-smoker 1,2 = 1 Smoker	Lifestyle
	9b Alcohol – highest number of drinks in any 'single sitting'	iJ8b	0 = 0 None 1,2,3 = 1 At least 1 drink	Lifestyle
K Oral and Nutritional Status				
	BMI	Scale_BMI	9- 18 Underweight 18 -25 Normal 26 – 30 Overweight 31 – 41 Obese Missing/Unknown	BMI
	2a Weight loss of 5% or more	iK2a	0 = 0 No 1 = 1 Yes	Co-morbidities
	2b Dehydrated	iK2c	0 = 0 No 1 = 1 Yes	Co-morbidities
	2e Decrease in amount of food or fluid usually consumed	iK2g	0 = 0 No 1 = 1 Yes	Co-morbidities
Q Environmental Assessment				
	1a Disrepair of the home 1b Squalid condition 1e Limited access to home or rooms in home	iQ1a, iQ1b, iQ1e	0 = 0 No 1 = 1,2,3 Yes	Environment

3.3.1 Missing Data

Within the interRAI-HC, all fields in assessments are required so there was very little missing data. In cases where there was missing data, the number of missing values have been reported in their respective descriptive tables. No imputation was done to fill in any missing data. The category with the largest number of missing variables was BMI. In the original dataset there

were 26,547 (39.4%) of people who were missing BMI information. These people were categorised as “Unknown” BMI for the purposes of complete-case analysis. Within the interRAI-HC assessment, gender can be reported as “male”, “female”, “unknown” and “indeterminate”. In the original interRAI-HC dataset, there were two people listed as indeterminate sex and two who were categorised as unknown, these four were excluded from further analysis.

3.4 Reporting Methods

3.4.1 RECORD Statement

The reporting of results in this study (chapters 4, 5, 6, and 7) was informed by the Reporting of Studies Conducted using Observational Routinely-collected health Data (RECORD) statement (204). The RECORD statement is an extension of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) (205) and is used to guide the reporting of observational studies that use routinely collected health data. The RECORD checklist contains 23 items to include when reporting the introduction, methods, results, and discussion sections of an analysis. A copy of the RECORD checklist can be found in Appendix A.

3.4.2 Software

Basic descriptive analysis, graphs, and data cleaning was undertaken using IBM SPSS version 23 (206). Competing risks regression models were conducted using Stata SE version 15.0 (207) as SPSS does not have this functionality. Graphs of the impact of risk factors were created using R version 3.6.1.

3.5 Ethics

All participants included in this study consented for their data to be used for planning and research purposes. Anyone who does not consent (approximately 7% of people undergoing an interRAI HC assessment (192)) is not included in the dataset when it is provided for research and planning, and for those people who do consent, all of their identifying information is removed. Ethics approval for this study was given by the Ministry of Health’s Health and Disability Ethics Committee (HDEC) (14/STH/140). See Appendix B for the Ethics permission letter.

3.6 Bias

Information bias may have occurred with the interRAI-HC data. Before the data were received, anyone who did not consent to have their data shared for research purposes were removed from the dataset; there may be health differences in this group that will go undetected. The interRAI-HC assessment is only used for people seeking publicly-funded health care services, and therefore, anyone who receives privately-funded home care services will not be included in this study. There are approximately 20% of people who are privately funded and do not have interRAI-HC information available (208). There will be bias as those who can afford private health care may have differing health needs. The results of this study may not be applicable to these two groups of people.

4 Exploratory Analysis

4.1 Introduction

The previous chapter provided an overview of the methodology and general methods used throughout this thesis. This chapter focuses on presenting the basic descriptive information of the whole original interRAI-HC dataset before it was separated into test and validation datasets. The objective of this chapter is to explore the dataset and provide descriptive information pertaining to participant demographics, hip fractures, mortality, and the Falls CAP.

4.2 Methods

4.2.1 Participants

Participants included community-dwelling older adults aged 65 years and older who underwent an interRAI-HC assessment from 1 September 2012 to 30 June 2015. Where individuals had more than one interRAI-HC assessment, only the first assessment was included for analysis. Any further assessments of the same person were excluded to avoid having multiple records of the same person, which may affect the results. The first assessment was used because all individuals have a first assessment to decide what health services they require, if any. Not all people who are assessed, have subsequent assessments, and those who do have an additional assessment because their circumstances have changed; they potentially already have supports in place which may make differences to the cohort. The score developed in this study has been designed for use at a person's first interRAI-HC assessment before they have any supports in place. A full list of the participant selection criteria is listed in Figure 4.

4.2.2 Variables

Demographic variables reported were sex, age, ethnicity, and living arrangement. Hip fractures were identified by the ICD-10-AM codes mentioned in the previous chapter. The Falls CAP is an outcome scale that is calculated at the end of an assessment to alert the clinical assessor if the individual is at a risk of having a fall (209). An individual is classed as having no to low risk of falls when they report no falls in the 90 days prior to the assessment, medium risk is when a person reports having a single fall in that time period, and high risk is when a person reports having multiple falls in that time period (197). Time-to-event status was determined as the first event occurring during the study period whether this was hip

fracture or death, where death was treated as a competing event. Anyone who did not have either event reported by the end of the study period was classified as alive with no fracture.

4.2.3 Statistical Analysis

Distributions of the demographic variables were reported overall and partitioned by outcome status at the end of the study period. The number and type of hip fractures were reported. Mortality figures were also reported. A log-rank test was conducted to assess if there was a difference between the two groups = those who had a hip fracture and those who did not. A cross-tabulation of hip fracture and Falls CAP was created to explore the number of people who had a hip fracture in each of the three Falls CAP risk groups. A ROC curve of the Falls CAP and how it predicts hip fracture was created and the AUC was reported.

4.3 Results

4.3.1 Participant Selection

4.3.1.1 interRAI Data

Participants of this study were those who underwent an interRAI-HC assessment in New Zealand from September 2012 to June 2015. The initial dataset consisted of 105,502 assessments. Some encrypted NHIs did not have a corresponding NHI and could not be matched to hospital admissions or mortality data; they were removed from the analysis. Follow-up assessments were excluded from analysis to ensure only the first assessment of each participant was included. Anyone below the age of 65 years at the time of their assessment was excluded, and anyone who was listed as being in an ARC facility at time of assessment was also excluded. People who were in ARC at the time of their interRAI-HC assessment were excluded as previous studies have shown that people living in ARC have different risk profiles (51, 75, 105, 106), and this study focused on identifying risk factors for people living in the community. After additional tidying steps as detailed in Figure below, a total of 67,337 assessments were left.

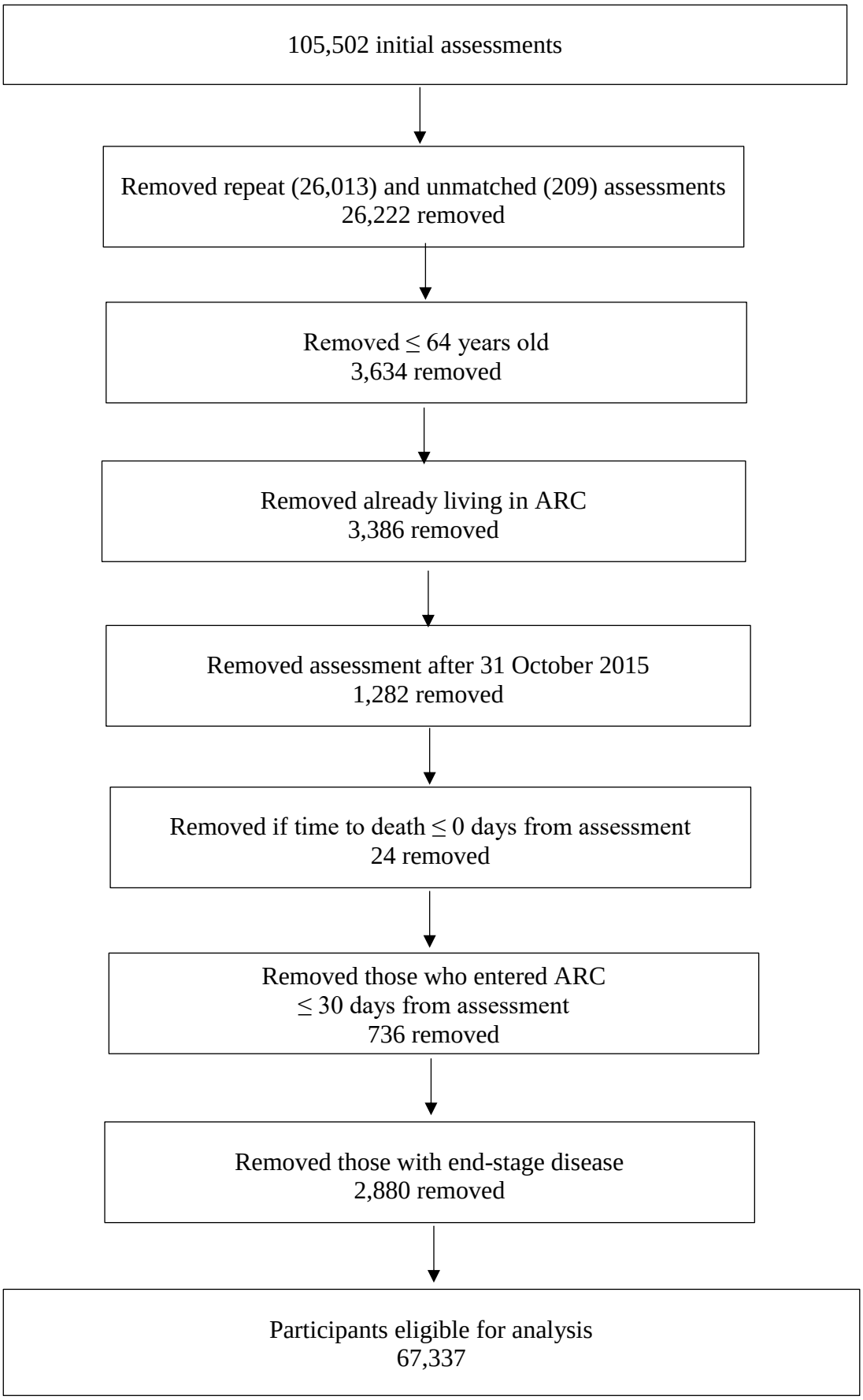

Figure 5 Participant exclusion criteria for the interRAI-HC assessments

4.3.1.2 Hospital Admissions Data

The hospital admissions dataset consisted of 341,154 records of hospital admissions from 5 January 2012 to 31 October 2015. There were 13,019 instances of hip fracture admission in the hospital admissions dataset. Additional considerations regarding the hospital admissions data were covered in Chapter Three.

Length of hospital stay and number of admissions for the same incident were calculated. Where there were multiple records of hip fracture for one individual, the hip fracture that took place first within the assessment period (3 September 2012 to 31 October 2015) was used in the analysis. Multiple admissions for the same injury were removed from the dataset to obtain a dataset of 6,576 first hip fractures. These were identified by a column in the hospital admissions dataset labelled "accident date", which details on which date the accident leading to the hospitalisation first occurred. The hip fracture admissions dataset was then matched with the interRAI home care assessment using an encrypted unique identifier. The date of assessment and the date of hip fracture admission were then used to determine who had a hip fracture before their assessment and those who had a hip fracture afterwards. A total of 4,317 people had their only hip fracture before they had their first interRAI-HC 9.1 assessment, leaving a total of 2,259 people who had a hip fracture after their first assessment. Of those who had a hip fracture following their first assessment, 123 people who had a subsequent fracture.

4.3.2 Demographic Information

The mean age of individuals was 82.8 years with a range from 65 to 106 years, with 11,331 (16.8%) aged 65-74 years, 27,703 (41.1%) 75-84 years, 26,058 (38.7%) aged 85-94 years, and 2,245 (3.3%) aged 95 years and older. In comparison, the 2013 New Zealand census data reports the number of people aged 65-74 years were 346,134 (57.0%), 75-84 years were 187,584 (30.9%), 85-94 years were 68,412 (11.3%), and 95+ were 4,902 (0.8%) (2, 192, 210). There were more females (61.6%) than males (38.4%). Within the study dataset, there were 3,618 (5.4%) people who identified as Māori, 2,088 (3.1%) Pacific people, 1,548 (2.3%) Asian, 59,567 (88.5%) European, and 516 (0.7%) as other ethnicities. In comparison with the New Zealand 2013 census data 5.6% identified as Māori, 2.4% identified as Pacific people, 4.7% identified as Asian and 87.8% of those aged over 65 years identified as European (2). Approximately half of individuals live alone (49.8%), while the 2013 census data reported 28.8% of people aged 65 years and older living alone. Among individuals who had a fracture, there more females who had a fracture than males - 70.3% of fractures occurred in females. More fractures occurred in people ages 85-94 years than any other age groups. Among those

who had a hip fracture, 94.8% (2,142) occurred in those who identified as European. Māori had the next highest number of fractures with 41 people having a fracture. Across each of the three first events, living arrangement was split with approximately half of individuals living alone and half living with others. A summary of these results can be found in Table 9. The total person-time for this study was 86,296 years. The person-time that an individual contributes to the total is the time from their first assessment in the study period to the first event - their next hip fracture, the death of the individual, or the end of the study period.

Table 9 Distribution of demographic variables - total number and partitioned by outcome

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Died n (%)
Sex				
Male	25,858 (38.4)	15,972 (61.8)	672 (2.5)	9,214 (35.7)
Female	41,477 (61.6)	29,410 (70.9)	1,587 (3.8)	10,478 (25.3)
Age Group (years)				
65-74	11,331 (16.8)	8,643 (76.3)	173 (1.5)	2,515 (22.2)
75-84	27,703 (41.1)	19,659 (70.9)	817 (2.9)	7,227 (26.1)
85-94	26,058 (38.7)	16,003 (60.4)	1,133 (4.3)	8,922 (34.2)
95+	2,245 (3.3)	1,080 (48.1)	136 (6.1)	1,029 (45.8)
Ethnicity				
Māori	3,618 (5.4)	2,484 (68.7)	41 (1.1)	1,093 (30.2)
Pacific	2,088 (3.1)	1,534 (73.5)	25 (1.2)	529 (25.3)
Asian	1,548 (2.3)	1,155 (74.6)	33 (2.1)	360 (23.3)
European	59,567 (88.5)	39,832 (66.9)	2,142 (3.6)	17,593 (29.5)
Other	516 (0.8)	380 (73.6)	18 (3.5)	118 (22.9)
Living Arrangement				
Lives alone	33,553 (49.8)	22,887 (68.0)	1,174 (3.5)	9,564 (28.5)
Lives with others	33,784 (50.2)	22,498 (66.6)	1,085 (3.2)	10,129 (30.2)

4.3.3 Hip Fracture Incidence and Hospital Admissions

Overall, there were a total of 2,259 hip fractures occurring after an interRAI-HC assessment. There are seven ICD-10AM codes for hip fracture. Most fractures were either fractures in the head and neck of femur (2,101, 48.7%) or pertrochanteric fractures (860, 38.1%), with 298 (13.2%) fractures occurring in the other areas of the hip. Table 10 below shows the frequencies of the different types of hip fracture diagnosis.

Table 10 Distribution of hip fractures partitioned by ICD-10-AM Code

ICD Code	Type of Fracture	Number (%)
S72.0	Head and neck of femur	1,101 (48.7)
S72.1	Pertrochanteric fracture	860 (38.1)
S72.2	Sub-trochanteric fracture	96 (4.2)
S72.3	Fracture of shaft of femur	102 (4.5)
S72.4	Fracture of lower end of femur	86 (3.7)
S72.8	Other fracture of femur	9 (0.4)
S72.9	Unspecified fracture of femur	5 (0.2)

The amount of time spent in hospital for each hip fracture injury varied with individuals staying between 1 day and 387 days. The median length of stay was 20 days (Interquartile Range (IQR): 10 – 32 days). Where individuals stayed in hospital longer than 32 days (the 75th percentile), they may have ended up in a care home that is also a hospital, or they may have had other further health complications leading to longer stays in hospital. Transfers between hospitals were initially listed as separate hospital admissions for the same event; where this was the case, admissions were condensed into one admission per hip fracture event (See Chapter 3 for more information on the cleaning process). The number of admissions per fracture event ranged from 1 to 7. Multiple admissions for single hip fracture events were typically due to transferring between different hospitals for surgery, recovery, and rehabilitation. In smaller hospitals, people stay in the same hospital for their surgery and rehabilitation and will only have one admission listed. In some bigger centres where there are multiple hospitals, the individual could have an admission to the acute hospital, then have another admission listed when they transfer to rehabilitation. Other reasons for multiple admissions listed could be that some centres have a temporary stay in the emergency department, people can get wound infections, they could become acutely unwell, or they may be transferred back to rehabilitation. The number of multiple admissions shows that hip fractures can be a burden for the patients and the hospital system. Table 11 below gives an overview of the number of transfers between hospital departments per patient.

Table 11 Number of hospital transfers for a hip fracture event

Number of Transfers	Patients N (%)
1	860 (38.1)
2	942 (41.7)
3	343 (15.2)
4	88 (3.9)
5	19 (0.8)
6	6 (0.3)
7	1 (0.0)

4.3.4 Hip Fractures and Mortality

By the end of the study period, there were a total of 20,711 (30.8%) people who had died. Of those who had a hip fracture after their first assessment, 736 (32.6%) died compared with 19,975 (30.7%) of individuals who did not have a fracture after their first assessment. A log-rank test showed there was a significant difference between the death rates of the fracture and non-fracture groups ($\chi^2_{(1)} = 59.1$, $p < 0.01$). In the first year of assessments, more people who did not have a hip fracture died than people who did have a fracture. After the one-year mark, more people who had a hip fracture died than those who did not have a hip fracture.

4.3.5 Falls CAP

The Falls CAP is an outcome score calculated at the end of a home care assessment. Within the cohort, more people triggered the low (39,978, 59.3%) falls risk group, and more of those people had a hip fracture than in the other two groups. Of those who were classified as high falls risk, 12.6% had hip fractures.

Table 12 Contingency table of Falls CAP triggers and number of hip fractures

	Low	Medium	High
No fracture	38,628 (59.4%)	18,699 (28.7%)	7,751 (11.9%)
Had hip fracture	1,350 (59.8%)	625 (27.7%)	284 (12.6%)

The ROC curve for the Falls CAP can be found in Figure 6. The AUC was 0.540 (95% CI: 0.527, 0.552). An AUC close to 0.5 suggests the model is marginally better than random chance at predicting hip fracture risk (165).

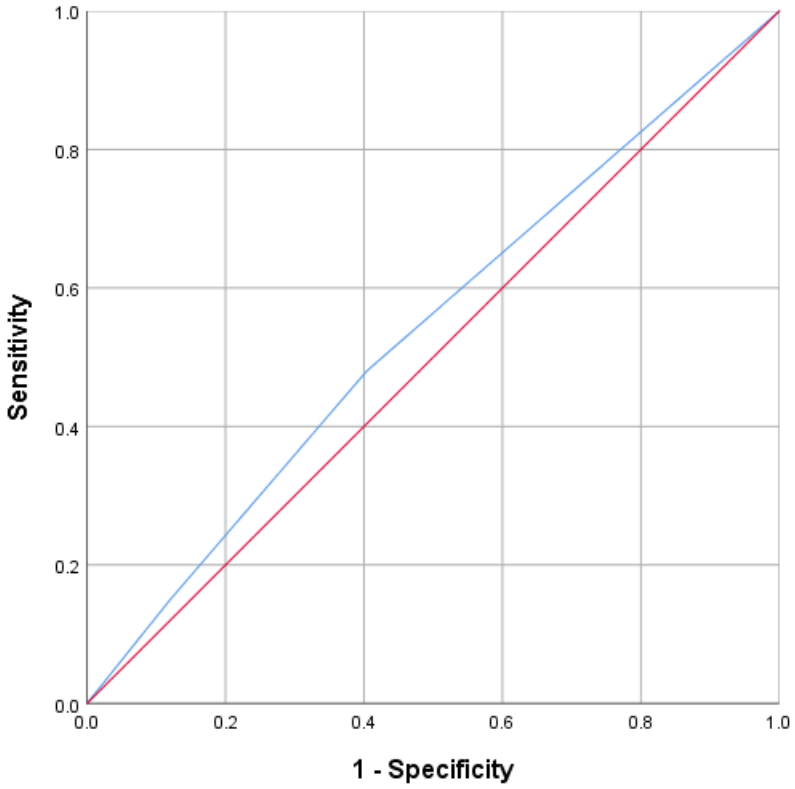

Figure 6 ROC curve of Falls CAP and hip fractures

4.4 Discussion

4.4.1 Key Points

A majority (41.1%) of people who had an interRAI-HC assessment were aged between 75 and 94 years of age. Māori and Pacific people are over-represented, particularly in the 65-74 years and 74-85 years age groups compared to the general population of New Zealanders in those age groups (192). This over-representation is in part because Māori and Pacific people tend to have a poorer health status (211, 212). The percentage of people who live alone was far higher in the interRAI-HC cohort than in the national population. This is possibly because anyone undergoing an interRAI-HC assessment does so because they are seeking health care services; many people who live alone may be more likely to require home care services because they do not have someone at home to assist with their care needs.

There was a total of 2,259 (3.4%) people who had a hip fracture after an interRAI-HC assessment. Most people who had a hip fracture had fractures of the head and neck of femur and the pertrochanteric region, with approximately 13% of fractures occurring in other parts of the hip. Length of hospital stay for those who have a fracture can be long with the median number of days being 20. Additionally, people can have between one and seven transfers between hospital wards, which may put extra stress on an already unwell individual.

By the end of the study period, 19,962 people had died. After hip fracture, there were a total of 736 people who died. Overall, there was a significantly higher percentage of people who died after hip fracture than people who did not have a hip fracture. After the one-year mark, more people who had a hip fracture died than those who did not have a hip fracture, but before that the no fracture group had a higher rate of mortality.

The group who had the highest number of fracture within the falls CAP triggers were those who were considered to be low risk. A potential reason for this is that those who trigger the medium and high risk are given interventions. There may also be some people who do not trigger the falls CAP due to having more complex health needs such as limited mobility, which means they have less opportunity to fall. Alternatively, it can be noted that any older person that has falls at some point must have a first fall in their older age, and someone could have a hip fracture as a result of their first fall. Another explanation is that older people have a significant change of suddenly starting to have several falls after having had no falls in their recent history. One potential reason for this is when an older person is prescribed a medication that can cause dizziness as a side effect. The AUC was 0.540, which suggests the Falls CAP is slightly better than random chance at predicting who is likely to have a hip fracture. However, the Falls CAP was not designed to predict hip fracture, but rather to assess who is at high risk of having falls. The low AUC of the Falls CAP suggests it is worthwhile to develop a score similar to the CAPs but specifically for predicting who is likely to have a hip fracture. These results suggest there may be other factors that can lead to hip fractures than just falls.

A Canadian study compared the Falls CAP with two other well-known fall screening tools, the Scott Fall Risk Screen (SFRS) and a Fall Risk Tool (FRT) that had been implemented as part of a Fall reduction strategy in Nova Scotia. The Falls CAP (C-statistic: 0.673) performed better at predicting an individual's falls risk than the other two screening tools (C-statistic for SFRS: 0.529, C-statistic for FRT: 0.609). However, when other items such as Parkinson's disease, multiple sclerosis (MS), Alzheimer's disease, COPD, and cardiovascular disease were added to the Falls CAP, its predictability improved (C-statistic: 0.749) (213). The Falls CAP appears to be a good predictor of falls; however, there are no known published studies where the Falls CAP is used to predict hip fracture.

4.4.2 Strengths and Limitations

This was a largely descriptive and explorative chapter that provided insight into the basic demographic information of people in the dataset and the number and type of hip fractures. The dataset provides a good description of the New Zealand interRAI-HC cohort, but may not

be generalisable to the general population of people in New Zealand aged 65 years and older, particularly as those who undergo an interRAI-HC assessment have more complex health care needs.

There is a large amount of data that can be used to explore how many people are having hip fractures and how those hip fractures impact mortality. Large data allows for high statistical power.

4.4.3 Concluding Statement

This chapter has provided a brief overview of the hip fracture dataset, including the data selection process and basic descriptive information. The next chapter will be an exploration of the home care data to assess risk factors for hip fracture that may be useful for creating a hip fracture risk score.

5 Risk Factors for Hip Fracture

5.1 Introduction

The previous chapter presented a general overview of the interRAI-HC assessment data, including how many people had fractures, how many died, and basic demographic information. This chapter presents the results for the first aim of the thesis: identifying risk factors for hip fracture. Risk factors will be explored for the whole group and will then be stratified by males and females to assess if there are any differences in risk profiles. The aim of this chapter is to identify risk factors for hip fracture within the interRAI-HC assessment that can be used to develop a hip fracture score.

5.2 Methods

5.2.1 Participants

Participants from the original interRAI-HC dataset of 67,337 individuals were split into two groups. Approximately two-thirds of the original dataset were randomly selected for the test dataset (45,046), and the remaining one-third (22,291) was set aside as a validation dataset. All analyses in this chapter employ the test dataset of 45,046. As the test dataset participants are a random subset of the participants featured in the previous chapter, their characteristics are still those who had an interRAI-HC assessment between 1 June 2012 and 30 June 2015, who were aged 65 years and older, and consented for their data to be used for research purposes. Figure 5 in Chapter 4 has a comprehensive breakdown of the participant selection criteria.

5.2.2 Variables

Variables used for analysis were derived from the interRAI-HC assessment and selected based on the literature outlined in Chapter 2. Groups from the literature were Falls, Environment, Cognition, Co-morbidities, Age, Sex, Exercise, Lifestyle, BMI, and Ethnicity.

Medication was not included in analysis. There is medication information collected as part of an interRAI-HC assessment; however, the medication data received from TAS was of low quality with severe formatting errors and therefore unusable for analysis purposes. Previous studies relyng on New Zealand medication data sourced this from pharmacy data held by the MoH. This was not done on this occassion as all items considered for use in this analysis were taken from the interRAI-HC assessment only. This was to ensure the hip fracture prediction score could be easily calculated at the end of an interRAI-HC assessment without having to

find extra information external to what was available in the interRAI-HC assessment. Additionally, there are no general questions, for example, a question on number of medications.

There are no questions in the interRAI-HC 9.1 assessment from the Bone category such as BMD, or whether the individual has a diagnosis of osteoporosis, so these risk factors were also excluded from analysis. A full description of the questions in the interRAI-HC assessment that were used in this analysis and the variable recoding applied for this purpose can be found in Chapter 3, Table 8.

5.2.3 Statistical Analysis

Basic descriptive information for the cohort was reported. This included the demographic variables and the variables of interest; the totals were reported alongside the numbers in each outcome group (Alive, no fracture, Fracture, and Death). Competing risk models using the Fine and Gray method (176) were utilised to determine risk factors for hip fracture. Hip fracture was the failure event and death was the competing event. Unadjusted models were constructed for each variable of interest. An adjusted model was then produced where all variables in the unadjusted models were included to ensure all potentially significant variables were found (214), with $\alpha = 0.05$ defining statistical significance. Subhazard ratios (SHRs) and 95% confidence intervals (CIs) were reported for each variable in the model. The relative importance of each significant variable was also assessed by calculating the percentage contribution of each variable to the model. The chi-square statistic minus the number of degrees of freedom (df) for each variable relative to the chi-square minus the number of degrees of freedom for the whole model was calculated. This information was presented as a graph. All analyses were conducted on the whole test dataset cohort and then repeated for males and females separately to determine if there were different risk profiles for each sex. Once significant variables were determined, new competing risk regression models were run containing only the significant variables. The competing risk regression model equation was extracted for each group to be used later in validating the risk factor score. The baseline cumulative incidence function (CIF) was also calculated for each model for a time of two years. The baseline CIF is calculated where the reference groups for all categorical variables is zero, and all continuous variables are zero.

5.3 Results

5.3.1 Participant Information

The mean age of the test cohort was 82.8 years (range 65 to 106 years). The cohort included 17,339 (38.5%) males and 27,705 (61.5%) females. Most of the cohort identified as European ethnicity (88.2%) and most hip fractures were sustained by those of European ethnicity (94.9%). At the end of the study period, 1,475 (3.3%) people had sustained a hip fracture, 13,167 (28.2%) had died without a hip fracture, and 30,404 (67.5%) were alive and had not had a hip fracture. Females had a higher rate of fracture (5.9%) than males (2.6%), and most fractures occurred in the 85-94 years age group. Of the males in the cohort, 35.7% died by end of the study period, compared to 25.2% of females. For living arrangement, 49.8% of individuals who lived alone. Over half (52.3%) of people had some level of cognitive impairment. Overall 70.7% of individuals had some level of fatigue: 12.1% of the cohort had severe fatigue, 50.1% had died by the end of the study period. This study had a total person-time of 55,444 years. Table 13 below provides a summary of the descriptive information. All variables are defined in section 3.3.

Table 13 Descriptive information of variables of interest for test cohort (n=45,046) with totals and partitioned by outcome

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
Sex				
Male	17,339 (38.5)	10,710 (61.8)	444 (2.6)	6,185 (35.7)
Female	27,707 (61.5)	19,692 (71.1)	1,031 (3.7)	6,982 (25.2)
Age Group (years)				
65-74	7,574 (16.8)	5,780 (76.3)	109 (1.4)	1,685 (22.2)
75-84	18,640 (41.4)	13,278 (71.2)	532 (2.9)	4,830 (25.9)
85-94	17,315 (38.4)	10,613 (61.3)	742 (4.3)	5,960 (34.4)
95+	1,517 (3.4)	733 (48.3)	92 (6.1)	692 (45.6)
Ethnicity				
Māori	2,487 (5.5)	1,724 (69.3)	26 (1.0)	737 (29.6)
Pacific	1,430 (3.2)	1,043 (72.9)	19 (1.3)	368 (25.7)
Asian	1,037 (2.3)	783 (75.5)	14 (1.4)	240 (23.1)
European	39,732 (88.2)	26,584 (66.9)	1,400 (3.5)	11,748 (29.6)
Other	360 (0.8)	270 (75.0)	16 (4.4)	74 (20.6)
Living Arrangement				
Lives alone	22,423 (49.8)	15,242 (68.0)	741 (3.3)	6,440 (28.7)
Lives with others	22,623 (50.2)	15,162 (67.0)	734 (3.2)	6,727 (29.7)
Cognitive Skills[b]				
Independent	21,505 (47.7)	15,293 (71.1)	590 (2.7)	5,622 (26.1)
Minimal Dependence	16,512 (36.7)	11,039 (66.9)	588 (3.6)	4,885 (29.6)
Moderate to Severe dependence	7,028 (15.6)	4,071 (57.9)	297 (4.2)	2,660 (37.8)
Hearing[c]				
Adequate	23,142 (51.4)	16,399 (70.9)	691 (3.0)	6,052 (26.2)
Minimal to moderate	20,056 (44.5)	13,011 (64.9)	709 (3.5)	6,336 (31.6)
Severe to none	1,841 (4.1)	993 (53.9)	75 (4.1)	773 (42.0)

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
Vision[d]				
Adequate	32,013 (71.1)	22,281 (69.6)	948 (3.0)	8,784 (27.4)
Minimal to moderate	11,863 (26.3)	7,429 (62.6)	477 (4.0)	3,957 (33.4)
Severe to none	1,162 (2.6)	692 (59.6)	50 (4.3)	420 (36.1)
Walking[a]				
Independent	34,524 (76.6)	25,199 (73.0)	1,084 (3.1)	8,241 (23.9)
Some assistance required	6,633 (14.7)	3,524 (53.1)	286 (4.3)	2,823 (42.6)
Maximum Assistance/Dependent	2,336 (5.2)	995 (42.6)	82 (3.5)	1,259 (53.9)
Locomotion[e]				
Independent	35,033 (77.8)	25,572 (73.0)	1,097 (3.1)	8,364 (23.9)
Some assistance required	6,228 (13.8)	3,274 (52.6)	273 (4.4)	2,681 (43.0)
Dependent	2,971 (6.6)	1,233 (41.5)	90 (3.0)	1,648 (55.5)
Primary Mode of Locomotion[b]				
Walking, no assistive device	14,486 (32.2)	11,225 (77.5)	411 (2.8)	2,850 (19.7)
Assisted walking	28,367 (63.0)	18,201 (64.2)	1,029 (3.6)	9,137 (32.2)
Unable to walk	2,192 (4.9)	977 (44.6)	35 (1.6)	1,180 (53.8)
Timed 4 metre walk (seconds)[f]				
0-15	27,062 (60.1)	20,011 (73.9)	869 (3.2)	6,182 (22.8)
16-29	3,927 (8.7)	2,603 (66.3)	146 (3.7)	1,178 (30.0)
30+	4,026 (8.9)	2,563 (63.7)	164 (4.1)	1,299 (32.3)
Incomplete test	10,025 (22.3)	5,224 (52.1)	296 (3.0)	4,505 (44.9)
Total hours of exercise or physical activity[b]				
None/Less than 1 hour	23,871 (53.0)	14,971 (62.7)	741 (3.1)	8,159 (34.2)
1-4 hours	18,745 (41.6)	13,612 (72.6)	642 (3.4)	4,491 (24)
4 hours or more	2,429 (5.4)	1,820 (74.9)	92 (3.8)	517 (21.3)
Number of days left house in last 3 days[b]				
None	14,987 (33.3)	8,037 (53.6)	514 (3.4)	6,436 (42.9)
1-2	11,963 (26.6)	8,277 (69.2)	438 (3.7)	3,248 (27.2)
3	18,095 (40.2)	14,089 (77.9)	523 (2.9)	3,483 (19.2)

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
Bladder Continence[g]				
Continent	28,200 (62.6)	19,706 (69.9)	867 (3.1)	7,627 (27.0)
Infrequently incontinent	4,280 (8.5)	2,937 (68.6)	134 (3.1)	1,209 (28.2)
Occasionally incontinent	4,079 (9.1)	2,668 (65.4)	162 (4.0)	1,249 (30.6)
Frequently Incontinent	6,865 (15.2)	4,335 (63.1)	257 (3.7)	2,273 (33.1)
Incontinent	1,586 (3.5)	742 (46.8)	53 (3.3)	791 (49.9)
Bowel Continence[h]				
Continent	37,767 (83.8)	26,519 (70.2)	1,216 (3.2)	10,032 (26.6)
Infrequently incontinent	2,912 (6.5)	1,759 (60.4)	104 (3.6)	1,049 (36.0)
Occasionally Incontinent	2,331 (5.2)	1,230 (52.8)	100 (4.3)	1,001 (42.9)
Frequently Incontinent	1,089 (2.4)	502 (46.1)	34 (3.1)	553 (50.8)
Incontinent	840 (1.9)	343 (40.8)	18 (2.1)	479 (57.0)
Fatigue[i]				
None	13,194 (29.3)	9,928 (75.2)	399 (3.0)	2,867 (21.7)
Minimal to Moderate	26,380 (58.6)	17,893 (67.8)	928 (3.5)	7,559 (28.7)
Severe	5,469 (12.1)	2,581 (47.2)	148 (2.7)	2,740 (50.1)
Difficult or unable to move self to standing[i]				
Not present	28,012 (62.2)	20,151 (71.9)	914 (3.3)	6,947 (24.8)
Present	17,031 (37.8)	10,251 (60.2)	561 (3.3)	6,219 (36.5)
Dizziness[i]				
Not present	38,108 (84.6)	25,860 (67.9)	1,235 (3.2)	11,013 (28.9)
Present	6,935 (15.4)	4,542 (65.5)	240 (3.5)	2,153 (31.0)
Unsteady Gait[i]				
Not present	21,569 (47.9)	15,416 (71.5)	669 (3.1)	5,484 (25.4)
Present	23,474 (52.1)	14,986 (63.8)	806 (3.4)	7,682 (32.7)
Previous Fall[i]				
No Fall	26,889 (59.7)	18,936 (70.4)	792 (2.9)	7,161 (26.6)
Had at least one fall	18,154 (40.3)	11,466 (63.2)	683 (3.8)	6,005 (33.1)

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
Previous hip fracture[a]				
None	44,232 (98.2)	29,939 (67.7)	1,442 (3.3)	12,851 (29.1)
Had previous fracture	812 (1.8)	464 (57.1)	33 (4.1)	315 (38.8)
Previous Other fracture[a]				
None	43,704 (97.0)	29,576 (67.7)	1,414 (3.2)	12,714 (29.1)
Had previous fracture	1,340 (3.0)	827 (61.7)	61 (4.6)	452 (33.7)
Easily Distracted[j]				
Not present	34,633 (76.9)	23,621 (68.2)	1,051 (3.0)	9,961 (28.8)
Present	10,400 (23.1)	6,779 (65.2)	424 (4.1)	3,197 (30.7)
Mental function varies over the course of a day[j]				
Not present	35,107 (77.9)	24,232 (69.0)	1,054 (3.0)	9,821 (28.0)
Present	9,926 (22.0)	6,168 (62.1)	421 (4.2)	3,337 (33.6)
Wandering[k]				
Not Present	43,254 (96.0)	29,284 (67.7)	1,379 (3.2)	12,591 (29.1)
Present	1,783 (4.0)	1,117 (62.6)	96 (5.4)	570 (32.0)
Frequency of Pain[i]				
No pain	18,291 (40.6)	11,960 (65.4)	632 (3.5)	5,699 (31.2)
Not in last 3 days	4,573 (10.2)	3,160 (69.1)	172 (3.8)	1,241 (27.1)
At least once in last 3 days	22,179 (49.2)	15,282 (68.9)	671 (3.0)	6,226 (28.1)
Intensity of Highest level of Pain[i]				
None	18,495 (41.1)	12,067 (65.2)	649 (3.5)	5,779 (31.2)
Mild to Moderate	19,860 (44.1)	13,679 (68.9)	618 (3.1)	5,563 (28.0)
Severe to Excruciating	6,688 (14.8)	4,656 (69.6)	208 (3.1)	1,824 (27.3)
Consistency of Pain[i]				
None/Very Little	19,792 (43.9)	12,972 (65.5)	683 (3.5)	6,137 (31.0)
Intermittent	19,399 (43.1)	13,323 (68.7)	612 (3.1)	5,464 (28.2)
Constant	5,852 (13.0)	4,107 (70.2)	180 (3.1)	1,565 (26.7)

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
BMI				
Underweight	2,292 (5.1)	1,230 (53.7)	151 (6.6)	911 (39.7)
Normal	13,538 (30.1)	9,064 (67.0)	498 (3.7)	3,976 (29.4)
Overweight	7,480 (16.6)	5,559 (74.3)	162 (2.2)	1,759 (23.5)
Obese	4,616 (10.0)	3,690 (79.9)	57 (1.2)	869 (18.8)
Undetermined	17,237 (38.3)	10,861 (63.0)	607 (3.5)	5,652 (32.8)
Smokes tobacco daily[i]				
No	42,644 (94.7)	28,827 (67.6)	1,383 (3.2)	12,434 (29.2)
Yes	2,399 (5.3)	1,575 (65.7)	92 (3.8)	732 (30.5)
Consumes Alcohol[i]				
None	35,914 (79.7)	23,808 (66.3)	1,209 (3.4)	10,897 (30.3)
At least one drink	9,129 (20.3)	6,594 (72.2)	266 (3.8)	2,269 (42.8)
Weight Loss of 5% or more[i]				
No	38,317 (85.1)	26,807 (67.9)	1,220 (3.2)	10,290 (26.9)
Yes	6,726 (14.9)	3,595 (53.4)	255 (3.8)	2,876 (42.8)
Dehydrated[i]				
No	44,175 (98.1)	30,008 (67.9)	1,443 (3.3)	12,724 (28.8)
Yes	868 (1.9)	394 (45.4)	32 (3.7)	442 (50.9)
Decrease in food/fluid consumed[i]				
No	40,280 (89.4)	27,975 (69.5)	1,315 (3.3)	10,990 (27.3)
Yes	4,763 (10.6)	2,427 (51.0)	160 (3.4)	2,176 (45.7)
Parkinson’s Disease[a]				
Not present	43,263 (96.0)	29,197 (67.5)	1,394 (3.2)	12,672 (29.3)
Diagnosis present	1,781 (4.0)	1,206 (67.7)	81 (4.5)	494 (27.7)
Stroke/CVA[a]				
Not Present	37,121 (82.4)	25,198 (67.9)	1,240 (3.3)	10,683 (28.8)
Diagnosis Present	7,923 (17.6)	5,205 (65.7)	2,483 (31.3)	2,483 (31.3)

Variable names	Total n (%)	First Event		
		Alive, no fracture n (%)	Fracture n (%)	Death n (%)
COPD[a]				
Not present	37,920 (84.2)	26,194 (69.1)	1,257 (3.3)	10,469 (27.6)
Diagnosis present	7,124 (15.8)	4,209 (59.1)	218 (3.1)	2,697 (37.9)
Dyspnoea[i]				
Not present	24,021 (53.3)	17,173 (71.5)	871 (3.6)	5,977 (24.9)
Present	21,022 (46.7)	13,229 (62.9)	604 (2.9)	7,189 (34.2)
Environment[d]				
No	39,487 (87.7)	26,787 (67.8)	1,282 (3.2)	11,418 (28.9)
Yes	5,551 (12.3)	3,611 (65.1)	193 (3.5)	1,747 (31.5)

[a]2 values missing, [b]1 value missing, [c]7 values missing, [d]8 values missing, [e]814 values missing, [f]6 variables missing, [g]36 values missing, [h]107 values missing, [i]3 values missing, [j]13 values missing, [k]9 values missing.

5.3.2 Competing Risks Regression

5.3.2.1 Whole Test Cohort

The risk factors for hip fracture identified by the model were age, sex, ethnicity, falls, mental function varies throughout the course of the day, wandering, tobacco use, BMI, and Parkinson's disease. Dyspnoea (shortness of breath) was also associated with hip fracture, but those who suffered from dyspnoea were at a reduced risk of hip fracture (SHR 0.81 95% CI: 0.72 to 0.91). For BMI, those who were underweight were at an increased risk of hip fracture (SHR 1.65 95% CI: 1.36 to 2.00) compared to individuals who had a normal BMI, and those who were overweight or obese had a reduced rate of hip fracture (Overweight SHR 0.67 95% CI: 0.56 to 0.81), Obese SHR 0.48 95% CI: 0.36 to 0.64). Table 14 presents the unadjusted and adjusted SHRs for each variable in the models.

Table 14 Unadjusted and adjusted competing risk regression models for the whole cohort

Variable Names	Unadjusted Model SHR (95% CI)	Adjusted* Model SHR (95% CI)
Sex		
Male	1 (reference)	1 (reference)
Female	1.46 (1.31, 1.64)	1.37 (1.21, 1.54)
Age Group (years)		
65-74	1 (reference)	1 (reference)
75-84	1.98 (1.61, 2.43)	1.83 (1.48, 2.27)
85-94	2.96 (2.42, 3.62)	2.51 (2.00, 3.13)
95+	4.27 (3.23, 5.63)	3.25 (2.38, 4.43)
Ethnicity		
Māori	0.30 (0.21, 0.45)	0.38 (0.25, 0.57)
Pacific People	0.36 (0.23, 0.57)	0.49 (0.30, 0.79)
Asian	0.38 (0.23, 0.65)	0.39 (0.22, 0.67)
European	1 (reference)	1 (reference)
Other	1.29 (0.79, 2.13)	1.42 (0.86, 2.34)
Living Arrangement		
Lives alone	1 (reference)	1 (reference)
Lives with others	0.98 (0.88, 1.08)	0.99 (0.89, 1.09)
Cognitive Skills		
Independent	1 (reference)	1 (reference)
Minimal Independence	1.32 (1.17, 1.47)	1.14 (1.00, 1.29)
Moderate to Severe dependence	1.50 (1.31, 1.73)	1.16 (0.96, 1.40)
Hearing		
Adequate	1 (reference)	1 (reference)
Minimal to moderate	1.18 (1.06, 1.31)	0.98 (0.88, 1.10)
Severe to none	1.35 (1.06, 1.71)	0.99 (0.77, 1.27)
Vision		
Adequate	1 (reference)	1 (reference)
Minimal to moderate	1.32 (1.18, 1.47)	1.15 (1.02, 1.29)
Severe to none	1.37 (1.03, 1.82)	1.19 (0.89, 1.59)

Variable Names	Unadjusted Model SHR (95% CI)	Adjusted* Model SHR (95% CI)
Walking		
Independent	1 (reference)	1 (reference)
Some assistance required	1.34 (1.17, 1.52)	1.04 (0.76, 1.42)
Maximum Assistance/Dependent	1.08 (0.86, 1.35)	1.21 (0.73, 2.00)
Locomotion		
Independent	1 (reference)	1 (reference)
Some assistance required	1.37 (1.20, 1.57)	1.07 (0.78, 1.47)
Dependent	0.93 (0.75, 1.15)	0.89 (0.54, 1.47)
Primary Mode of Locomotion		
Walking, no assistive device	1 (reference)	1 (reference)
Assisted walking	1.24 (1.11, 1.39)	1.09 (0.95, 1.25)
Unable to walk	0.52 (0.37, 0.73)	0.73 (0.41, 1.32)
Timed 4 metre walk (seconds)		
0-15	1 (reference)	1 (reference)
16-29	1.07 (0.90, 1.28)	1.00 (0.83, 1.20)
30+	1.13 (0.95, 1.33)	1.04 (0.88, 1.24)
Incomplete test	0.86 (0.76, 0.99)	0.88 (0.75, 1.03)
Total hours of exercise or physical activity		
None/Less than 1 hour	1 (reference)	1 (reference)
1-4 hours	1.06 (0.95, 1.17)	1.04 (0.93, 1.17)
4 hours or more	1.05 (0.84, 1.30)	1.11 (0.89, 1.40)
Number of days left house in last 3 days		
None	1 (reference)	1 (reference)
1-2	1.08 (0.95, 1.22)	1.18 (1.02, 1.37)
3	0.86 (0.77, 0.98)	1.03 (0.88, 1.20)
Bladder Continence		
Continent	1 (reference)	1 (reference)
Infrequently incontinent	1.03 (0.86, 1.24)	0.94 (0.78, 1.13)
Occasionally incontinent	1.29 (1.09, 1.52)	1.09 (0.92, 1.30)
Frequently Incontinent	1.20 (1.05, 1.38)	1.07 (0.92, 1.30)
Incontinent	1.04 (0.79, 1.37)	1.27 (0.91, 1.76)
Bowel Continence		
Continent	1 (reference)	1 (reference)
Infrequently incontinent	1.11 (0.90, 1.35)	0.98 (0.79, 1.21)
Occasionally Incontinent	1.31 (1.07, 1.61)	1.10 (0.87, 1.38)
Frequently Incontinent	0.93 (0.66, 1.31)	0.83 (0.57, 1.21)
Incontinent	0.64 (0.40, 1.03)	0.84 (0.47, 1.49)
Fatigue		
None	1 (reference)	1 (reference)
Minimal to Moderate	1.18 (1.05, 1.32)	1.16 (1.02, 1.31)
Severe	0.89 (0.73, 1.07)	0.89 (0.72, 1.11)
Difficult or unable to move self to standing		
Not present	1 (reference)	1 (reference)
Present	1.00 (0.90, 1.12)	0.98 (0.86, 1.11)
Dizziness		
Not present	1 (reference)	1 (reference)
Present	1.06 (0.93, 1.22)	1.08 (0.93, 1.25)

Variable Names	Unadjusted Model SHR (95% CI)	Adjusted* Model SHR (95% CI)
Unsteady Gait		
Not present	1 (reference)	1 (reference)
Present	1.10 (0.99, 1.21)	1.01 (0.89, 1.14)
Previous Fall		
No Fall	1 (reference)	1 (reference)
Had at least one fall	1.30 (1.17, 1.44)	1.14 (1.02, 1.28)
Previous hip fracture		
None	1 (reference)	1 (reference)
Had previous fracture	1.22 (0.86, 1.72)	0.90 (0.62, 1.29)
Previous Other fracture		
None	1 (reference)	1 (reference)
Had previous fracture	1.44 (1.11, 1.86)	1.05 (0.80, 1.38)
Easily Distracted		
Not present	1 (reference)	1 (reference)
Present	1.34 (1.20, 1.50)	1.10 (0.96, 1.27)
Mental function varies over the course of a day		
Not present	1 (reference)	1 (reference)
Present	1.39 (1.24, 1.56)	1.16 (1.01, 1.34)
Wandering		
Not Present	1 (reference)	1 (reference)
Present	1.68 (1.37, 2.07)	1.40 (1.02, 1.77)
Frequency of Pain		
No pain	1 (reference)	1 (reference)
Not in last 3 days	1.13 (0.96, 1.34)	1.36 (1.01, 1.83)
At least once in last 3 days	0.89 (0.80, 1.00)	1.12 (0.81, 1.52)
Intensity of Highest level of Pain		
None	1 (reference)	1 (reference)
Mild to Moderate	0.91 (0.81, 1.01)	0.69 (0.50, 0.95)
Severe to Excruciating	0.91 (0.78, 1.06)	0.76 (0.53, 1.09)
Consistency of Pain		
None/Very Little	1 (reference)	1 (reference)
Intermittent	0.94 (0.85, 1.05)	1.21 (0.93, 1.57)
Constant	0.89 (0.76, 1.05)	1.25 (0.93, 1.69)
Body Mass Index (BMI)		
Underweight	1.81 (1.51, 2.17)	1.65 (1.36, 2.00)
Normal	1 (reference)	1 (reference)
Overweight	0.59 (0.49, 0.70)	0.67 (0.56, 0.81)
Obese	0.34 (0.26, 0.45)	0.48 (0.36, 0.64)
Undetermined	0.93 (0.82, 1.04)	0.99 (0.87, 1.12)
Smokes tobacco daily		
No	1 (reference)	1 (reference)
Yes	1.21 (0.98, 1.49)	1.55 (1.24, 1.95)
Consumes Alcohol		
None	1 (reference)	1 (reference)
At least one drink	0.87 (0.76, 0.99)	0.90 (0.78, 1.03)
Weight Loss of 5% or more		
No	1 (reference)	1 (reference)
Yes	1.19 (1.04, 1.37)	1.08 (0.93, 1.25)

Variable Names	Unadjusted Model SHR (95% CI)	Adjusted* Model SHR (95% CI)
Dehydrated		
No	1 (reference)	1 (reference)
Yes	1.12 (0.79, 1.59)	0.82 (0.56, 1.20)
Decrease in food/fluid consumed		
No	1 (reference)	1 (reference)
Yes	1.05 (0.89, 1.23)	0.95 (0.79, 1.15)
Parkinson's Disease		
Not present	1 (reference)	1 (reference)
Diagnosis present	1.37 (1.09, 1.71)	1.46 (1.15, 1.86)
Stroke/CVA		
Not Present	1 (reference)	1 (reference)
Diagnosis Present	0.87 (0.76, 1.00)	0.92 (0.79, 1.06)
COPD		
Not present	1 (reference)	1 (reference)
Diagnosis present	0.92 (0.80, 1.06)	1.14 (0.79, 1.06)
Dyspnoea		
Not present	1 (reference)	1 (reference)
Present	0.80 (0.72, 0.89)	0.81 (0.72, 0.91)
Environment		
No	1 (reference)	1 (reference)
Yes	1.05 (0.90, 1.22)	1.10 (0.94, 1.29)

*Adjusted variables: age, sex, ethnicity, living arrangement, cognitive impairment, hearing, vision, walking, locomotion, primary mode of locomotion, timed 4 metre walk, exercise hours, left house in last 3 days, bladder continence, bowel continence, fatigue, difficulty standing, dizziness, unsteady gait, falls, previous hip fracture, previous other fracture, easily distracted, mental function varies, wandering, frequency of pain, intensity of pain, consistency of pain, BMI, tobacco use, alcohol consumption, weight loss, dehydration, decrease in food consumption, Parkinson's disease, stroke, COPD, dyspnoea, environment, and living arrangement.

5.3.2.2 Males and Females

Adjusted competing risk regression models were run for males and females separately. These models are presented in Table 15 below. The variables associated with hip fracture for males were age, Parkinson's disease and Dyspnoea. Dyspnoea was associated with a reduced risk of fracture for males (SHR 0.78 95% CI: 0.63 to 0.97). For the females only group the significant variables were age, ethnicity, wandering, BMI, tobacco use, and dyspnoea. High BMI (Overweight SHR 0.60 95% CI 0.47 to 0.76), Obese SHR 0.47 95% CI 0.34 to 0.66), and dyspnoea (SHR 0.82 95% CI: 0.71, 0.94) were associated with a reduced rate of hip fracture. The variables for the whole group and the female cohort were similar, but falls, mental function varies throughout the day, and Parkinson's disease were not associated risk factors for the female cohort.

Table 15 Adjusted competing risk regression models for male and female groups

Variable names	Males Adjusted* Analysis SHR (95% CI)	Females Adjusted* Analysis SHR (95% CI)
Age Group (years)		
65-74	1 (reference)	1 (reference)
75-84	2.11 (1.47, 3.03)	1.69 (1.29, 2.22)
85-94	2.42 (1.65, 3.54)	2.49 (1.89, 3.28)
95+	3.43 (1.86, 6.32)	3.13 (2.17,4.53)
Ethnicity		
Māori	0.36 (0.16, 0.82)	0.38 (0.23, 0.60)
Pacific People	0.57 (0.25, 1.29)	0.45 (0.25, 0.81)
Asian	0.58 (0.26, 1.29)	0.30 (0.14, 0.64)
European	1 (reference)	1 (reference)
Other	1.75 (0.76, 4.00)	1.26 (0.67, 2.38)
Living Arrangement		
Lives alone	1 (reference)	1 (reference)
Lives with others	0.84 (0.69, 1.01)	1.06 (0.93, 1.20)
Cognitive Skills		
Independent	1 (reference)	1 (reference)
Minimal Independence	1.18 (0.94, 1.48)	1.11 (0.95, 1.30)
Moderate to Severe dependence	1.06 (0.74, 1.51)	1.20 (0.96, 1.50)
Hearing		
Adequate	1 (reference)	1 (reference)
Minimal to moderate	1.04 (0.85, 1.29)	0.96 (0.84, 1.10)
Severe to none	1.17 (0.78, 1.76)	0.91 (0.66, 1.25)
Vision		
Adequate	1 (reference)	1 (reference)
Minimal to moderate	1.52 (0.93, 1.42)	1.15 (1.00, 1.32)
Severe to none	1.16 (0.66, 2.03)	1.19 (0.85, 1.68)
Walking		
Independent	1 (reference)	1 (reference)
Some assistance required	0.97 (0.58, 1.63)	1.08 (0.73, 1.58)
Maximum Assistance/Dependent	0.78 (0.37, 1.64)	1.19 (0.79, 2.80)
Locomotion		
Independent	1 (reference)	1 (reference)
Some assistance required	1.12 (0.66, 1.89)	1.05 (0.71, 1.55)
Dependent	1.37 (0.68, 2.74)	0.73 (0.38, 1.41)
Primary Mode of Locomotion		
Walking, no assistive device	1 (reference)	1 (reference)
Assisted walking	1.11 (0.87, 1.42)	1.08 (0.92, 1.28)
Unable to walk	0.66 (0.24, 1.83)	0.78 (0.38, 1.60)
Timed 4 Metre walk		
0-15 seconds	1 (reference)	1 (reference)
16-29 seconds	0.90 (0.64, 1.26)	1.05 (0.84, 1.29)
30+ seconds	1.02 (0.74, 1.41)	1.05 (0.86, 1.30)
Incomplete test	0.75 (0.55, 1.02)	0.94 (0.78, 1.14)

Variable names	Males Adjusted* Analysis SHR (95% CI)	Females Adjusted* Analysis SHR (95% CI)
Total hours of exercise or physical activity		
None/Less than 1 hour	1 (reference)	1 (reference)
1-4 hours	1.07 (0.87, 1.32)	1.03 (0.90, 1.18)
4 hours or more	0.88 (0.56, 1.38)	1.22 (0.93, 1.58)
Number of days left house in last 3 days		
None	1 (reference)	1 (reference)
1-2 days	1.29 (0.98, 1.71)	1.14 (0.96, 1.35)
3 days	1.02 (0.77, 1.36)	1.03 (0.85, 1.23)
Bladder Continence		
Continent	1 (reference)	1 (reference)
Infrequently incontinent	0.84 (0.58, 1.23)	0.98 (0.79, 1.22)
Occasionally incontinent	1.03 (0.73, 1.46)	1.12 (0.91, 1.37)
Frequently Incontinent	0.86 (0.61, 1.21)	1.14 (0.95, 1.36)
Incontinent	1.58 (0.95, 2.62)	1.13 (0.73, 1.75)
Bowel Continence		
Continent	1 (reference)	1 (reference)
Infrequently incontinent	0.87 (0.58, 1.31)	1.05 (0.82, 1.34)
Occasionally Incontinent	1.03 (0.67, 1.59)	1.14 (0.86, 1.50)
Frequently Incontinent	0.66 (0.32, 1.37)	0.94 (0.60, 1.48)
Incontinent	0.95 (0.41, 2.21)	0.73 (0.33, 1.65)
Fatigue		
None	1 (reference)	1 (reference)
Minimal to Moderate	1.33 (1.04, 1.70)	1.10 (0.95, 1.28)
Severe	1.27 (0.87, 1.85)	0.75 (0.57, 0.99)
Difficult or unable to move self to standing		
Not present	1 (reference)	1 (reference)
Present	0.94 (0.74, 1.18)	1.00 (0.85, 1.17)
Dizziness		
Not present	1 (reference)	1 (reference)
Present	1.08 (0.83, 1.40)	1.08 (0.91, 1.29)
Unsteady Gait		
Not present	1 (reference)	1 (reference)
Present	1.04 (0.82, 1.32)	0.99 (0.86, 1.15)
Previous Fall		
No Fall	1 (reference)	1 (reference)
Had at least one fall	1.17 (0.82, 1.32)	1.13 (0.98, 1.29)
Previous hip fracture		
None	1 (reference)	1 (reference)
Had previous fracture	0.88 (0.41, 1.91)	0.88 (0.58, 1.33)
Previous Other fracture		
None	1 (reference)	1 (reference)
Had previous fracture	1.48 (0.83, 2.64)	0.97 (0.71, 1.33)
Easily Distracted		
Not present	1 (reference)	1 (reference)
Present	1.07 (0.83, 1.38)	1.11 (0.94, 1.31)
Mental Function Varies over the course of a day		
Not present	1 (reference)	1 (reference)
Present	1.26 (0.98, 1.63)	1.12 (0.94, 1.33)

Variable names	Males Adjusted* Analysis SHR (95% CI)	Females Adjusted* Analysis SHR (95% CI)
Wandering		
Not Present	1 (reference)	1 (reference)
Present	1.14 (0.74, 1.77)	1.54 (1.16, 2.05)
Frequency of Pain		
No pain	1 (reference)	1 (reference)
Not in last 3 days	1.40 (0.84, 2.34)	1.34 (0.93, 1.94)
At least once in last 3 days	1.35 (0.78, 1.77)	1.03 (0.71, 1.53)
Intensity of Highest level of Pain		
None	1 (reference)	1 (reference)
Mild to Moderate	0.63 (0.36, 1.10)	0.72 (0.48, 1.07)
Severe to Excruciating	0.76 (0.41, 1.43)	0.78 (0.50, 1.21)
Consistency of Pain		
None/Very Little	1 (reference)	1 (reference)
Intermittent	0.97 (0.63, 1.48)	1.31 (0.94, 1.81)
Constant	0.97 (0.57, 1.63)	1.37 (0.94, 1.97)
BMI		
Underweight	1.54 (0.97, 2.44)	1.67 (1.35, 2.06)
Normal	1 (reference)	1 (reference)
Overweight	0.81 (0.61, 1.07)	0.60 (0.47, 0.76)
Obese	0.48 (0.28, 0.82)	0.47 (0.34, 0.66)
Undetermined	0.98 (0.78, 1.23)	0.99 (0.86, 1.15)
Smokes tobacco daily		
No	1 (reference)	1 (reference)
Yes	1.31 (0.87, 1.97)	1.70 (1.30, 2.23)
Consumes Alcohol		
None	1 (reference)	1 (reference)
At least one drink	0.84 (0.67, 1.06)	0.93 (0.78, 1.11)
Weight Loss of 5% or more		
No	1 (reference)	1 (reference)
Yes	1.25 (0.96, 1.64)	1.01 (0.84, 1.21)
Dehydrated		
No	1 (reference)	1 (reference)
Yes	0.54 (0.24, 1.22)	0.95 (0.62, 1.45)
Decrease in food/fluid consumed		
No	1 (reference)	1 (reference)
Yes	0.93 (0.66, 1.32)	0.96 (0.77, 1.20)
Parkinson’s Disease		
Not present	1 (reference)	1 (reference)
Diagnosis present	1.53 (1.10, 2.13)	1.37 (0.96, 1.95)
Stroke/CVA		
Not Present	1 (reference)	1 (reference)
Diagnosis Present	1.08 (0.86, 1.37)	0.84 (0.70, 1.01)
COPD		
Not present	1 (reference)	1 (reference)
Diagnosis present	1.18 (0.89, 1.56)	1.11 (0.91, 1.35)
Dyspnoea		
Not present	1 (reference)	1 (reference)
Present	0.78 (0.63, 0.97)	0.82 (0.71, 0.94)

Variable names	Males Adjusted* Analysis SHR (95% CI)	Females Adjusted* Analysis SHR (95% CI)
Environment		
No	1 (reference)	1 (reference)
Yes	1.02 (0.69, 1.01)	1.14 (0.95, 1.38)

*Adjusted variables: age, ethnicity, living arrangement, cognitive impairment, hearing, vision, walking, locomotion, primary mode of locomotion, timed 4 metre walk, exercise hours, left house in last 3 days, bladder continence, bowel continence, fatigue, difficulty standing, dizziness, unsteady gait, falls, previous hip fracture, previous other fracture, easily distracted, mental function varies, wandering, frequency of pain, intensity of pain, consistency of pain, BMI, tobacco use, alcohol consumption, weight loss, dehydration, decrease in food consumption, Parkinson's disease, stroke, COPD, dyspnoea, environment, and living arrangement.

5.3.3 Explanatory Variables

5.3.3.1 Whole Test Cohort

Figure 7 below is a graph of all significant risk factors associated with hip fracture for the whole test cohort and the percentage they contribute to the model. Age was the most influential variable and it accounted for almost 50% of the predictive power of the model. BMI was the least explanatory variable included in the analysis.

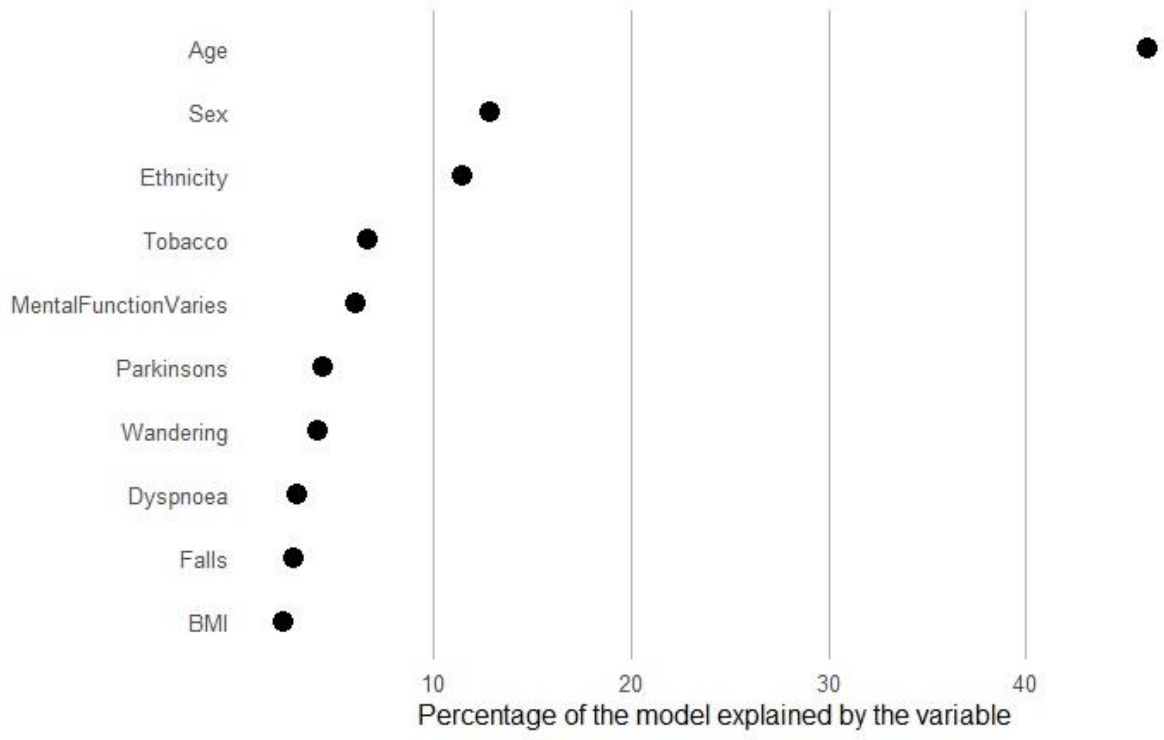

Figure 7 Percentage of the model explained by each variable for the whole cohort

5.3.3.2 Males

Figure 8 presents the three risk factors associated with hip fracture in males and the percentage of the model they explained. As was the case for the whole cohort, age had the highest percentage contribution to the model. Dyspnoea had the lowest percentage contribution to the males-only model.

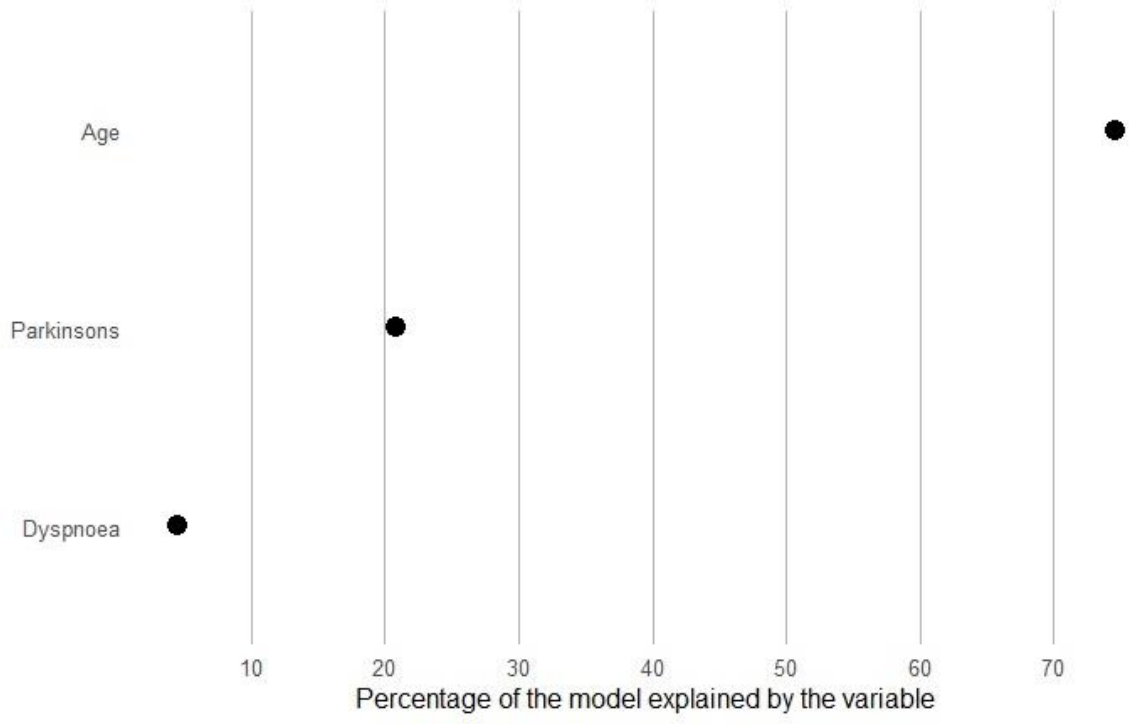

Figure 8 Percentage of the model explained by each variable for the males only model

5.3.3.3 Females

Figure 9 presents the percentage contribution to the model of each risk factor associated with hip fracture in females. Again, age had the highest percentage contribution. For the females, wandering had the next highest percentage contribution, followed by ethnicity. The lowest percentage contribution was BMI.

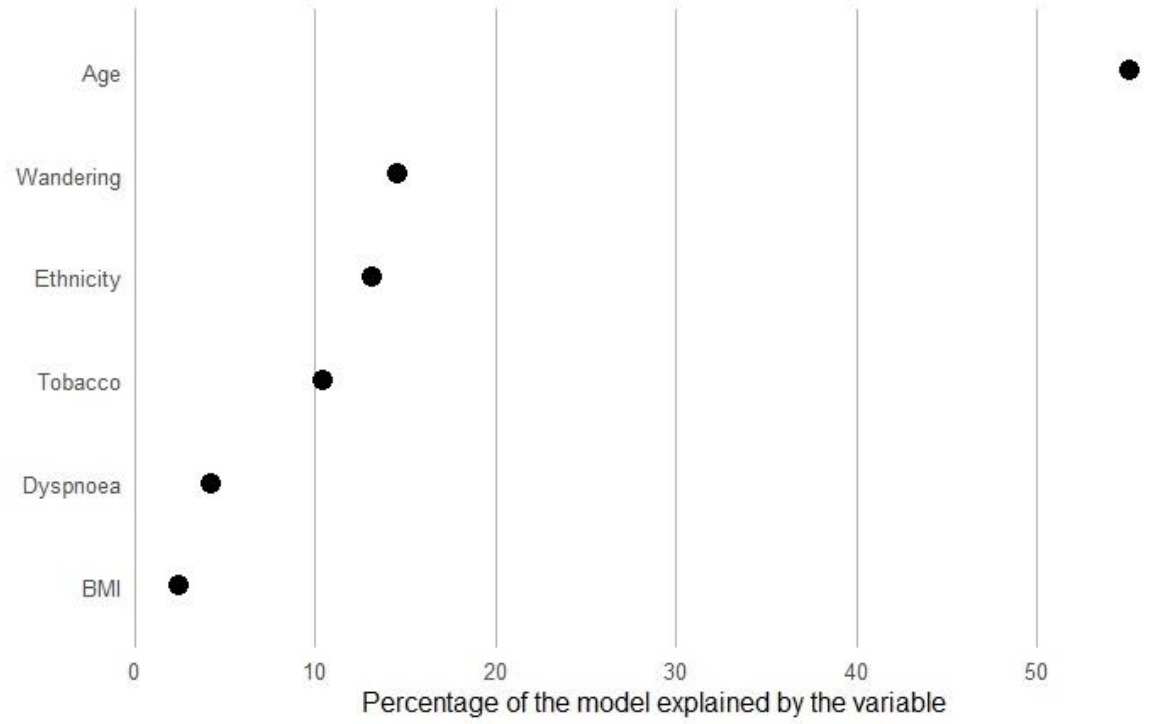

Figure 9 Percentage of the model explained by each variable for the females only model

5.3.4 Model Coefficients

The coefficients of the variables associated with hip fracture risk for the whole cohort, the males-only model, and the females-only model are listed below in Table 16. The coefficients are derived from the model and multiplied by their corresponding variable as part of the whole model calculation. For the males and females models, any variable not used in the model was listed as N/A (Not applicable). The baseline CIF at two years for the whole cohort was 0.0160; the baseline CIF for the males cohort was 0.0150, and for females was 0.0263. The baseline CIF is the value calculated when all variables in the model are set to zero.

Table 16 β coefficients from the competing risk regressions for whole cohort, males, and females only models

Participant Characteristics	**β coefficient (95% CI) Whole cohort**	**β coefficient (95% CI) Males**	**β coefficient (95% CI) Females**
Age Group			
65-74	0 (Reference)	0 (Reference)	0 (Reference)
75-84	0.62 (0.42, 0.83)	0.77 (0.43, 1.12)	0.56 (0.30, 0.82)
85-94	0.94 (0.73, 1.15)	1.02 (0.68, 1.37)	0.94 (0.68, 1.19)
95+	1.23 (0.95, 1.52)	1.41 (0.85, 1.98)	1.21 (0.87, 1.54)
Sex			
Male	0 (Reference)	N/A	N/A
Female	0.34 (0.23, 0.46)	N/A	N/A
Ethnicity			
Māori	-0.920 (-1.31, -0.53)	N/A	-0.90 (-1.35, -0.45)
Pacific People	-0.726 (-1.18, -0.27)	N/A	-0.80 (-1.35, -0.24)
Asian	-0.914 (-1.44, -0.39)	N/A	-1.11 (-1.81, -0.41)
European	0 (Reference)	N/A	0 (Reference)
Other	0.327 (-0.17, 0.82)	N/A	0.23 (-0.40, 0.86)
Falls			
None	0 (Reference)	N/A	N/A
Had at least one fall	0.16 (0.06, 0.26)	N/A	N/A
Mental Function Varies			
No	0 (Reference)	N/A	N/A
Yes	0.25 (0.13, 0.37)	N/A	N/A
Wandering			
No	0 (Reference)	N/A	0 (Reference)
Yes	0.42 (0.20, 0.64)	N/A	0.69 (0.44, 0.94)
BMI			
Underweight	0.49 (0.31, 0.68)	N/A	0.52 (0.32, 0.73)
Normal	0 (Reference)	N/A	0 (Reference)
Overweight	-0.39 (-0.57, -0.21)	N/A	-0.51 (-0.75, -0.28)
Obese	-0.74 (-1.02, -0.47)	N/A	-0.76 (-1.10, -0.43)
Undetermined	-0.03 (-0.15, 0.82)	N/A	-0.003 (-0.14, 0.14)
Tobacco use			
No	0 (Reference)	N/A	0 (Reference)
Yes	0.46 (0.24, 0.68)	N/A	0.55 (0.29, 0.81)
Parkinson’s Disease			
No diagnosis	0 (Reference)	0 (Reference)	N/A
Diagnosis Present	0.44 (0.21, 0.66)	0.56 (0.25, 0.87)	N/A
Dyspnoea			
No	0 (Reference)	0 (Reference)	0 (Reference)
Yes	-0.16 (-0.26, -0.05)	-0.18 (-0.37, 0.003)	-0.17 (-0.30, -0.05)

5.4 Discussion

5.4.1 Key Findings

The variables associated with hip fracture were age, sex, ethnicity, falls, mental function varies throughout the course of the day, wandering, BMI, tobacco use, Parkinson's disease, and dyspnoea. Males and females had different risk profiles; this may have been due to the lower number of males making it more difficult to detect small effects in that population. The risk factors associated with hip fracture for males were age, Parkinson's disease, and dyspnoea. The females-only model included age, ethnicity, wandering, BMI, tobacco use, and dyspnoea as factors relating to hip fracture.

For each of the three risk factor models, age contributed the most to hip fracture risk. This is reflected in previous studies on hip fracture risk, particularly with all hip fracture scores in Table 5 of Chapter 2 including age as a variable (49-52, 76, 84, 92, 102, 166, 167, 169). This is because as age increases, so does the chance of sustaining a hip fracture (60, 61, 89).

Previous hip fracture was included in nine out of the 11 models (FRAiL and Qfracture did not find this to be a significant risk factor) but was not found to be associated with hip fracture for this cohort.

Falls are a significant risk factor associated with hip fracture and was included in six out of the 11 models in Table 5. In this cohort, when examining the whole group, falls were significantly associated with hip fracture, but they were not when the data was stratified by sex. This is possibly due to a loss of power when separating the model into males- and females-only cohorts.

Most of the risk factors identified in this study were included in at least one of the hip fracture scores listed in Table 5. Mental function varies throughout the course of the day was not specifically found to be associated with hip fracture risk; however, in this case, it could be a proxy for cognitive impairment, which was found in two fracture scores (FRAiL and FRS). Dyspnoea was not included in any of the scores and has not been explicitly studied in the literature; in this study, it was noted that people with dyspnoea were likely to be at a reduced risk of fracture, possibly due to the inability to move around without becoming short of breath.

5.4.2 Strengths and Limitations

Most variables in the cohort had very little missing information, except for BMI where 38.3% of assessments did not have a value recorded. This is likely due to the difficulty of measuring the height and weight of people with limited mobility. All other variables had consistently

low missing data rates, which allows for higher quality results. The less data that is missing, the less impact that any systematic bias can have on the model.

The medication data within the interRAI-HC was not in a format that could be used for analysis. As detailed in the literature review, people who are prescribed certain medications such as corticosteroids are at an increased risk of osteoporotic fractures, including hip fracture (51, 81, 139). However, Berry *et al.* examined medications and their association with hip fracture for individuals who underwent an interRAI-LTCF assessment and found there was little association between medications and hip fractures (76).

Falls are a significant factor associated with hip fracture as the majority of hip fracture sustained by older adults are the result of a fall (20, 215). Falls appear to be less of a contributing factor to this model (see 5.3.3) than other variables. A potential explanation for this is that those who are frequent fallers within this cohort are captured by the Falls CAP and interventions are put in place for those individuals, and those who do not trigger the Falls CAP are sustaining more fractures.

The New Zealand version of the interRAI-HC 9.1 no longer has osteoporosis diagnosis information; therefore, it was unable to be included in the analysis. Osteoporosis diagnosis could be an important risk factor for hip fracture as noted in the literature.

5.4.3 Concluding Statement

Risk factors for hip fracture in the New Zealand interRAI-HC cohort were identified and analysed in this chapter. These results were similar to those of previous studies discussed in the literature review. The next chapter will utilise the results from this chapter to calculate and validate two hip fracture prediction scores: one for males and one for females.

6 Hip Fracture Score

6.1 Introduction

The previous chapter contained an exploration of the test dataset (two-thirds of the original dataset) to determine risk factors for hip fracture. Competing risk regression models were conducted to assess which variables were associated with hip fracture. In the data, several risk factors were found to be significantly associated with hip fracture for males, but were not found to be significantly associated with hip fracture for females and vice versa. Further analysis of the combined male and female cohort was not performed. Both males and females had different risk profiles, which suggests that separate hip fracture prediction models would need to be developed for each group. In additon, Berry *et al.* also chose to develop separate hip fracture prediction scores for males and females (76).

For males, the risk factors found to be associated with hip fracture were age, previous hip fracture, Parkinson's disease, and dyspnoea. For females, the associated risk factors were age, ethnicity, falls, previous hip fracture, wandering, BMI, tobacco use, and dyspnoea. In this chapter, two hip fracture scores will be validated using the results from the previous chapter; one score for males and one for females. The aim of this chapter is to assess how well the hip fracture scores can identify individuals at an elevated risk of hip fracture using the validation dataset (the remaining one-third of the original interRAI-HC dataset).

6.2 Methods

6.2.1 Participants

Participants were those in the validation dataset, the remaining one-third from the original interRAI-HC dataset of 67,331 individuals, after two-thirds were randomly selected as the test dataset. The validation dataset used in this analysis consisted of 22,291 people. Figure 5 in Chapter Three provides a breakdown of the participant selection criteria.

6.2.2 Variables

The variables utilised for this analysis were those that were determined to be significantly associated with hip fracture in the previous chapter. These variables were age, ethnicity, falls, mental function varies throughout the course of the day, wandering, BMI, tobacco use, Parkinson's disease, and dyspnoea. A description of the variables listed here can be found in Chapter Three, Table 8.

6.2.3 Statistical Analysis

Basic descriptive information of the cohort including numbers of the variables of interest were reported. Hip fracture scores were calculated for each member of the test and validation datasets using Equation 1 below and the coefficients listed in section 5.3.4. Separate scores were calculated for the male cohort and the female cohort for both the test dataset and the validation dataset for comparative purposes. A cumulative distribution plot was created for each of the male and female scores. In this instance, CIF is the hip fracture risk.

$$CIF = 1 - e^{-\lambda_{10}(t)} * e^{(\Sigma \beta x_i)}$$

Equation 1 Equation to calculate the CIF to determine risk of hip fracture

Where $\lambda_{10}(t)$ is the baseline cumulative hazard, the baseline cumulative hazard is when each variable in the equation is set to zero at time t. For this model, when time is two years, the baseline cumulative hazard is 0.0150 for males, and 0.0263 for females. The sum of the β coefficients ($\Sigma\beta x_i$) is calculated by using the β coefficient as given by the model multiplied by the participant characteristic (x_i). The β coefficients used to calculate the relative risk for each characteristic were listed in Table 16. Graphs of the distribution of each score were produced. ROC curves were created for each score and the AUC reported.

Cut-off points were established for each model to suggest when an individual has a high probability of receiving a correct positive or negative result. In this instance, a true positive is when an individual is at an elevated risk of hip fracture and actually sustained a hip fracture, and a true negative is when an individual is not at an elevated risk of hip fracture and they do not have a hip fracture by the end of the study period. Sensitivity is the true positive rate of a test; for example, it is how accurately the hip fracture score determines an individual's risk of hip fracture. In cases where there are large numbers of people who do not have the disease or, in this instance, are not at an elevated risk of hip fracture, a test that has high specificity could be a useful measure. Specificity is a measure of how accurately the test identifies individuals who are not at risk; for example, how many people with a negative test result did not have a hip fracture. A perfect test would have a sensitivity and specificity of 1.

It is common in medical tests to have a range of values that a patient can score, and some of these scores suggest the patient is free from the issue, while other scores suggest the individual may have the specific medical issue. Often, it can be clear whether a patient has a negative result or a positive (216). For example, the hip fracture score developed in this chapter ranges from 0 to 1. A patient with a score close to 0 would not be deemed to be at an elevated risk of hip fracture, and a patient with a score close to 1 would be determined to be at

an elevated risk of hip fracture. The problem lies in the middle of this score where it is unclear whether the individual is at an elevated risk of hip fracture or not.

There are multiple ways of determining and assessing cut-off points for tests. One way to establish a cut-off point and assess the predictability of a test is by examining ROC curves. ROC curves provide a visual representation of the test values among patients based on their sensitivity and specificity. Additionally, the AUC for a ROC curve can be calculated to determine how accurately the score itself can predict between positive and negative subjects. When examining a ROC curve, the closer to the diagonal line the ROC curve is the less accurate the model is, and the closer to the point (0,1) at the top left-hand corner of the graph, the more accurate the model is. The diagonal line represents random chance.

Additionally, clinical judgment can help to identify the best cut-off point. In cases where it would be important to make sure positive test results are identified early, a cut-off point with a high sensitivity may be more important (216, 217).

Six cut-off points were explored for each hip fracture score, to determine where the best cut-off point might be. The first cut-off point was determined by calculating the closest point on the ROC curve to (0,1). Cut-off points two, three, and four were based on high sensitivity, and were established by choosing the co-ordinates on the graph where sensitivity was approximately 75%, 85%, and 95% respectively. Cut-off points five and six were based on high specificity and were established by choosing the co-ordinates on the graph where 1-specificity was approximately 5% and 15% (specificity of 95% and 85%) respectively.

The validity of each cut-off point was assessed by calculating the sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) for the test. The PPV is used to assess how likely it is that an individual that receives a positive result is truly positive. The NPV measures how likely it is that an individual is that receives a negative result is truly negative (216, 218). Sensitivity, specificity, PPV, and NPV for a test can be calculated with a contingency table. A contingency table is a 2x2 table that displays the number of people who tested positive, broken down into those who actually had the outcome as predicted and those who did not, and the people who tested negative, broken down into those who did had the outcome contrary to the prediction and those who did not have the outcome, as predicted.

6.3 Results

6.3.1 Score calculation for test dataset

For comparative purposes, the male and female scores were calculated using the test datasets of 17,339 males and 27,707 females mentioned in Chapter Five. By the end of the study period, 44 (2.5%) males had sustained a hip fracture and 6,185 (35.7%) had died. For the females, 1,031 (3.7%) sustained a hip fracture and 6,982 (25.2%) had died by the end of the study period. The ROC for the male score is displayed in Figure 10, and the AUC was 0.617 (95% CI: 0.577, 0.657). The ROC for the females score can also be found in Figure 10 and the AUC was 0.645 (95% CI: 0.629, 0.661).

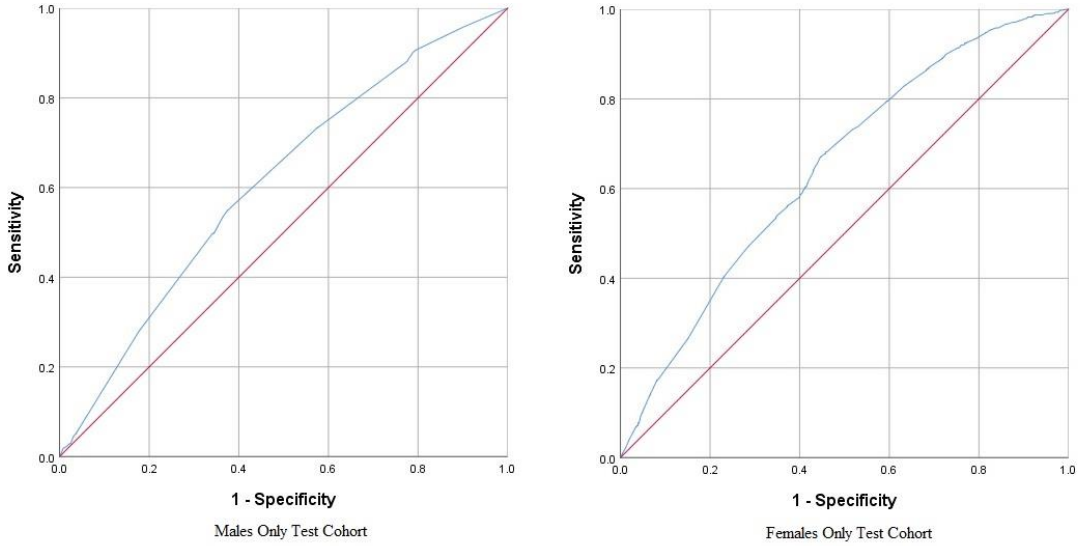

Figure 10 ROC curves of male and female hip fracture scores developed from the test cohort

6.3.2 Participant Information

The internal validation dataset consisted of 22,291 people with a mean age of 82.8 (range 65 to 105 years). There were 8,519 (38.2%) males and 13,770 (61.8%) females. Within the cohort, a total of 784 (3.5%) people sustained a hip fracture, and 6,526 (29.3%) people died by the end of the period. Table 17 provides a summary of the variables used in the hip fracture scores.

Table 17 Descriptive information of significant variables for validation cohort with totals and partitioned by outcome

Variable names	Total n (%)	First Event		
		Alive, no fracture	Fracture	Death
Sex				
Male	8,519 (38.2)	5,262 (61.8)	228 (2.7)	3,029 (35.6)
Female	13,770 (61.8)	9,718 (70.6)	556 (4.0)	3,496 (25.4)
Age Group (years)				
65-74	3,757 (16.9)	2,863 (76.2)	64 (1.7)	830 (22.1)
75-84	9,063 (40.7)	6,381 (70.4)	285 (3.1)	2,397 (26.4)
85-94	8,743 (39.2)	5,390 (61.6)	391 (4.5)	2,962 (33.9)
95+	728 (3.3)	347 (47.7)	44 (6.0)	337 (46.3)
Ethnicity				
Māori	1,131 (5.1)	760 (67.2)	15 (1.3)	356 (31.5)
Pacific	658 (3.0)	491 (74.6)	6 (0.9)	161 (24.5)
Asian	511 (2.3)	372 (72.8)	19 (3.7)	120 (23.5)
European	19,835 (89.0)	13,248 (66.8)	742 (3.7)	5,845 (29.5)
Other	156 (0.7)	110 (70.5)	2 (1.3)	44 (28.2)
Previous Fall				
No Falls	13,085 (58.7)	9,125 (69.7)	383 (2.9)	3,577 (27.3)
Had at least one fall	9,206 (41.3)	5,856 (63.6)	401 (4.4)	2,949 (32.0)
Wandering[b]				
Not Present	21,322 (95.7)	14,396 (67.5)	727 (3.4)	6,199 (29.1)
Present	965 (4.3)	585 (60.6)	57 (5.9)	323 (33.5)
BMI				
Underweight	1,208 (5.4)	645 (53.4)	92 (7.6)	471 (39.0)
Normal	6,658 (29.9)	4,420 (66.4)	256 (3.8)	1,982 (29.8)
Overweight	3,601 (16.2)	2,692 (74.8)	84 (2.3)	825 (22.9)
Obese	1,945 (8.7)	1,498 (77.0)	28 (1.4)	419 (21.5)
Undetermined	8,879 (39.8)	5,726 (64.5)	324 (3.6)	2,829 (31.9)

Variable names	Total n (%)	First Event		
		Alive, no fracture	Fracture	Death
Smokes tobacco daily[a]				
No	21,067 (94.5)	14,162 (67.2)	739 (3.5)	6,166 (29.3)
Yes	1,223 (5.5)	818 (66.9)	45 (3.7)	360 (29.4)
Parkinson's Disease				
Not present	21,439 (96.2)	14,421 (67.3)	752 (3.5)	6,266 (29.2)
Diagnosis present	852 (3.8)	560 (65.7)	32 (3.8)	260 (30.5)
Dyspnoea[a]				
Not present	11,985 (53.8)	8,610 (71.8)	455 (3.8)	2,920 (24.4)
Present	10,305 (46.2)	6,370 (61.8)	329 (3.2)	3,606 (35.0)

[a]1 value missing, [b]4 values missing

6.3.3 Internal Validation Hip Fracture Scores

The hip fracture scores were calculated using the β coefficients from Table 16. The cumulative distribution plot shows the cumulative percentage of the hip fracture score for both males and females (Figure 11).

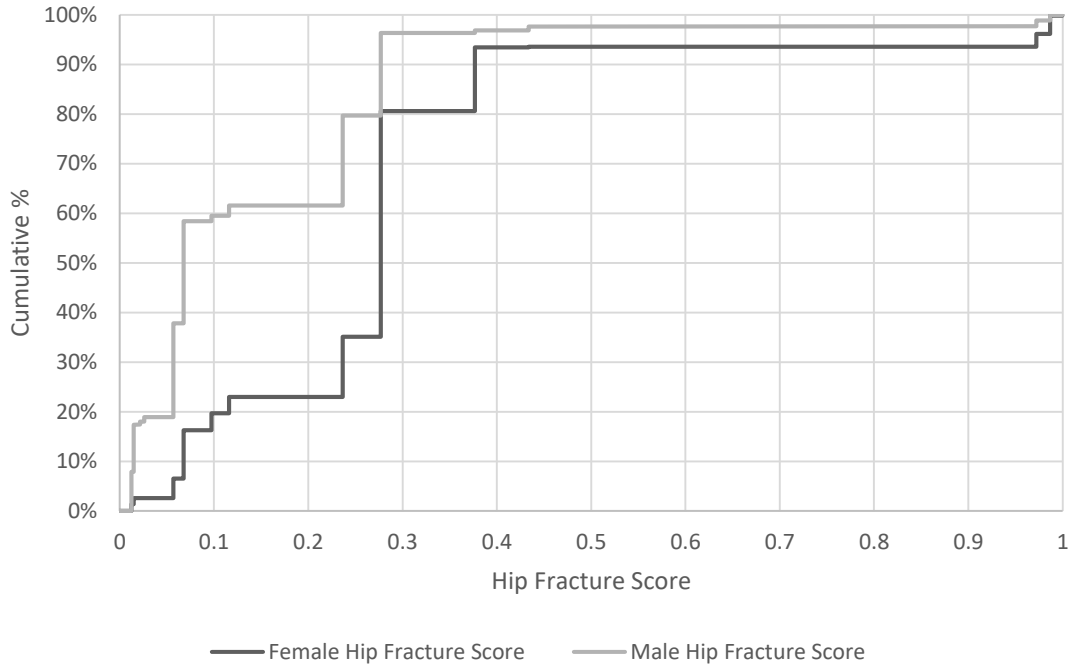

Figure 11 Cumulative distribution of male and female hip fracture scores

The ROC curves for the male and female scores are shown in Figure 12. For males, the AUC was 0.586 (95% CI: 0.548, 0.625), and for females, the AUC was slightly better with 0.615 (95% CI: 0.593, 0.637). However, the 95% CIs overlap, which suggests the two scores may be similar when predicting hip fracture risk. An AUC of between 0.5 and 0.7 suggests there is some discrimination, but an AUC greater than 0.7 is a more acceptable range according to Hosmer *et al.* (219).

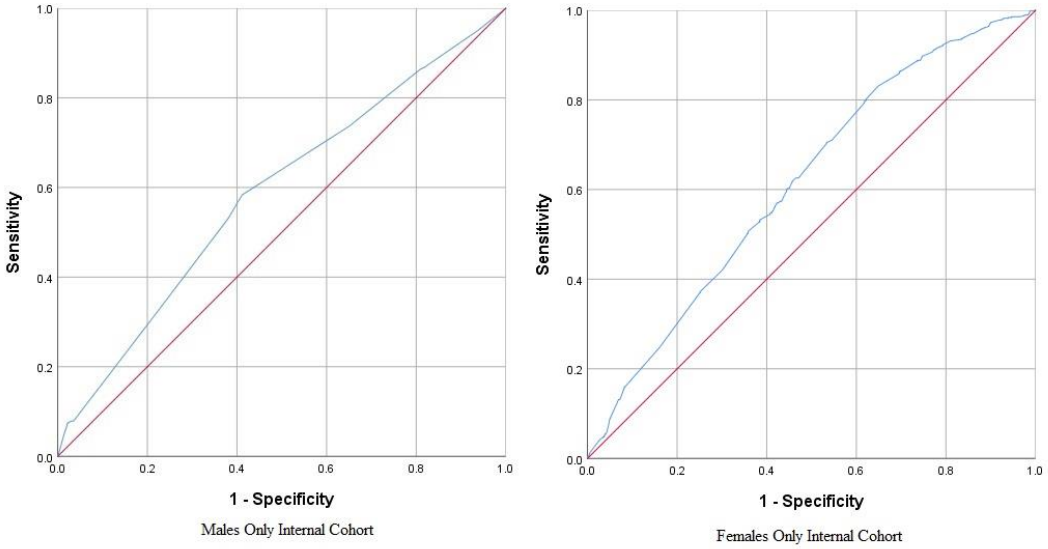

Figure 12 ROC curves of male and female hip fracture scores developed from the internal validation cohort

The cut-off points for the hip fracture scores were explored. For the males-only score, cut-off points one and two had the same values. The most ideal cut-off point would have high sensitivity and specificity. In cases where the sensitivity is high, but the specificity is low, there are large numbers of people who are at an elevated risk of hip fracture. With a high specificity, the focus is more on correctly identifying those who are not likely to have a hip fracture, which leaves a smaller pool of people who have an elevated risk of hip fracture. As health care resources are limited, it is better, in this instance, to focus on narrowing down the pool of people who are at an elevated risk of hip fracture by focusing on a higher specificity. Cut-off point six is the best cut-off point to use based on this criteria because while it does not have the highest specificity, the sensitivity is higher than for cut-off point five (which has the highest specificity), making it a more balanced score because there is a higher sensitivity (32.9%). Table 18 details each cut-off point and their respective sensitivity, specificity, PPV, and NPV.

Table 18 Summary of all cut-off points for males only internal validation cohort

Cut-off Point	Sensitivity	Specificity	PPV	NPV
COP 1 = 0.0624*	73.7%	34.9%	3.1%	98.0%
COP 2 = 0.0624*	73.7%	34.9%	3.1%	98.0%
COP 3 = 0.0414	86.4%	19.1%	2.9%	98.0%
COP 4 = 0.0137	95.2%	6.0%	2.7%	97.8%
COP 5 = 0.3269	7.9%	96.5%	5.8%	97.4%
COP 6 = 0.2567	32.9%	77.3%	3.8%	97.7%

*Cut-off point 1 and 2 are the same value because they were both calculated using different calculation methods, but both methods rendered the same cut-off point.

For the females only score, cut-off point six appears to be the best cut-off point according to the criteria described above. While cut-off point five has the highest specificity (95.1%), it also has the lowest specificity (8.6%). Cut-off point six has a specificity of 84.0% suggesting that there is an 84% chance the hip fracture score will correctly identify people who are not at an elevated risk of hip fracture. Table 19 below, outlines all six cut-off points and the sensitivity, specificity, PPV, and NPV of each one.

Table 19 Summary of all cut-off points for females only internal validation cohort

	Sensitivity	Specificity	PPV	NPV
COP 1 = 0.0910	61.9%	54.3%	5.4%	97.1%
COP 2 = 0.0764	71.0%	83.7%	5.2%	97.4%
COP 3 = 0.0637	85.8%	56.3%	4.9%	98.1%
COP 4 = 0.0170	95.7%	12.3%	4.4%	98.5%
COP 5 = 0.5243	8.6%	95.1%	6.9%	96.1%
COP 6 = 0.3533	24.6%	84.0%	6.1%	96.4%

6.4 Discussion

6.4.1 Key Findings

The hip fracture scores for males and females were validated in a smaller set of 22,291 people. The female score had slightly better predictability with an AUC of 0.615 (95% CI: 0.593, 0.637) compared to 0.586 (95% CI: 0.548, 0.625) for males. Both AUC values suggest the models have better predictability than random chance, but there is room for improvement.

When compared to the hip fracture scores outlined in Table 20, both the males and females scores have low AUCs. No scores published had an AUC below 0.67, which means they are much stronger at predicting hip fracture than the interRAI-HC models. A full discussion of why these AUCs may be low can be found in section 8.2.9.

Table 20 Summary of hip fracture scores including year developed, country of origin, cohort size, statistical technique used, and AUC updated with interRAI-HC scores

Hip Score	Year	Country	Cohort	Statistical Method	AUC (95% CI)
FRAX	2008	UK	Unknown	Poisson regression	Unknown
Garvan	2007	Australia	1,768	Cox proportional hazards model	0.85* $^{\Delta}$
Qfracture (Females)	2009	UK	1,183,663	Cox proportional hazards model	0.890 (0.786, 0.790)
Qfracture (Males)	2009	UK	1,174,232	Cox proportional hazards model	0.856 (0.851, 0.860)
Qfracture Updated (Females)	2012	UK	1,598,294	Cox proportional hazards model	0.893 (0.890, 0.896)
Qfracture Updated (Males)	2012	UK	1,544,379	Cox proportional hazards model	0.875 (0.868, 0.883)
FRACTURE	2001	USA	7,782	Logistic regression	0.714* $^{\Delta}$
FRAMO	2004	Sweden	1,248	Logistic regression	0.72 (0.64, 0.81) $^{\Delta}$
FRISC	2010	Japan	1,787	Poisson regression	0.727 (0.660, 0.794)
Van Staa	2006	UK	366,104	Cox proportional hazards model	0.84* $^{\Delta}$
WHI	2007	USA	93,676	Cox proportional hazards model	0.80 (0.77, 0.82)
FRAiL (Males)	2017	USA	119,874	Competing risk regression	0.692*$^{\Delta}$
FRAiL (Females)	2017	USA	299,794	Competing risk regression	0.711* $^{\Delta}$
FRS	2017	Canada	29,386	Decision tree	0.687*
Internal males	2019	NZ	8,521	Competing risks regression	0.586 (0.548, 0.625)
Internal females	2019	NZ	13,770	Competing risks regression	0.615 (0.593, 0.637)

*Confidence intervals were not reported, $^{\Delta}$Test cohort, internal validation AUC were not reported

Various cut-off points for each model were also explored. When trying to determine which would be the best cut-off point, one with a high specificity and high NPV was preferable. There would be fewer individuals who have a fracture than not. As resources for hip fracture prevention programs are limited, it is a better use of health resources to concentrate on correctly identifying low risk individuals and have a smaller number of people being provided with support and interventions. One benefit of a greater focus on high sensitivity, would be that more individuals are identified who have an elevated risk of fracture. A consequence of this would be people who are genuinely at elevated risk not receiving the preventive medicine or other measures that they should. There would be limited resources being spread among a larger population of people who were not at an elevated risk and would not benefit as significantly from those interventions.

6.4.2 Strengths and Limitations

The cross-validation method is good for assessing how the hip fracture score can predict hip fractures in a dataset that was not used for creating the model. Only the variables that were determined to be statistically significant were included in the hip fracture score model. If more variables had been included in the hip fracture prediction scores, there would be more information to base a prediction on. Perhaps future work could explore including a large array of variables available in the interRAI-HC assessment to compare how well that model can predict hip fracture risk.

The internal validation dataset is a small cohort compared to the test cohort and there are very small numbers of people who have fractures, particularly in the males-only score. This suggests the results have low statistical power. The results may not be as strong as they could be because of these small numbers.

6.4.3 Concluding Statement

Hip fracture scores were validated using the remaining one-third of the data from the original interRAI-HC dataset. The next chapter will repeat the analysis conducted here, but with a separate cohort of New Zealand interRAI-HC data from assessments performed later in time. This is to evaluate how well the hip fracture score can predict hip fractures in a dataset independent from the dataset originally used to develop the model.

7 External Validation

7.1 Introduction

The previous chapter contained information on the development of the hip fracture score using two different models: one for a male cohort and one for a female cohort. Various cut-off points were assessed to find which cut-off point was the best at identifying individuals at an elevated risk of fracture. In this chapter, the same analyses performed in the previous chapter is repeated using a more recent interRAI-HC dataset. This is to assess how well the hip fracture score can predict hip fractures in a dataset that was not part of the development dataset, nor part of the internal validation which was taken from the original dataset. This is advantageous as it allows the score to be used in other cohorts, not just the one it was developed for. The aim of this chapter is to assess how the scores that were developed in the previous chapter can identify individuals who are at an elevated risk of hip fracture.

7.2 Methods

7.2.1 Participants

Participants of the study were selected using the same exclusion criteria as applied to the original dataset as outlined in 4.3.1. Participants included community-dwelling adults aged 65 years and over who had an interRAI-HC assessment from 1 November 2015 to 1 June 2018. Where individuals had more than one HC assessment, only the first one was included.

7.2.2 Variables

Variables used for analysis were those used for creation of the hip fracture scores and the sex variable. These variables were age, ethnicity, falls, wandering, BMI, tobacco use, Parkinson's disease, and dyspnoea. All variables were recoded using the methods outlined in section 3.3.

7.2.3 Statistical Analysis

Descriptive information about the cohort was reported. Hip fracture scores were calculated for both male and female cohorts using Equation 1. A cumulative frequency distribution plot of the scores and ROC curves were created for each group. The AUC values were reported for each ROC curve. The cut-off points determined in section 6.3 were explored for the external validation cohort. The cut-off point that suggests an individual is at an elevated risk of hip fracture was 0.2567 or higher for males and 0.3533 or higher for females. Sensitivity, specificity, PPV, and NPV were reported for each cut-off point.

7.3 Results

7.3.1 Participant Selection

7.3.1.1 interRAI Data

The initial interRAI dataset received contained home care, long-term care (LTCF), palliative care (PC), and palliative care hospice supplement (PCH) assessments. The LTCF, PC, and PCH assessments were removed from the dataset, leaving only the HC assessments. Only assessments undertaken after 31 October 2015 were included. There were a total of 62,678 interRAI-HC assessments for analysis. The figure below (Figure 13) details the data selection process for the external validation cohort.

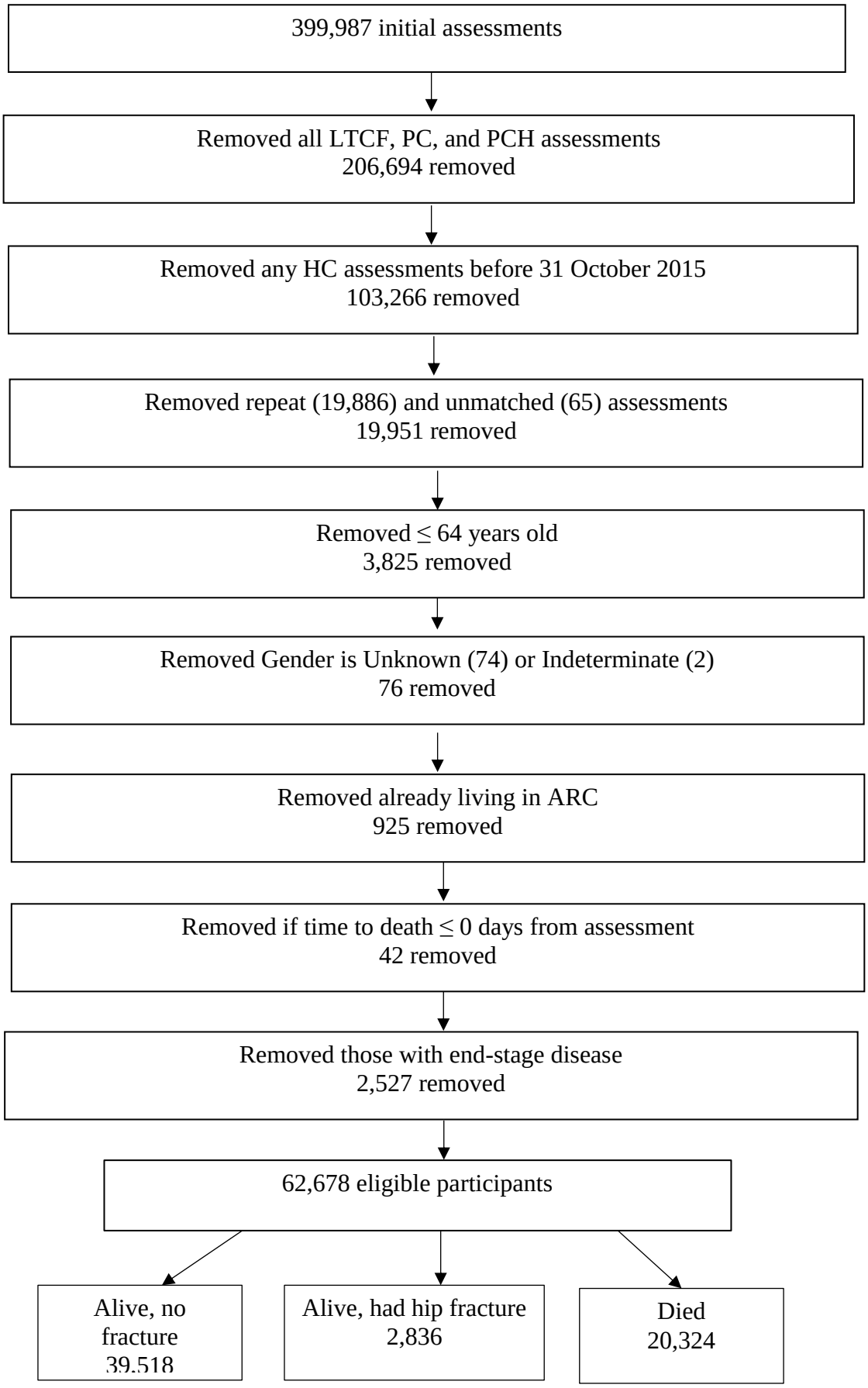

Figure 13 Participant selection criteria for the external validation cohort

7.3.1.2 Hospital Admissions Data

The hip fracture hospital admissions were processed in the same manner described in section 3.3. The hospital admissions dataset consisted of 549,319 records of patient hospital admissions from 14 October 2015 to 17 July 2018. There were 19,238 instances of hip fracture admissions; however, several patients had multiple admissions listed for the same event, and this was confirmed in the dataset by the event date column. Some people had multiple hip fracture events, and the first event after 31 October 2015 was used for analysis. After condensing the dataset, there were a total of 4,392 first hip fractures. Anyone who had a hip fracture before their interRAI-HC assessment was not counted as having a hip fracture; this left a total of 2,836 participants with a hip fracture.

7.3.2 Participant Characteristics

The external validation dataset consisted of 62,728 interRAI-HC assessments. It was similar in size to the original dataset before it was partitioned for cross-validation purposes. Participants had a mean age of 82.5 years (range 65 to 109 years) and there were 37,685 (60.1%) females. The mean age and sex distributions were similar to the original dataset (mean age: 82.8 years, 61.6% female). The ethnic distributions were similar to that of the original dataset. Within the external cohort 2,836 (4.5%) people had a hip fracture, and 20,324 (32.4%) had died. There was a smaller percentage of people with an undetermined BMI in the external cohort (16,436, 26.2%) than in the original cohort (26,116, 38.8%). There was a slightly higher percentage of people who had a hip fracture in this cohort (4.5%) compared with the original cohort (3.4%), and there was a slightly higher percentage of deaths (32.4%) than in the original cohort (29.2%). Table 21 below lists the frequencies for all variables used in the hip fracture score.

Table 21 Descriptive information of significant variables for external validation cohort with totals and partitioned by outcome

Variable names	Total n (%)	First Event		
		Alive, no fracture	Fracture	Death
Sex				
Male	24,917 (39.8)	14,368 (36.4)	947 (33.4)	9,602 (47.3)
Female	37,761 (60.2)	25,150 (63.5)	1,889 (66.6)	10,722 (52.7)
Age Group (years)				
65-74	12,279 (19.6)	8,929 (22.6)	298 (10.5)	3,052 (15.0)
75-84	26,353 (42.0)	17,460 (44.2)	1,075 (37.9)	7,818 (38.5)
85-94	22,493 (35.9)	12,469 (31.6)	1,366 (48.2)	8,658 (42.6)
95+	1,553 (2.5)	660 (1.7)	97 (3.4)	796 (3.9)
Ethnicity				
Māori	3,838 (6.1)	2,539 (6.4)	63 (2.2)	1,236 (6.1)
Pacific	2,191 (3.5)	1,524 (3.9)	35 (1.2)	632 (3.1)
Asian	1,823 (2.9)	1,295 (3.3)	53 (1.9)	475 (2.3)
European	54,201 (86.5)	33,701 (85.3)	2,654 (93.6)	17,846 (87.8)
Other	625 (1.0)	459 (1.2)	31 (1.1)	135 (0.7)
Previous Fall[a]				
No Fall	36,664 (58.5)	24,298 (61.5)	1,444 (50.9)	10,922 (53.7)
Had at least one fall	26,013 (41.5)	15,219 (38.5)	1,392 (49.1)	9,402 (46.3)
Wandering[b]				
Not Present	59,932 (95.6)	37,963 (96.1)	2,657 (93.7)	19,312 (95.1)
Present	2,734 (4.4)	1,553 (3.9)	179 (6.3)	1,002 (4.9)
BMI				
Underweight	3,784 (6.0)	1,791 (4.5)	284 (10.0)	1,709 (8.4)
Normal	22,156 (35.3)	13,447 (34.0)	1,237 (43.6)	7,472 (36.8)
Overweight	12,916 (20.6)	8,887 (22.5)	446 (15.7)	3,583 (17.6)
Obese	7,386 (11.8)	5,504 (13.9)	157 (5.5)	1,725 (8.5)
Unknown	16,436 (26.2)	9,889 (25.0)	712 (25.1)	5,835 (28.7)

Variable names	Total n (%)	First Event		
		Alive, no fracture	Fracture	Death
Smokes tobacco daily[a]				
No	59,400 (94.8)	37,444 (94.8)	2,680 (94.5)	19,276 (94.8)
Yes	3,277 (5.2)	2,073 (5.2)	156 (5.5)	1,048 (5.2)
Parkinson's Disease[a]				
Not present	60,149 (96.0)	37,907 (95.9)	2,679 (94.5)	19,563 (96.3)
Diagnosis present	2,528 (4.0)	1,610 (4.1)	157 (5.5)	761 (3.7)
Dyspnoea[a]				
Not present	31,909 (50.9)	21,814 (55.2)	1,579 (55.7)	8,516 (41.9)
Present	30,768 (49.1)	17,703 (44.8)	1,257 (44.3)	11,808 (58.1)

[a]1 value missing, [b]12 values missing

7.3.3 External Validation Hip Fracture Scores

Hip fracture scores for both males and females were calculated using the β coefficient from Table 16. The cumulative distribution plot (Figure 14) shows the cumulative percentage of each hip fracture score.

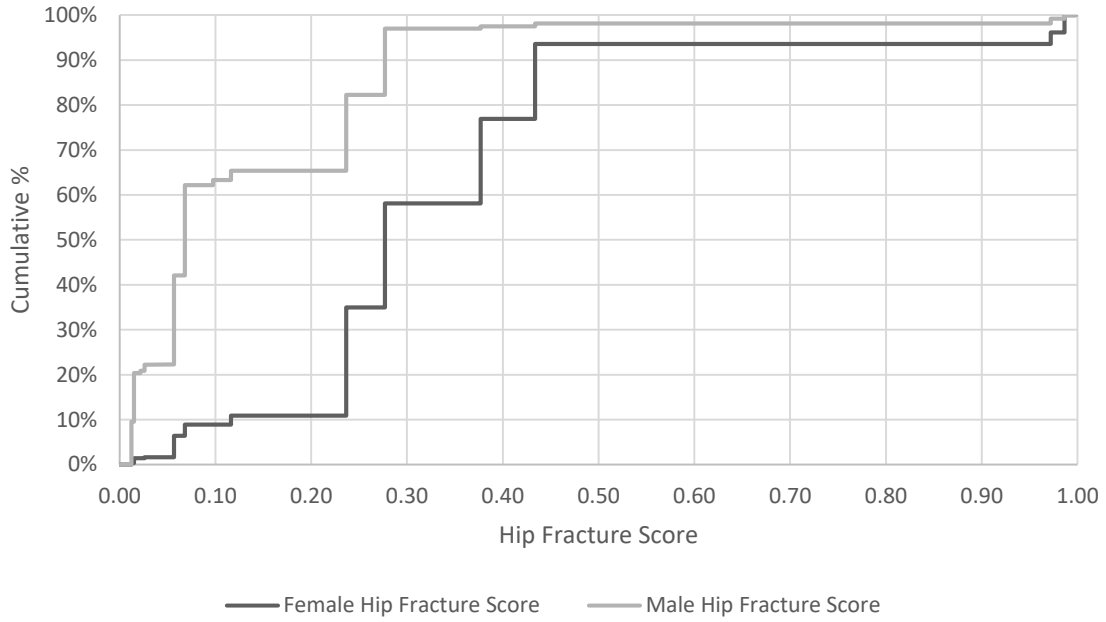

Figure 14 Cumulative distribution of male and female hip fracture scores in the external validation cohort

The ROC curves for the male and female scores can be found in Figure 15. For males, the AUC was 0.611 (95% CI: 0.594, 0.629) and for females the AUC was 0.624 (95% CI: 0.612, 0.636). These AUCs suggest the models are better than random chance at predicting hip fracture risk in older adults, but a value closer to 1 would be better (219).

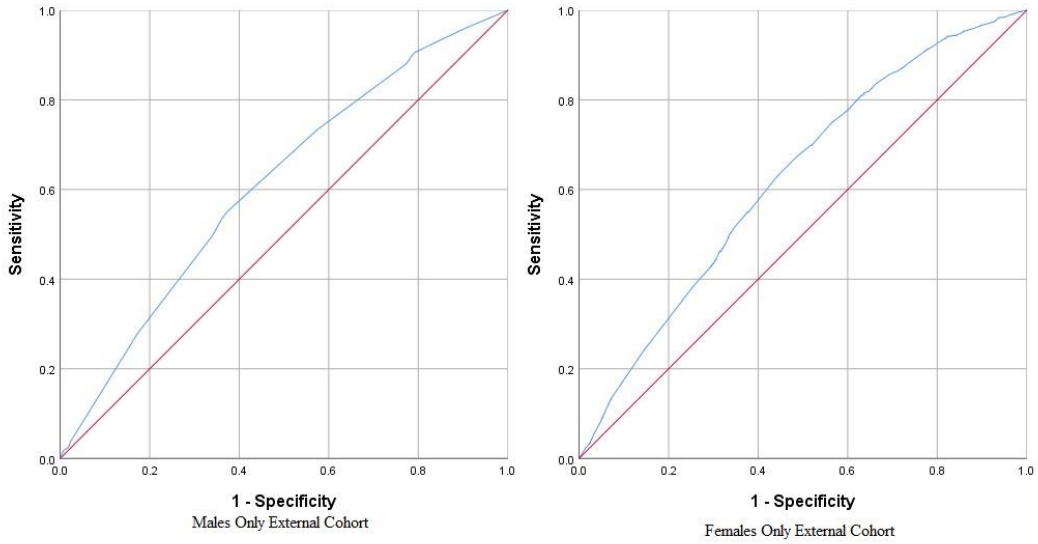

Figure 15 ROC curves of male and female hip fracture scores developed from the external validation cohort

The cut-off points of 0.2567 or higher for males and 0.3533 or higher for females determined in Chapter Six were used to indicate whether a person was at an elevated risk of hip fracture or not. For the males score, the sensitivity was 28.0% and the specificity was 82.6%. The females had slightly lower sensitivity (24.2%), but a higher specificity (85.5%).

Table 22 Sensitivity, specificity, PPV, and NPV of males and females external validation scores

Cohort	Sensitivity	Specificity	PPV	NPV
Males	28.0%	82.6%	6.0%	96.7%
Females	24.2%	85.5%	8.1%	95.5%

7.3.4 Summary of Hip fracture scores

The AUCs for the test scores (original dataset) were the highest (0.617 for males, 0.645 for females). Overall, the females score had higher AUCs suggesting it was better at predicting hip fracture risk in the interRAI-HC cohort. The internal validation cohort had the lowest AUCs with 0.586 for males (95% CI: 0.548, 0.637) and 0.615 (95% CI: 0.593, 0.637) for females. Table 23 below provides a summary of each of the AUCs for each cohort.

Table 23 Summary of AUCs for the test cohort, internal validation cohort, and external validation cohort

Cohort	Male AUC (95% CI)	Female AUC (95% CI)
Test	0.617 (0.577, 0.657)	0.645 (0.629, 0.661)
Internal validation	0.586 (0.548, 0.637)	0.615 (0.593, 0.637)
External validation	0.611 (0.594, 0.629)	0.624 (0.612, 0.636)

The sensitivity, specificity, PPV, and NPV appear to be similar between the two females scores with sensitivity of 24.6% for the internal cohort and 24.2% for the external cohort. The specificity is also similar at 84.0% for the internal cohort and 85.5% for the external cohort. There are more differences between the males, but they still appear similar. Table 24 provides a summary of each of the hip fracture risk scores and their corresponding sensitivity, specificity, PPV, and NPV.

Table 24 Summary of sensitivity, specificity, PPV, and NPV for the internal validation cohort, and external validation cohort

Cohort	Sensitivity	Specificity	PPV	NPV
Internal Males	32.9%	77.3%	3.8%	97.7%
Internal Females	24.6%	84.0%	6.1%	96.4%
External Males	28.0%	82.6%	6.0%	96.7%
External Females	24.2%	85.5%	8.1%	95.5%

7.4 Discussion

7.4.1 Key Findings

Both the males and females scores performed better than they did with the internal validation cohort. This is likely due to the smaller cohort sizes in the internal validation cohort. The AUC for the males external score was 0.611 (95% CI: 0.594, 0.629) compared to the internal score of 0.586 (0.548, 0.625). The females external score was 0.624 (95% CI: 0.612, 0.636) and the internal score was 0.615 (0.593, 0.637). All four of the scores had AUCs that were better than random chance (0.5 or lower); however, they would all be considered to have moderate predictability, which suggests there is room for improvement with these hip fracture scores.

Both male scores had similar sensitivity, specificity, PPV, and NPV to each other, as did the female scores. The higher levels of specificity indicate there is a higher level of accuracy concerning people who are less likely to be at risk of having a hip fracture. If there was a focus on sensitivity, there would be larger numbers of people who would be classified as being at an elevated risk of hip fracture, and as resources are limited, it would be more difficult to decide who should be referred for hip fracture prevention programmes.

7.4.2 Strengths and Weaknesses

The external validation dataset was large, which allowed for a strong analysis of the hip fracture score; the AUCs were higher than in the internal validation set, possibly because of these larger numbers.

Both the original and the external cohorts are from New Zealand and were similar cohorts, so the results of the external validation cohort were similar to the test and internal validation cohorts. However, the score may not perform as well in a cohort from another country where there may be differences between the characteristics of people who undergo interRAI-HC assessments from those countries.

7.4.3 Concluding Statement

The females hip fracture score was a better predictor of hip fracture risk than the males score. External validation for the model was good, and the hip fracture scores performed better than they did with the internal validation cohort. The next chapter provides an extended discussion about the results of the whole study, including the interpretation of all results, and the strengths and weaknesses of the study.

8 Discussion

8.1 Key Findings

Risk factors for hip fracture for the entire interRAI-HC cohort were age, sex, ethnicity, previous falls, mental function varies throughout the course of the day, wandering, BMI, tobacco use, Parkinson's disease, and dyspnoea. Sex differences were assessed, and it was noted that males and females had different risk profiles. The risk factors associated with hip fracture for males were age, Parkinson's disease, and dyspnoea, and for females, the associated risk factors were age, ethnicity, wandering, BMI, tobacco use, and dyspnoea.

Hip fracture scores were developed for male and females separately. The males-only score (AUC: 0.586, 95% CI: 0.548, 0.625) performed worse than the females-only score (AUC: 0.615, 95% CI: 0.593, 0.637) in the internal validation dataset, but both had some predictability. The scores were also tested on an external validation set and the male scores (AUC: 0.611, 95% CI: 0.594, 0.629) and the female scores (AUC: 0.624, 95% CI: 0.612, 0.636) performed better than they did with the internal validation cohort. The hip fracture scores had higher AUCs than the Falls CAP (AUC: 0.540, 95% CI: 0.527, 0.552), which suggests both scores are better at predicting hip fracture risk than the Falls CAP.

8.2 Integration with the Literature

8.2.1 Falls

It is well documented in the literature that falls are a leading cause of fractures in older adults (15, 74-76, 79). It was not surprising that, for the whole cohort, falls were significantly associated with hip fracture. However, when the cohort was separated into males and females, falls were not associated with hip fracture. This is possibly due to the reduced number of people in each cohort and less statistical power when developing the predictive models than when the whole cohort was used. Additionally, the Falls CAP is triggered in those people who are consistently having falls, and it was noted in section 4.3.5 that those who did not trigger the Falls CAP had a higher number of hip fractures than those who triggered the medium and high risk categories - where 59.7% (2,259) of hip fractures were sustained by those who did not trigger the falls CAP. This suggests the possibility that falls prevention programs may be put in place for those who do trigger the Falls CAP and this could possibly reduce their risk of falling in future and sustaining a hip fracture.

Five of the hip fracture prediction tools discussed in the literature review did not include falls as an item in the model. The FRAX tool did not include falls as a measure and did not assess whether this would improve their model. Kanis *et al.* acknowledged that other studies had included a question on falls, but no explanation was given as to why they opted not to include falls in their tool (161). Neither the FRISC nor the WHI included falls as an item either, and falls as a risk factor for hip fracture was not mentioned (102, 167). Both the FRACTURE and the FRAMO scores explored falls as a potential risk factor to include in their prediction models. Both found falls were not significantly associated with hip fracture and so were omitted from the final prediction models (84, 166). A potential explanation for these findings was that both studies had very small numbers with 7,782 people included in the FRACTURE score (30.2% of people reported having a fall), and 1,248 people included in the FRAMO score (33.3% of people reported having a fall).

8.2.2 Fractures

Neither previous hip fracture nor previous other fracture were associated with hip fracture. Both the FRAiL and the FRS scales which were developed using interRAI-LTCF data explored associations between hip fracture and previous hip fracture. Berry *et al.* found previous hip fracture was not associated with an increased risk of hip fracture either (76). However, Ioannidis *et al.* found those who had a previous hip fracture were at an elevated risk of sustaining a subsequent fracture (94). These differences may have occurred from the way that previous fracture was calculated. Berry *et al.* took previous hip fracture information from Medicare information and linked it with interRAI data, and Ioannidis *et al.* had previous fracture information from the last 180 days in the interRAI-LTCF, whereas the New Zealand interRAI-HC data only contains information on previous fractures within the last 30 days prior to assessment. The shorter time frame of the New Zealand data reduced the time-frame available for identifying individuals who have had a previous hip or other fracture.

Nine of the eleven hip fracture prediction models mentioned in Table 5 included previous hip fracture. The FRAiL model explored previous hip fracture but found it was not significantly associated with hip fracture (76). The Qfracture did not contain the variable previous hip fracture, but the Updated Qfracture study explored previous fracture information and added it to the updated model (51, 92).

8.2.3 Age and Sex

Demographic differences such as age, sex, and ethnicity are all commonly known risk factors for hip fracture (60). As age increases, the likelihood of a hip fracture increases (60, 89). Unsurprisingly, the results of this study showed that age was significantly associated with hip

fracture risk, where those in the higher age groups were more likely to sustain a hip fracture than those in the lower age groups. Age was also a key risk factor that explained more of the models than any other variable. As an individual ages, they are likely to have more health issues such as impaired vision, low BMD, muscle weakness, and balance issues, which can all lead to an increase in hip fracture risk (15, 60, 89, 91).

Females are known to have a higher risk of hip fracture than males as they are more likely to develop osteoporosis and have lower bone mineral density (61, 68, 84, 85). In this study, females had a higher number of significant risk factors than did men suggesting there are more risks common to females, therefore there is a higher chance that females will sustain a hip fracture. However, these findings could also be related to the larger cohort size for the females or a combination of both. Additionally, there was less data available for males; therefore, the statistical power is lower. Males and females were found to have different risk factors profiles. However, the FRAiL study found that males and females had almost identical risk factor profiles except that diabetes was significantly associated with fracture risk in females but not males (76). A potential explanation is that their study had larger cohorts, which would lead to more statistical power, or the LTCF cohort may have more similar risk profiles for males and females than in the HC cohort. A German study identified that males have a higher falls incidence in nursing homes leading to similar risk of hip fracture in aged care facilities (220).

All of the hip fracture prediction models mentioned in Table 5 included age as an item. The FRACTURE, FRAMO, FRISC, Van Staa, and WHI prediction models were developed for women only, so sex was not included in these models (52, 84, 102, 166, 167). Of the remaining prediction models, only the FRS did not include sex as an item for calculating risk prediction.

8.2.4 Ethnicity

People with different ethnic backgrounds have differing risks for hip fracture in the current study and in previous hip fracture risk studies (106, 221, 222). This study found that those of European ethnicity were deemed to be at a high risk of hip fracture compared to Māori, Pacific people, and Asians. There is a large amount of literature identifying that those who are white or European have higher rates of hip fracture than other ethnic groups (20, 69, 92, 222). Additionally, studies have noted that individuals who identify as Hispanic have similar hip fracture rates to those of white/European ethnicity (221, 222). Berry *et al.* and Robbins *et al.* noted that Native American individuals had a higher risk of sustaining a hip fracture than white individuals (76, 102).

An earlier New Zealand study noted that Māori males are less likely to have a hip fracture than non-Māori and female Māori (30). In this study, after adjusting for age and sex, Māori and Asian participants had the lowest risk of hip fracture, followed by Pacific people; individuals who were classified as other ethnicities had the highest risk of fracture but the group was small and diverse, therefore, no substantial conclusions can be made about that group. People who identified as European had the highest number of fractures and, after the ethnic group "other", were more likely to sustain a hip fracture. These results are similar to earlier findings in New Zealand where Europeans are more likely to have fractures than Māori or Pacific people (20, 30).

8.2.5 Cognition

Wandering was found to be associated with hip fracture risk for this cohort; these results were also found among interRAI-LTCF cohorts, and wandering was included in both the FRAiL and FRS models (76, 94). A study by Stolee *et al.* did not examine the effect of wandering on hip fracture risk in the Canadian interRAI-HC cohort (75). None of the non-interRAI hip fracture prediction models identified in Table 6 included wandering as an item.

Cognitive impairment was not associated with hip fracture. All three of the other interRAI cohort studies used the CPS as a measure of cognitive impairment. For all three studies, CPS was found to be associated with hip fracture (75, 76, 94). The CPS was not specifically explored in this study as it is an outcome scale calculated at the end of an assessment (95). However, the question regarding cognitive skills for daily decision making is an item in the CPS, and this was used as one of the primary measures for cognitive impairment within this study. It was not found to be associated with hip fracture risk. Mental function varies throughout the course of the day was associated with hip fracture risk for the whole cohort, but it was not associated with hip fracture risk in either the male or female cohorts. This item was not noted to be examined in any of the other known studies but is a measure of cognitive impairment within the interRAI-HC assessment.

Dementia was not included in this study based on research conducted by Berry *et al.* and Ioannidis *et al.* (76, 94). Berry *et al.* did not include dementia diagnosis as a variable of interest however, Ioannidis *et al.* included dementia diagnosis as a variable of interest in their study but found it was not associated with hip fracture (94). Bohlken *et al.*, however, found that individuals with dementia who lived in care homes were more likely to sustain a hip fracture than those who did not have a diagnosis of dementia (96). Their study had a large number of individuals with dementia (53,156 people), which may have allowed them more statistical power than Ioannidis' (16,778 individuals with dementia). Both the QFracture

Updated and the FRISC hip fracture prediction models included dementia as an item (92, 167).

8.2.6 BMI

Those with a low BMI are more likely to have a hip fracture than those who have a normal BMI, and those overweight or obese had a lowered risk for hip fracture. These findings are consistent with the literature (66, 68, 99, 100). Typically, older people who are underweight tend to be frailer than those who have a BMI in the normal or overweight categories (223). They are also more likely to fracture their bones than those who are overweight or obese because they have a lower body fat percentage, and less padding around the hip areas. Therefore, when they fall and land on the hip, the impact is less cushioned (67, 224).

Many studies have also identified those who have a high BMI are at a reduced risk of fracture (99, 103, 104, 225, 226). Studies have examined the relationship between high BMI and BMD and discovered that some individuals with a high BMI are also likely to have a high BMD (103, 104). Although a recent study conducted by Greco *et al.* found that some individuals with a high BMI had lower-than-expected lumbar BMD suggesting that it is still important to test an individual's BMD when they have a high BMI (227).

All of the hip fracture prediction models previously discussed included weight as a component of their scores. The FRAiL, FRS, Qfracture, Qfracture Updated, and Van Staa included weight information as a BMI calculation. WHI and FRAX included both height and weight information independently, and the other scores did not include height as a variable in their prediction models.

8.2.7 Lifestyle Factors

Smoking tobacco has been associated with hip fracture risk in previous studies (75, 228, 229), and this study also found that those who smoked tobacco were at an increased risk of sustaining a hip fracture. Kanis *et al.* found that non-smokers had the lowest risk of sustaining a hip fracture and current smokers had a higher risk of hip fracture than people who were smokers but had since quit (228). Tobacco smoking was included in six of the eleven fracture risk prediction models. The FRAiL and the FRS did not include smoking as there is no question on tobacco use in the interRAI-LTCF assessment (230). Nguyen *et al.* chose not to include smoking as a measurement as this would be reflected in the BMD measurement (169, 231). Both the FRAMO and FRISC included smoking status in their initial research but excluded it from their final models as they did not find a strong association between smoking and hip fracture for their cohorts (166, 167), although both had sample sizes below 2,000 and

may not have had the statistical power to detect associations between hip fracture and tobacco smoking.

Alcohol consumption was not associated with hip fracture for this cohort, though there have been a number of studies identifying alcohol as a risk factor for hip fracture (61, 65, 115, 117, 118). A potential reason for this could be because the cohort may be less likely to drink alcohol, therefore they are less likely to be impaired from the alcohol, reducing their falls risk. The questions in the interRAI-HC are also based on the reports of the person being assessed, any family members present at the time of the assessment, and medical records where needed. For topics such as alcohol use, it may be difficult to tell precisely how much alcohol a person consumes as they may not wish to disclose the true amount they drink from a possible fear of criticism or judgement. The alcohol consumption question itself is also vague and asks for the highest number of drinks in any "single setting" in the 14 days prior to assessment. The term "single setting" is vague and may result in unclear answers.

Alcohol information was only included in the FRAX, Qfracture, and Qfracture Updated prediction models (50, 51, 92). There is no question within the interRAI-LTCF assessment on alcohol consumption so this item was not included in the FRAiL or FRS models (230). Similar to tobacco use, alcohol consumption was not included in the Garvan as it is believed to be reflected in the patient's BMD (231). Robbins *et al.* found alcohol consumption was statistically significantly associated with hip fracture risk but did not affect the AUC of the model and so was not included in their final risk prediction model (102).

8.2.8 Co-Morbidities

Within this study Parkinson's disease and Dyspnoea were the co-morbidities associated with hip fracture risk. Other co-morbidities such as Stroke/CVA, COPD, and incontinence were explored but were not significantly associated with hip fracture. Parkinson's disease has previously been found to be associated with hip fracture (232-236). Parkinson's disease was a significant risk factor for hip fracture in the whole cohort and the males-only cohort, but not for females. This may be because males are more commonly diagnosed with Parkinson's disease than females (237). Parkinson's disease is a neurodegenerative disorder that can lead to impaired motor-skills, which can lead to falls (237). The Qfracture Updated score was the only hip fracture model to include Parkinson's disease as an item (92). The FRS study included Parkinson's disease for analysis, but did not find any association with hip fracture (94).

Dyspnoea was associated with hip fracture for the whole cohort and for females. Those who had shortness of breath were less likely to have a hip fracture. This is possibly because the people with dyspnoea are unable to move around without feeling short of breath, and are unlikely to be mobile enough to have falls. No hip fracture prediction models mentioned in the literature include dyspnoea, and it does not appear to be considered as a risk factor in other hip fracture studies. Within the body of literature, dyspnoea appears to be discussed as an issue that arises after an individual sustains a hip fracture, rather than as a potential risk factor (238-241).

A total of thirteen co-morbidities were included among the hip fracture prediction models. The Qfracture Updated score included items such as COPD, epilepsy, cancer, systemic lupus erythematosus, Parkinson's disease, and chronic renal disease (92). None of these items were included in any other hip fracture models; however, Hippisley-Cox *et al.* had the largest cohort (3,142,673), which gave them greater statistical power. Cardiovascular issues were included in both the Qfracture and the Qfracture Updated and were analysed by Tanaka *et al.* but were not deemed significant (51, 92, 167).

Diabetes was included in the FRAiL, Qfracture, and Qfracture Updated models (51, 76, 92). Ioannidis *et al.* included diabetes in their initial analyses, but found it was not associated with hip fracture (94). Osteoarthritis was included in the FRAiL model; no other study explored osteoarthritis (76). However, FRAX, Qfracture, and Qfracture Updated models included rheumatoid arthritis (51, 92, 161). Tanaka *et al.* examined rheumatoid arthritis as a potential risk factor for hip fracture but found it was not statistically significant (167). A low cohort size (1,787) could be the reason for their lack of findings. Asthma was included in the Qfracture and Qfracture Updated models, and no other scores included asthma or COPD in their studies (51, 92). The Van Staa model included an item labelled "chronic disease" which was consisted of any recent GP visits or hospitalisation for COPD, asthma, cerebrovascular accident, heart failure, rheumatoid arthritis, or inflammatory bowel disease (52).

8.2.9 Exercise

Several studies have shown that individuals who do not engage in regular exercise are at an increased risk of hip fracture (68, 86, 102, 145, 146). This study did not find exercise to be significantly associated with hip fracture. Multiple studies have noted that exercise in early life is important for reaching peak bone mass, which results in stronger bones in older age (154-157). There is currently only one question about physical activity in the interRAI-HC assessment, which asks the individual for the total hours of exercise or physical activity in the three days prior to their assessment. This question includes activities such as walking, but the

intensity of the exercise is not recorded. Including a question about activity level in early adulthood may serve as a proxy for estimating an individual's bone strength or BMD.

WHI was the only hip fracture prediction model that included an item about physical activity as part of their prediction model (102). Participants in the study reported their physical activity and this was converted to a Metabolic Equivalent Task (MET) by Robbins *et al.* A MET is a measure of the intensity and energy expenditure of an activity (242). In this instance, a MET score of 7 or higher was considered to be strenuous activity, 4-6 was moderate, and 3 was considered a low intensity activity, such as walking (102). There was only one other hip fracture score that explored physical activity as a possible risk factor. The FRACTURE index included a question on whether participants went for a walk, and this was not found to be statistically significant (84). All other scores did not include exercise as a possible risk factor; however, the Qfracture, Van Staa, and FRAMO acknowledged the lack of information about exercise was a limitation with their studies (51, 52, 166). Using a more specific measure of the intensity of exercise within the interRAI-HC assessment could give more information about the physical capability of an individual, and may be a significant predictor for hip fracture.

Figure 16 below, shows an updated conceptual framework diagram of the risk factors associated with hip fracture derived from the literature review (Figure 2). The dark grey items were items that were unavailable for use in the model, and the light grey items were not statistically significant in the model.

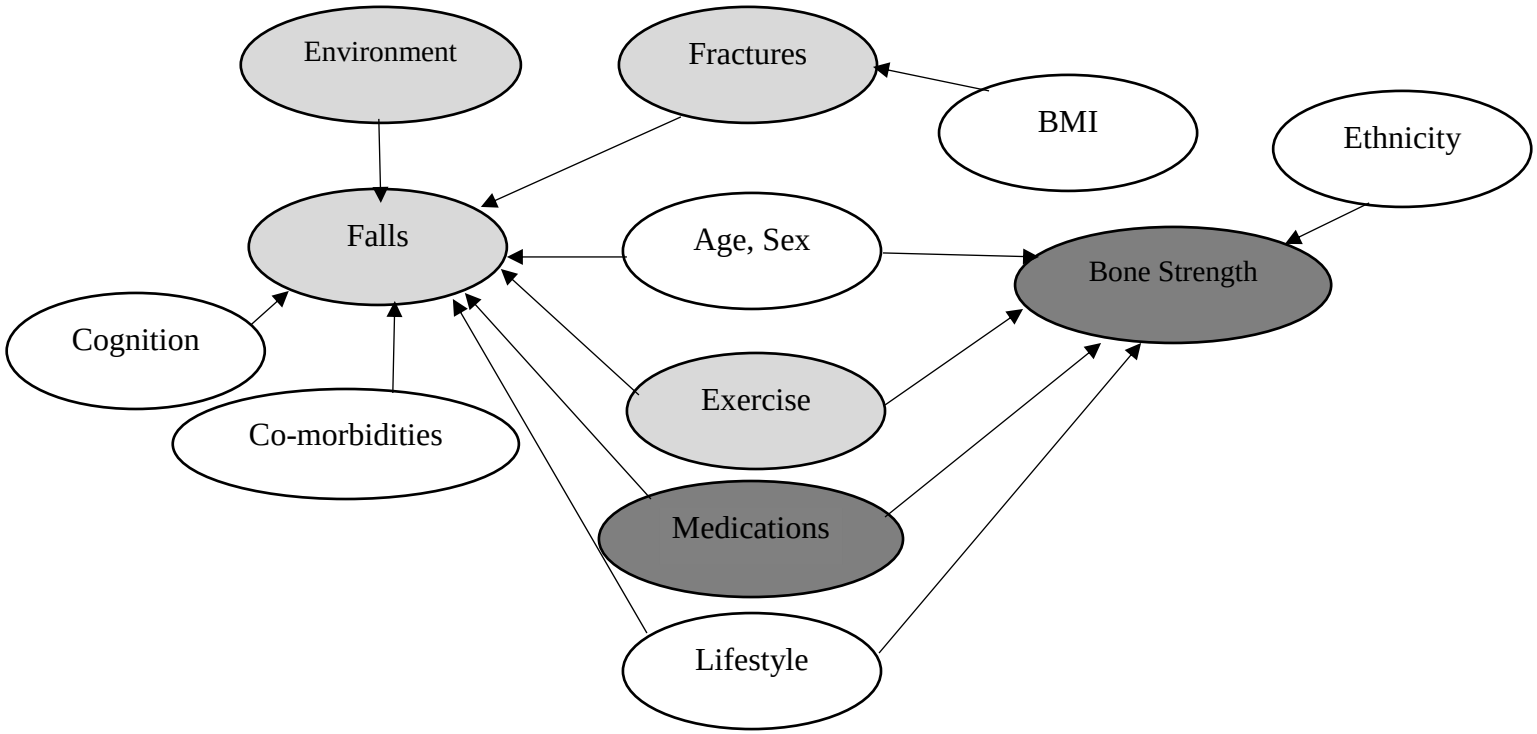

Figure 16 Diagram of factors relating to hip fracture and how they relate to each other

8.2.10 Comparison with Other Hip Fracture Scores

There were some similarities across several of the hip fracture scores developed in the literature, and the two scores derived from the interRAI-HC 9.1 assessment data. All hip fracture scores included age as a variable. Only the males-only hip fracture score derived from the interRAI-HC 9.1 did not contain weight as a variable. Both Parkinson's disease and dyspnoea were not included in any other hip fracture score. People who had dyspnoea had a reduced risk of hip fracture compared to those who did not; perhaps the other hip fracture scores were interested in items that, when present, were more likely to increase the risk of hip fracture than reduce it.

The two hip fracture scores created for interRAI assessments (FRAiL and FRS) used some variables that were consistent with the variables found in the hip fracture score developed in this study. The two previously published hip fracture scales were developed for the LTCF assessment, which is a different cohort to those undergoing the HC assessment, therefore not all risk factors will be the same. The score developed by Berry *et al.* consisted of 15 items, and six of those items were included in the HC score. These items were age, sex, ethnicity/race, previous falls, wandering, and BMI (76). Previous falls was not used in the male- and female-only cohorts, but it was significantly associated with hip fracture for the whole cohort.

The fracture risk score developed by Ioannidis *et al.* included eight items and five of these were also in the HC score; the items in common were age, BMI, previous falls, wandering, and previous fracture (94). All three scores included age, previous falls, wandering, and BMI.

Table 25 Items used across different fracture scores including the scores developed in this thesis

	FRAX(50)	Garvan(169)	FRAiL(76)	FRS(94)	interRAI HC Males	interRAI HC Females	Qfracture(51)	Qfracture Updated(92)	FRACTURE Index(84)	FRAMO(166)	FRISC(167)	Van Staa(52)	WHI(102)
Age	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Weight	✓	✓	✓[a]	✓[a]		✓[a]	✓[a]	✓[a]	✓	✓	✓	✓[a]	✓
Height	✓		✓[a]	✓[a]		✓[a]	✓[a]	✓[a]				✓[a]	✓
Sex	✓		✓				✓	✓					
Race/ Ethnicity						✓		✓					✓
BMD	✓	✓							✓		✓		
Previous fracture	✓	✓		✓				✓	✓	✓	✓	✓	✓
Parental history of fracture	✓						✓	✓	✓				✓
Falls		✓	✓	✓			✓	✓				✓	
Smoking	✓					✓	✓	✓	✓			✓	✓
Alcohol	✓						✓	✓					
Osteoporosis	✓						✓	✓			✓		
Rheumatoid Arthritis	✓						✓	✓					
Specific medications	✓		✓				✓	✓				✓	✓
Cognitive Impairment			✓	✓									
ADL			✓										
Locomotion in room			✓										
Bladder continence			✓										
Transfer performance			✓	✓									
Easily distracted			✓										
Wandering			✓	✓		✓							
Osteoarthritis			✓										
Pressure ulcer			✓										

	FRAX(50)	Garvan(169)	FRAiL(76)	FRS(94)	interRAI HC Males	interRAI HC Females	Qfracture(51)	Qfracture Updated(92)	FRACTURE Index(84)	FRAMO(166)	FRISC(167)	Van Staa(52)	WHI(102)
Diabetes			✓				✓	✓					✓
Walking in corridor				✓									
Asthma							✓	✓					
Cardiovascular disease							✓	✓					
COPD								✓					
Epilepsy								✓					
Dementia								✓			✓		
Cancer								✓					
Systemic lupus erythematosus								✓					
Parkinson’s disease					✓			✓					
Chronic renal disease								✓					
Care or nursing home residence								✓					
Aid to get up from sitting									✓	✓			
Menopausal											✓		
Back pain											✓		
Self-reported health													✓
Early menopause												✓	
Chronic disease												✓	
Central nervous system medication												✓	
Physical activity													✓
Dyspnoea					✓	✓							

The test cohort had the highest AUC (males: 617 95% CI: 0.577, 0.657; females: 0.645 95% CI: 0.629, 0.661) of any of the interRAI-HC scores, which is to be expected because the score was developed for that cohort, therefore it would be expected that it would be the most accurate at identifying people at an elevated risk of fracture. The external validation cohort had a higher AUC than those in the internal validation cohort, possibly due to the low numbers of people and therefore lower statistical power in the internal cohort.

None of the scores mentioned in the literature review had an AUC below 0.67, suggesting they are much stronger at predicting hip fracture than the interRAI-HC models. All models developed for use with interRAI assessments had the lowest AUCs (FRAiL females: 0.711, FRAiL males: 0.692, FRS: 0.673). A potential explanation is that these people have more complex health care needs than those in the other cohorts. Due to their complex health needs, there may be other competing issues or underlying health concerns that make it harder to predict hip fracture in this population.

Those who undergo an interRAI-HC assessment may have greater heterogeneity than other cohorts. This means these individuals have a wider range of health issues than more specific populations so it may be harder to predict who in the group is likely to have a hip fracture. Another example of a national cross-sectional (like the population in this thesis) population with greater heterogeneity is in a recent study by Schluter *et al.* which aimed to evaluate how well preschool development indicators measured within a comprehensive assessment could screen for early literacy interventions. Their study identified strong associations between variables within the cohort, but had a low AUC (0.624, 95% CI: 0.618, 0.629) (243).

The highest AUC of any score was the female's Qfracture Updated score with an AUC of 0.893 (0.890, 0.896); it also had the largest development cohort (1,598,294), which would have allowed for greater statistical power when exploring the associations to hip fracture. Additionally, the Qfracture and Qfracture updated scores included a high numbers of items used to calculate their scores (14 for Qfracture and 24 for Qfracture updated). One way to improve prediction of a model is to include a high number of variables. This study aimed to characterise risk factors in addition to developing a prediction score, which meant there were less items used in the final prediction model, which could lead to a lower AUC. The selection criteria of variables in the model was based on which variables were statistically associated with hip fracture similar to the methods used by Berry *et al.* (76).

There were some studies with smaller cohorts (<2,000) that had higher AUCs such as the FRAMO (AUC: 0.72 95% CI: 0.64, 0.81) and the FRISC (0.727 95% CI: 0.660, 0.794). This

is most likely due to the cohort being a less heterogeneous group - for instance, both scores were developed for postmenopausal women, a group that is likely to have similar health issues compared to a more heterogeneous group as the interRAI-HC cohort. When the group is likely to be similar, the risk factors for hip fracture will also be similar and therefore easier to predict the likelihood of fracture.

Table 26 provides a summary of all hip fracture scores mentioned in section 2.4 and those developed in this study.

Table 26 Summary of hip fracture scores including year developed, country of origin, cohort size, statistical technique used, and AUC updated with interRAI-HC scores

Hip Fracture Score	Year	Country	Cohort	Statistical Method	AUC (95% CI)
FRAX	2008	UK	Unknown	Poisson regression	Unknown
Garvan	2007	Australia	1,768	Cox proportional hazards model	0.85*
Qfracture (Females)	2009	UK	1,183,663	Cox proportional hazards model	0.890 (0.786, 0.790)
Qfracture (Males)	2009	UK	1,174,232	Cox proportional hazards model	0.856 (0.851, 0.860)
Qfracture Updated (Females)	2012	UK	1,598,294	Cox proportional hazards model	0.893 (0.890, 0.896)
Qfracture Updated (Males)	2012	UK	1,544,379	Cox proportional hazards model	0.875 (0.868, 0.883)
FRACTURE	2001	USA	7,782	Logistic regression	0.714*
FRAMO	2004	Sweden	1,248	Logistic regression	0.72 (0.64, 0.81)
FRISC	2010	Japan	1,787	Poisson regression	0.727 (0.660, 0.794)
Van Staa	2006	UK	366,104	Cox proportional hazards model	0.84*
WHI	2007	USA	93,676	Cox proportional hazards model	0.80 (0.77, 0.82)
FRAiL (Males)	2017	USA	119,874	Competing risk regression	0.692*
FRAiL (Females)	2017	USA	299,794	Competing risk regression	0.711*
FRS	2017	Canada	29,386	Decision tree	0.673*
Test cohort males	*2019*	*NZ*	*17,339*	*Competing risks regression*	*0.617 (0.577, 0.657)*
Test cohort females	*2019*	*NZ*	*27,707*	*Competing risks regression*	*0.645 (0.629, 0.661)*
Internal males	*2019*	*NZ*	*8,521*	*Competing risks regression*	*0.586 (0.548, 0.625)*
Internal females	*2019*	*NZ*	*13,770*	*Competing risks regression*	*0.615 (0.593, 0.637)*
External males	*2019*	*NZ*	*24,917*	*Competing risks regression*	*0.611 (0.594, 0.629)*
External females	*2019*	*NZ*	*37,761*	*Competing risks regression*	*0.624 (0.612, 0.636)*

*Confidence intervals were not reported

8.3 Strengths and Limitations

The data arises from a national interRAI-HC cohort in New Zealand, which has distinct demographic characteristics. This allows scores derived from this cohort to potentially be more applicable to the population of New Zealanders with complex needs than other scores are. For example, the FRAX score is used to determine the ten-year probability of hip fracture, but among New Zealand individuals having an interRAI-HC assessment from July 2012 to June 2014, approximately 30% had died by the end of the 2-year period (192), suggesting ten years may be an unsuitable time period to estimate fracture risk in New Zealand. Conversely, the results from this study may not be as generalisable to international interRAI-HC users as some questions such as ethnicity have been specially tailored for a New Zealand cohort.

This is the first study to explore the development of a hip fracture risk score for use with the interRAI-HC cohort. The high quality source of data available in New Zealand and the ability to match to external datasets such as mortality records and hospital admissions presents a great opportunity to develop a hip fracture score and include mortality as a competing risk, which is important for cohorts with high mortality rates such as the interRAI-HC cohort.

The format of the medications data in the interRAI-HC assessments was such that it could not be easily extracted for analysis. However, the medications data obtained from the external validation dataset was in a different format to the original data, which after a considerable amount of tidying could possibly have been used for analysis. The literature indicates that medications are a significant risk factor for hip fracture, but this had to be excluded from the analysis. Berry *et al.* initially included medications in their interRAI-LTCF hip fracture prediction measure but found there was almost no difference when medications were included so opted not to include medications in the final model (76).

One limitation of this study is that the interRAI-HC 9.1 assessment does not have a question relating to osteoporosis so cannot be used to identify those who may be at risk of a severe injury. Osteoporosis is strongly associated with hip fracture risk in the literature (61). A question in the interRAI-HC assessment on osteoporosis may be helpful to make decisions about hip fracture risk.

While the initial dataset had large numbers, once it was divided for the purposes of cross-validation, and then again separated into male and female groups, there were small numbers of hip fractures available for analysis. This was especially true for the internal validation dataset, where the results were not as high as those found in the external validation dataset.

For instance, falls, which are the main cause of hip fracture in older adults, were considered to be statistically significant in the whole cohort model; however, they were not considered statistically significant in the males- and females-only cohorts, this may be due to low numbers. Additionally, the AUCs for the internal validation cohort were lower than those of the external validation cohort, which is unusual but is most likely due to the very low number of fractures in the internal validation cohort.

The New Zealand interRAI-HC assessment is for older people who are frailer and more vulnerable than the general population of older people in New Zealand; these people are therefore more likely to be at high risk of falls and hip fractures.

The time between an individual having an interRAI-HC assessment and a subsequent hip fracture event varies, and any changes to a person's health or any of the characteristics used in the hip fracture score between the two events are unknown.

This whole study explores main effects of specific risk factors for hip fracture. There may be interactions between various risk factors that were not explored in this thesis. For example, the risk factors BMI, alcohol, and sex may have interactions that can lead to hip fractures.

8.4 Implications/Recommendations

Based on the analysis in this study, the hip fracture risk scores have a modest ability to predict hip fracture risk in older adults undergoing an interRAI-HC assessment. The results of this analysis set the foundations for developing a hip fracture score that can be used clinically in the interRAI-HC assessment. The ROCs are not sufficient to include as an outcome score within the interRAI-HC at present. Additionally, there is strict criteria for including prediction tools in an interRAI assessment. Therefore, further work should be undertaken to optimise the scores by aiming to increase the sensitivity and specificity, where they are accurate enough to be adopted for clinical use. In addition to this, further external validation should be done using interRAI-HC assessments from other countries such as Canada or Belgium to test how well the hip fracture score can predict hip fractures outside of New Zealand.

Practical application of the hip fracture scores could be tested, where, at the end of an interRAI-HC assessment, the score is calculated, and the assessor uses this information to assess whether the individual should be referred to hip fracture prevention programs.

In the literature it was noted that there are differences in hip fracture incidence among different ethnic groups. Further research could be undertaken to explore whether there are

different risk profiles among different ethnic groups. Unfortunately, there are exceptionally low numbers of hip fracture for non-European groups, therefore analysis of the smaller ethnic groups would be unlikely to produce meaningful results. It is likely that part of the predictive power of ethnicity results from it acting as a proxy for socioeconomic status. The MoH track socioeconomic status by meshblock (a grouping of physical addresses that roughly correspond to street blocks) and interRAI-HC assessment data includes address information. Future studies could use this data to evaluate socioeconomic status more directly as a risk factor for hip fracture.

Additional items could be added to the interRAI-HC assessment to improve its ability to produce a more accurate risk prediction model. For instance, osteoporosis is an important risk factor for assessing hip fracture scores, and, therefore, it would be helpful to include as part of the interRAI-HC assessment. A question about whether an individual has a diagnosis of osteoporosis was included in older versions of the interRAI-HC in New Zealand, but for an unknown reason, it was removed. Berry *et al.* included osteoarthritis in their LTCF hip fracture prediction tool (76). This item is unavailable in the New Zealand interRAI-HC assessment and could be a risk factor for hip fractures in the New Zealand home care cohort.

The medications data extracted from the interRAI-HC assessment could be better formatted for analysis. Initially, the data was received in a broken and unusable format, but the external validation dataset had the medications listed in a separate spreadsheet. While this was a better format, the medication names were included in a column that also contained dosage information for each medication; this would require a significant amount of tidying to be usable for analysis. If the data were listed with the medication name in its own data column, it would be easier to analyse. Additionally, the medications data is currently entered into the interRAI-HC assessment form via a drop-down menu or by typing the medication information directly into the electronic form (195). This can lead to inconsistencies in medication names; a better method would be to only allow medications information to be inserted from a drop-down menu, which would reduce the spelling errors and make it easier to find certain medications.

There is an opportunity to explore the incidence of hip fracture across different regions of New Zealand. The external validation interRAI-HC dataset specifies which DHB administers the hospital that each patient was initially admitted to. An exploration into whether there were regional differences in the rate of hip fracture could be undertaken.

The literature indicates that hip fracture and other osteoporotic fractures have similar risk profiles. In future studies this novel methodology could be applied to further data to assess to what degree hip fracture scores can be used to predict the risk of other osteoporotic fractures such as humeral fractures and pelvic fractures.

It may be possible to utilise the medications data available from the MoH to test for relationships between medication and hip fracture instead of relying on data in the assessments. Where medication data from both a source like the MoH and the assessment is available, an opportunity exists for comparative analysis looking at which source of medication data can be used to produce the most predictive model, and to see how much improvement is made by using both sources together.

There is value in developing a hip fracture prediction model for the interRAI-LTCF cohort in New Zealand. There is already international work being undertaken to develop hip fracture scores for the interRAI-LTCF in the United States (76) and Canada (94); collaborative efforts could be made to develop a score that predicts hip fracture well for the same interRAI assessment across multiple countries. Additionally, the hip fracture score developed for the interRAI-HC could be tested and further developed across multiple countries where the interRAI-HC is already in use. The interRAI-HC assessment is used extensively around the world in populations similar to the New Zealand population.

8.5 What Could Have Been Done Differently

Some DHBs in New Zealand have a policy where some people aged between 50 and 65 years are eligible for older people's health services including interRAI-HC. For instance, the Canterbury District Health Board has a policy titled Assessing "Close in Age and Need" Guidelines which states that older persons health (which the interRAI-HC assessment is a part of) is a service available to people aged 65 years and older with disabilities, Māori and Pacific people aged 50 years and older with disabilities, and people aged 50 years and older with a confirmed dementia with disabilities (244). Studies following on from this one could include interRAI-HC assessment for Māori and Pacific people and people with a diagnosis of dementia who are 50 years and older.

Further studies could explore other methods of analysis such as artificial neural networks to see if the results produced using the competing risk regression model are similar to those developed by a neural network. Additionally, as there were small numbers of people in the internal validation cohort, another method of selecting a dataset for validation, such as

bootstrapping, could have been employed instead. Bootstrapping is a technique where a dataset is created by randomly selecting individuals one at a time to be part of the dataset. After each person is selected, they are added back into the selection dataset so they could be selected again. In this way a dataset is created that is similar to the original one that was used for developing the hip fracture score (245).

The size of the cohorts appeared to limit the predictive power of the models produced from this analysis. When working with a demographically distinct population as small as the one of New Zealand, it may be valuable to perform analyses over cohorts drawn from broader time periods to increase the sample size available.

8.6 Concluding Statement

This thesis identified risk factors associated with hip fracture and found that males and females had different risk profiles. Scores were developed for males and females individually, and both scores performed better than random chance but could be improved. Further work on optimising the scores could be undertaken to produce scores that may one day be used to predict hip fracture risk as part of the interRAI-HC assessment.

9 Bibliography

1. Shetty P. Grey matter: ageing in developing countries. The Lancet. 2012;379(9823):1285-7. DOI: 10.1016/S0140-6736(12)60541-8

2. Statistics New Zealand. Stats NZ. [Internet]. Wellington: Statistics New Zealand; 2015. People aged 65+ living in New Zealand 2015 [cited 2018 Jun 10]; [about 10 screens]. Available from: https://www.stats.govt.nz/infographics/people-aged-65-plus-living-in-new-zealand

3. Johnell O, Kanis J. Epidemiology of osteoporotic fractures. Osteoporos Int. 2005;16(2):S3-S7. DOI: 10.1007/s00198-004-1702-6

4. American Academy of Orthopaedic Surgeons. OrthoInfo. [Internet]. Rosemont (IL): American Academy of Orthopaedic Surgeons; 2009. Hip Fractures [cited 2018 Oct 15]; [about 15 screens]. Available from: https://orthoinfo.aaos.org/en/diseases--conditions/hip-fractures/

5. Kanis J, Oden A, Johnell O, Jonsson B, De Laet C, Dawson A. The burden of osteoporotic fractures: a method for setting intervention thresholds. Osteoporos Int. 2001;12(5):417-27. DOI: 10.1007/s001980170112

6. Haentjens P, Boonen S. The American Society of Anesthesiologists (ASA) Physical Status Classification System is an independent determinant of long-term mortality in older patients with hip fracture: systematic review and meta-analysis of longitudinal studies. Journal of Clinical Densitometry. 2014;3(17):422. DOI: 10.1016/j.jocd.2014.04.086

7. Osteoporosis New Zealand. Osteoporosis New Zealand Strategic Plan 2017-2020. [Internet]. Wellington: Osteoporosis New Zealand; 2017. [cited 2019 Apr 17]. p. 13. Available from: https://osteoporosis.org.nz/about-us/our-strategy/

8. Cooper C. The crippling consequences of fractures and their impact on quality of life. Am J Med. 1997;103(2):S12-S9. DOI: 10.1016/S0002-9343(97)90022-X

9. Jones S, Blake S, Hamblin R, Petagna C, Shuker C, Merry A. Reducing harm from falls. N Z Med J. 2016;129(1446):89-103.

10. Ariza-Vega P, Jiménez-Moleón JJ, Kristensen MT. Change of residence and functional status within three months and one year following hip fracture surgery. Disabil Rehabil. 2014;36(8):685-90. DOI: 10.3109/09638288.2013.813081

11. Keller JM, Sciadini MF, Sinclair E, O'Toole RV. Geriatric trauma: demographics, injuries, and mortality. Orthop Trauma. 2012;26(9):e161-e5. DOI: 10.1097/BOT.0b013e3182324460

12. Walker N, Norton R, Vander SH, Rodgers A, MacMahon S, Clark T, *et al.* Mortality after hip fracture: regional variations in New Zealand. N Z Med J. 1999;112(1092):269-71.

13. New Zealand Health Information Service. Fracture of Neck of Femur Services in New Zealand Hospitals 1999-2000. [Internet]. Wellington: Ministry of Health; 2002. [cited 2018 Apr 17]. p. 12-15. Available from: http://www.moh.govt.nz/notebook/nbbooks.nsf/0/34AAE6E97FD30F07CC2578320068FA7E/$file/fnf2002.pdf

14. Abrahamsen B, Van Staa T, Ariely R, Olson M, Cooper C. Excess mortality following hip fracture: a systematic epidemiological review. Osteoporos Int. 2009;20(10):1633-50. DOI: 10.1007/s00198-009-0920-3

15. Marks R, Allegrante JP, MacKenzie CR, Lane JM. Hip fractures among the elderly: causes, consequences and control. Ageing Res Rev. 2003;2(1):57-93. DOI: 10.1016/S1568-1637(02)00045-4

16. Harvey L, Toson B, Mitchell R, Brodaty H, Draper B, Close J. Incidence, timing and impact of comorbidity on second hip fracture: a population-based study. ANZ J Surg. 2018:88(6):577-581. DOI: 10.1111/ans.14507

17. Ensrud KE. Epidemiology of fracture risk with advancing age. J Gerontol A Biol Sci Med Sci. 2013;68(10):1236-42. DOI: 10.1093/gerona/glt092

18. Burge R, Dawson-Hughes B, Solomon DH, Wong JB, King A, Tosteson A. Incidence and economic burden of osteoporosis-related fractures in the United States, 2005–2025. Journal Bone Miner Res. 2007;22(3):465-75. DOI: 10.1359/jbmr.061113

19. Brown P, McNeill R, Radwan E, Willingale J. The burden of osteoporosis in New Zealand: 2007-2020. [Internet]. Auckland: School of Population Health University of Auckland; 2007. [cited 2018 Oct 15]. Available from: https://www.iofbonehealth.org/sites/default/files/PDFs/white_paper_new_zealand_2007.pdf

20. Health Quality & Safety Commission New Zealand. [Internet]. Wellington: HQSC; 2018. Falls in people aged 50 and over. [cited 2019 Jul 21]; [about 10 screens]. Available

from: https://www.hqsc.govt.nz/our-programmes/health-quality-evaluation/projects/atlas-of-healthcare-variation/falls/

21. Ministry of Health. Ministry of Health NZ. [Internet]. Wellington: Ministry of Health. District Health Boards; 2019 Mar 19 [cited 2019 Jul 21]; [about 3 screens]. Available from: https://www.health.govt.nz/new-zealand-health-system/key-health-sector-organisations-and-people/district-health-boards

22. New Zealand Government. [Internet]. Wellington: New Zealand Government; 2018. Ministry of Health [cited 2019 Oct 6]; [about 3 screens]. Available from: https://www.govt.nz/organisations/ministry-of-health/

23. Ministry of Health. Your Broken Hip (Fractured Neck of Femur) [Internet]. Wellington: Ministry of Health; 2015 Jan 27 [cited 2018 Oct 14]. p. 3-13. Available from: https://www.health.govt.nz/system/files/documents/pages/guide-hip-fracture.pdf

24. Australian & New Zealand Hip Fracture Registry. Australian and New Zealand guideline for hip fracture care: improving outcomes in hip fracture management of adults. [Internet]. Sydney: Australian and New Zealand Hip Fracture Registry Steering Group; 2014. [cited 2018 Oct 14]. p. 11-78. Available from: https://anzhfr.org/wp-content/uploads/2016/07/ANZ-Guideline-for-Hip-Fracture-Care.pdf

25. Australian & New Zealand Hip Fracture Registry. ANZHFR Bi-National Annual Report of Hip Fracture Care 2018. [Internet]. Sydney: Australian and New Zealand Hip Fracture Registry Steering Group; 2018. [cited 2018 Oct 14]. p. 10-84. Available from: https://anzhfr.org/2018-national-report/

26. Kanis JA, Oden A, McCloskey EV, Johansson H, Wahl DA, Cooper CJ. A systematic review of hip fracture incidence and probability of fracture worldwide. Osteoporos Int. 2012;23(9):2239-56. DOI: 10.1007/s00198-012-1964-3

27. Van Staa T, Dennison E, Leufkens H, Cooper C. Epidemiology of fractures in England and Wales. Bone. 2001;29(6):517-22. DOI: 10.1016/S8756-3282(01)00614-7

28. Langley J, Samaranayaka A, Davie G, Campbell AJ. Age, cohort and period effects on hip fracture incidence: analysis and predictions from New Zealand data 1974-2007. Osteoporos Int. 2011;22(1):105-11. DOI: 10.1007/s00198-010-1205-6

29. Butler M, Norton R, Lee-Joe T, Cheng A, Campbell AJ. The risks of hip fracture in older people from private homes and institutions. Age Ageing. 1996;25(5):381-5. DOI: 10.1093/ageing/25.5.381

30. Barber J, Mills H, Horne G, Purdie G, Devane P. The incidence of hip fractures in Maori and non-Maori in New Zealand. N Z Med J. 1995;108(1007):367-8.

31. World Health Organization. World Report on Ageing and Health [Internet]. Geneva: World Health Organization; 2015. [cited 2019 Apr 17]. p. 3-24. Available from: https://www.who.int/ageing/events/world-report-2015-launch/en/

32. United Nations Publications. World Population Ageing. [Internet]. New York: United Nations; 2017 [cited 2018 Jun 5]. p. 1-9. Available from: https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2017_Highlights.pdf

33. World Health Organization. Global Strategy and Action Plan on Ageing and Health (2016-2020): A Framework for Coordinated Global Action by the World Health Organization, Member States, and Partners Across the Sustainable Development Goals. [Internet]. Geneva: World Health Organisation; 2017. [cited 2019 Apr 17]. p. 6-27. Available from: https://www.who.int/ageing/global-strategy/en/

34. Statistics New Zealand. Stats NZ. [Internet]. Wellington: Statistics New Zealand; 2016. National Population Projections: 2016-2068. [cited 2018 Jun 5]; [about 18 screens]. Available from: http://archive.stats.govt.nz/browse_for_stats/population/estimates_and_projections/NationalPopulationProjections_HOTP2016/Commentary.aspx

35. Gullery C, Hamilton G. Towards integrated person-centred healthcare–the Canterbury journey. Future Hosp J. 2015;2(2):111-6. DOI: 10.7861/futurehosp.2-2-111

36. Rechel B, Doyle Y, Grundy E, McKee M. How can health systems respond to population ageing? [Internet]. Copenhagen: WHO Regional Office for Europe; 2009. [cited 2019 Apr 17]. p. 1-24. Available from: http://www.euro.who.int/__data/assets/pdf_file/0004/64966/E92560.pdf

37. Ministry of Health. New Zealand Health Strategy: Future Direction. [Internet]. Wellington: Ministry of Health; 2016. [cited 2018 Oct 14]. p. 1-36. Available from: https://www.health.govt.nz/system/files/documents/publications/new-zealand-health-strategy-futuredirection-2016-apr16.pdf

38. Ministry of Health. New Zealand Health Strategy: Roadmap of actions 2016. [Internet]. Wellington: Ministry of Health; 2016. [cited 2018 Oct 14]. p. 4-25. Available from: https://www.health.govt.nz/new-zealand-health-system/new-zealand-health-strategy-roadmap-actions-2016

39. Ministry of Health. Healthy Ageing Strategy. [Internet]. Wellington: Ministry of Health; 2016. [cited 2018 Oct 14]. p. 1-67. Available from: https://www.health.govt.nz/publication/healthy-ageing-strategy

40. Ministry of Social Development. New Zealand Disability Strategy 2016-2026. [Internet]. Wellington: Ministry of Social Development; 2016. [cited 2018 Oct 14]. p. 9-48. Available from: https://www.odi.govt.nz/nz-disability-strategy/about-the-strategy/new-zealand-disability-strategy-2016-2026/

41. Fielden J, Purdie G, Horne G, Devane P. Hip fracture incidence in New Zealand, revisited. N Z Med J. 2001;114(1129):154-6.

42. Osteoporosis New Zealand. [Internet]. Wellington: Osteoporosis New Zealand; 2016. About us [cited 2019 Apr 13]; [about 2 screens]. Available from: https://osteoporosis.org.nz/about-us/

43. Osteoporosis New Zealand. Bone Care 2020: A systematic approach to hip fracture care and prevention for New Zealand. [Internet]. Wellington: Osteoporosis New Zealand; 2012. [cited 2019 Apr 13]. p. 5-19 Available from: https://osteoporosis.org.nz/bones-care-2020/

44. Kim D, Mackenzie D, Cutfield R. Implementation of fracture liaison service in a New Zealand public hospital: Waitemata district health board experience. N Z Med J. 2016;129(1445):50-55.

45. Osteoporosis New Zealand. Guidance on the Diagnosis and Management of Osteoporosis in New Zealand. [Internet]. Wellington: Osteoporosis New Zealand; 2017. [cited 2019 Apr 13]. p. 1-7. Available from: https://osteoporosis.org.nz/resources/health-professionals/clinical-guidance/

46. American Academy of Orthopaedic Surgeons. OrthoInfo. [Internet]. Rosemont (IL): American Academy of Orthopaedic Surgeons; 2013. Hip Fracture Prevention [cited 2019 Apr 13]; [about 4 screens]. Available from: https://orthoinfo.aaos.org/en/staying-healthy/hip-fracture-prevention/.

47. Kannus P, Parkkari J, Niemi S, Pasanen M, Palvanen M, Järvinen M, *et al.* Prevention of hip fracture in elderly people with use of a hip protector. N Engl J Med. 2000;343(21):1506-13. DOI: 10.1056/NEJM200011233432101

48. Health Quality & Safety Commission New Zealand. Reducing harm from falls: recommended evidence-based resources. [Internet]. Wellington: HQSC;2019. [cited 2019 Oct 24]. p. 7-11. Available from: https://www.hqsc.govt.nz/assets/Falls/PR/falls-2019-evidence-base-final.pdf.

49. Nguyen ND, Frost S, Center JR, Eisman JA, Nguyen T. Development of a nomogram for individualizing hip fracture risk in men and women. Osteoporos Int. 2007;18(8):1109-17. DOI: 10.1007/s00198-007-0362-8

50. Centre for Metabolic Bone Diseases. University of Sheffield. [Internet]. Sheffield: University of Sheffield; 2008. Frax Fracture risk assessment tool. [cited 2017 Aug 31]; [about 3 screens]. Available from: https://www.sheffield.ac.uk/FRAX/tool.aspx?country=9

51. Hippisley-Cox J, Coupland C. Predicting risk of osteoporotic fracture in men and women in England and Wales: prospective derivation and validation of QFractureScores. BMJ. 2009;339:b4229. DOI: 10.1136/bmj.b4229

52. Van Staa T, Geusens P, Kanis J, Leufkens H, Gehlbach S, Cooper C. A simple clinical score for estimating the long-term risk of fracture in post-menopausal women. QJM. 2006;99(10):673-82. DOI: 10.1093/qjmed/hcl094

53. New Zealand Guidelines Group. Assessment processes for older people. [Internet]. Wellington: New Zealand Guidelines Group; 2003. [cited 2018 Oct 14]. p. 1-66. Available from: https://www.health.govt.nz/publication/assessment-processes-older-people

54. Martin G, Martin I. Assessment of community dwelling older people in New Zealand: A review of the tools. [Internet]. Wellington: New Zealand Guidelines Group; 2003. [cited 2019 Aug 26]. p. 13-70. Available from: http://www.moh.govt.nz/notebook/nbbooks.nsf/0/539F6497746F96D2CC257D8D0079C013?OpenDocument

55. Weidenbohm K, Parson M, Dixon R, Keeling S, Brandt T, Kilpatrick J. The exploration of the interRAI training programme implemented across five district health boards in New Zealand. Auckland: University of Auckland; 2006.

56. Meehan B, McCreadie M. Agreements for use of the interRAI assessment system. [Internet]. Wellington: interRAI New Zealand Governance Board; 2016. [cited 2019 Aug 26]. p. 1-11. Available from: https://www.interrai.co.nz/assets/Documents/ESS-Information-for-Managers/fa1b5c6120/interRAI-Governance-Board-Agreements-for-use-of-the-interRAI-assessment.pdf

57. Ryall T. Beehive. [Internet]. Wellington: New Zealand Government; 2013. Care assessments improving rest home care [cited 2019 Aug 26]; [about 2 screens]. Available from: https://www.beehive.govt.nz/release/care-assessments-improving-rest-home-care

58. interRAI New Zealand. [Internet]. Wellington: interRAI New Zealand. interRAI assessments; 2019 [cited 2019 Sep 10]; [about 2 screens]. Available from: https://www.interrai.co.nz/about/interrai-assessments-in-new-zealand/

59. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2010;8(5):336-41. DOI: 10.1371/journal.pmed.1000097

60. Marks R. Hip fracture epidemiological trends, outcomes, and risk factors, 1970–2009. Int J Gen Med. 2010;3:1-17. DOI: 10.2147/IJGM.S5906

61. Hamdy RC. Fracture risk assessment in postmenopausal women. Rev Endocr Metab Disord. 2010;11(4):229-36. DOI: 10.1007/s11154-009-9118-4

62. Shaw FE. Falls in cognitive impairment and dementia. Clin Geriatr Med. 2002;18(2):159-73. DOI: 10.1016/S0749-0690(02)00003-4

63. Neutel CI, Perry S, Maxwell C. Medication use and risk of falls. Pharmacoepidemiol Drug Saf. 2002;11(2):97-104. DOI: 10.1002/pds.686

64. Walter J, Aitchison S, Gochenour K. Fall prevention assessment and exercise recommendations. Proceedings of the 15th Annual Symposium on Graduate Research and Scholarly Projects; 2019 Apr 26; Wichita, KS. Wichita State University; 2019.

65. Chang VC, Do MT. Risk factors for falls among seniors: implications of gender. Am J Epidemiol. 2015;181(7):521-31. DOI: 10.1093/aje/kwu268

66. Margolis KL, Ensrud KE, Schreiner PJ, Tabor HK. Body size and risk for clinical fractures in older women. Ann Intern Med. 2000;133(2):123-7. DOI: 10.7326/0003-4819-133-2-200007180-00011

67. Robinovitch S, Hayes WC, McMahon T. Prediction of femoral impact forces in falls on the hip. J Biomech Eng. 1991;113(4):366-74. DOI: 10.1115/1.2895414

68. Armstrong ME, Spencer EA, Cairns BJ, Banks E, Pirie K, Green J, *et al.* Body mass index and physical activity in relation to the incidence of hip fracture in postmenopausal women. J Bone Miner Res. 2011;26(6):1330-8. DOI: 10.1002/jbmr.315

69. Chin K, Evans M, Cornish J, Cundy T, Reid I. Differences in hip axis and femoral neck length in premenopausal women of Polynesian, Asian and European origin. Osteoporos Int. 1997;7(4):344-7. DOI: 10.1007/BF01623775

70. Van Staa T, Leufkens H, Abenhaim L, Zhang B, Cooper C. Use of oral corticosteroids and risk of fractures. J Bone Miner Res. 2000;15(6):993-1000. DOI: 10.1359/jbmr.2000.15.6.993

71. Xu J, Lombardi G, Jiao W, Banfi G. Effects of exercise on bone status in female subjects, from young girls to postmenopausal women: an overview of systematic reviews and meta-analyses. Sports Med. 2016;46(8):1165-82. DOI: 10.1007/s40279-016-0494-0

72. Deurenberg P, Yap M, Van Staveren WA. Body mass index and percent body fat: a meta analysis among different ethnic groups. Int J Obes. 1998;22(12):1164. DOI: 10.1038/sj.ijo.0800741

73. Rush E, Plank L, Chandu V, Laulu M, Simmons D, Swinburn B, *et al.* Body size, body composition, and fat distribution: a comparison of young New Zealand men of European, Pacific Island, and Asian Indian ethnicities. N Z Med J. 2004:117(1207):36-44.

74. Grisso JA, Kelsey JL, Strom BL, Ghiu GY, Maislin G, O'Brien LA, *et al.* Risk factors for falls as a cause of hip fracture in women. N Engl J Med. 1991:324(19):1326-31. DOI: 10.1056/NEJM199105093241905

75. Stolee P, Poss J, Cook RJ, Byrne K, Hirdes JP. Risk factors for hip fracture in older home care clients. J Gerontol A Biol Sci Med Sci. 2009;64(3):403-10. DOI: 10.1093/gerona/gln035

76. Berry SD, Zullo AR, Lee Y, Mor V, McConeghy KW, Banerjee G, *et al.* Fracture Risk Assessment in Long-term Care (FRAiL): development and validation of a prediction model. J Gerontol A Biol Sci Med Sci. 2017. DOI: 10.1093/gerona/glx147

77. Formiga F, Navarro M, Duaso E, Chivite D, Ruiz D, Perez-Castejon JM, *et al.* Factors associated with hip fracture-related falls among patients with a history of recurrent falling. Bone. 2008: 43(5):941-4. DOI: 10.1016/j.bone.2008.06.014

78. Stevens JA, Olson S. Reducing falls and resulting hip fractures among older women. Home Care Provid. 2000;5(4):134-41. DOI: 10.1067/mhc.2000.109232

79. Hayes WC, Myers E, Robinovitch S, Van Den Kroonenberg A, Courtney AC, McMahon T. Etiology and prevention of age-related hip fractures. Bone. 1996;18(1):S77-S86. DOI: 10.1016/8756-3282(95)00383-5

80. Schrøder H, Petersen KK, Erlandsen M. Occurrence and incidence of the second hip fracture. Clin Orthop Rel Res. 1993(289):166-9. DOI: 10.1097/00003086-199304000-00022

81. Kanis JA, Oden A, Johnell O, Johansson H, De Laet C, Brown J, *et al.* The use of clinical risk factors enhances the performance of BMD in the prediction of hip and osteoporotic fractures in men and women. Osteoporos Int. 2007;18(8):1033-46. DOI: 10.1007/s00198-007-0343-y

82. Schuit S, Van der Klift M, Weel A, De Laet C, Burger H, Seeman E, *et al.* Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam Study. Bone. 2004;34(1):195-202. DOI: 10.1016/j.bone.2003.10.001

83. Wainwright SA, Marshall LM, Ensrud KE, Cauley JA, Black DM, Hillier TA, *et al.* Hip Fracture in Women without Osteoporosis. J Clin Endocrinol Metab. 2005;90(5):2787-93. DOI: 10.1210/jc.2004-1568

84. Black D, Steinbuch M, Palermo L, Dargent-Molina P, Lindsay R, Hoseyni M, *et al.* An assessment tool for predicting fracture risk in postmenopausal women. Osteoporos Int. 2001;12(7):519-28. DOI: 10.1007/s001980170072

85. Ettinger B, Hillier TA, Pressman A, Che M, Hanley DAJJoWsH. Simple computer model for calculating and reporting 5-year osteoporotic fracture risk in postmenopausal women. J Womens Health 2005;14(2):159-71. DOI: 10.1089/jwh.2005.14.159

86. Grisso JA, Kelsey JL, O'Brien LA, Miles CG, Sidney S, Maislin G, *et al.* Risk Factors for Hip Fracture in Men. Am J Epidemiol. 1997: 145(9):786-93. DOI: 10.1093/oxfordjournals.aje.a009171

87. Abrahamsen B, Nielsen MF, Eskildsen P, Andersen JT, Walter S, Brixen K. Fracture risk in Danish men with prostate cancer: a nationwide register study. BJU Int. 2007: 100(4):749-54. DOI: 10.1111/j.1464-410X.2007.07163.x

88. Sterling RS. Gender and race/ethnicity differences in hip fracture incidence, morbidity, mortality, and function. Clin Orthop Relat Res. 2011;469(7):1913-8. DOI: 10.1007/s11999-010-1736-3

89. Cummings SR, Melton LJ. Epidemiology and outcomes of osteoporotic fractures. Lancet. 2002;359(9319):1761-7. DOI: 10.1016/S0140-6736(02)08657-9

90. Koeck CM, Schwappach L, Niemann FM, Strassmann TJ, Ebner H, Klaushofer K. Incidence and costs of osteoporosis-associated hip fractures in Austria. Wien Klin Wochenschr. 2001;113(10):371-7.

91. Rapp K, Büchele G, Dreinhöfer K, Bücking B, Becker C, Benzinger P. Epidemiology of hip fractures. Z Gerontol Geriatr. 2019: 52(1):10-6. DOI: 10.1007/s00391-018-1382-z

92. Hippisley-Cox J, Coupland C. Derivation and validation of updated QFracture algorithm to predict risk of osteoporotic fracture in primary care in the United Kingdom: prospective open cohort study. BMJ. 2012;344:e3427. DOI: 10.1136/bmj.e3427

93. Wilson RT, Chase GA, Chrischilles EA, Wallace RB. Hip fracture risk among community-dwelling elderly people in the United States: a prospective study of physical, cognitive, and socioeconomic indicators. Am Journal Public Health. 2006;96(7):1210-8. DOI: 10.2105/AJPH.2005.077479

94. Ioannidis G, Jantzi M, Bucek J, Adachi JD, Giangregorio L, Hirdes J, *et al.* Development and validation of the Fracture Risk Scale (FRS) that predicts fracture over a 1-year time period in institutionalised frail older people living in Canada: an electronic record-linked longitudinal cohort study. BMJ Open. 2017;7(9):e016477. DOI: 10.1136/bmjopen-2017-016477

95. Morris JN, Fries BE, Mehr DR, Hawes C, Phillips C, Mor V, *et al.* MDS cognitive performance scale©. J Gerontol. 1994;49(4):174-82. DOI: 10.1093/geronj/49.4.M174

96. Bohlken J, Jacob L, Schaum P, Rapp MA, Kostev K. Hip fracture risk in patients with dementia in German primary care practices. Dementia. 2017;16(7):853-64. DOI 10.1177/1471301215621854

97. Harvey L, Mitchell R, Brodaty H, Draper B, Close J. The impact of dementia and other comorbidities on increased risk of subsequent hip fracture following hip fracture in Australia: a competing risk approach. Int J Popul Data Sci. 2017;1(141). DOI: 10.23889/ijpds.v1i1.160

98. Pi-Sunyer FX, Becker DM, Bouchard C, Carleton R, Colditz G, Dietz W, *et al.* Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: Executive summary. Am J Clin Nutr. 1998;68(4):899-917. DOI: 10.1093/ajcn/68.4.899

99. De Laet C, Kanis J, Odén A, Johanson H, Johnell O, Delmas P, *et al.* Body mass index as a predictor of fracture risk: a meta-analysis. Osteoporos Int. 2005;16(11):1330-8. DOI: 10.1007/s00198-005-1863-y

100. Prieto-Alhambra D, Premaor MO, Fina Avilés F, Hermosilla E, Martinez-Laguna D, Carbonell-Abella C, *et al.* The association between fracture and obesity is site-dependent: a population-based study in postmenopausal women. J Bone Miner Res. 2012;27(2):294-300. DOI: 10.1002/jbmr.1466

101. Bean N, Bennett K, Lehmann A. Habitus and hip fracture revisited: skeletal size, strength and cognition rather than thinness? Age Ageing. 1995;24(6):481-4. DOI: 10.1093/ageing/24.6.481

102. Robbins J, Aragaki AK, Kooperberg C, Watts N, Wactawski-Wende J, Jackson RD, *et al.* Factors associated with 5-year risk of hip fracture in postmenopausal women. JAMA. 2007;298(20):2389-98. DOI: 10.1001/jama.298.20.2389

103. Hla MM, Davis JW, Ross PD, Wasnich RD, Yates AJ, Ravn P, *et al.* A multicenter study of the influence of fat and lean mass on bone mineral content: evidence for differences in their relative influence at major fracture sites. Early Postmenopausal Intervention Cohort (EPIC) Study Group. Am J Clin Nutr. 1996;64(3):354-60. DOI: 10.1093/ajcn/64.3.345

104. Simpson E, Rubin G, Clyne C, Robertson K, O'Donnell L, Davis S, *et al.* Local estrogen biosynthesis in males and females. Endocr Relat Cancer. 1999;6(2):131-7. DOI: 10.1677/erc.0.0060131

105. Chen JS, Sambrook PN, Simpson JM, Cameron ID, Cumming RG, Seibel MJ, *et al.* Risk factors for hip fracture among institutionalised older people. Age Ageing. 2009;38(4):429-34. DOI: 10.1093/ageing/afp051

106. Berry SD, Lee Y, Zullo AR, Kiel DP, Dosa D, Mor V. Incidence of hip fracture in US nursing homes. J Gerontol A Biol Sci Med Sci. 2016;71(9):1230-4. DOI: 10.1093/gerona/glw034

107. Parker MJ, Twemlow TR, Pryor GA. Environmental hazards and hip fractures. Age Ageing. 1996;25(4):322-5. DOI: 10.1093/ageing/25.4.322

108. Norton R, Campbell AJ, Lee-Joe T, Robinson E, Butler M. Circumstances of falls resulting in hip fractures among older people. J Am Geriatr Soc. 1997;45(9):1108-12. DOI: 10.1111/j.1532-5415.1997.tb05975.x

109. Clemson L, Cumming RG, Roland M. Case–control study of hazards in the home and risk of falls and hip fractures. Age Ageing. 1996;25(2):97-101. DOI: 10.1093/ageing/25.2.97

110. Farahmand BY, Persson P-G, Michaëlsson K, Baron JA, Parker M, Ljunghall S, *et al.* Socioeconomic status, marital status and hip fracture risk: a population-based case–control study. Osteoporos Int. 2000;11(9):803-8. DOI: 10.1007/s001980070060

111. Curtis EM, van der Velde R, Moon RJ, van den Bergh JP, Geusens P, de Vries F, *et al.* Epidemiology of fractures in the United Kingdom 1988–2012: variation with age, sex, geography, ethnicity and socioeconomic status. Bone. 2016;87:19-26. DOI: 10.1016/j.bone.2016.03.006

112. Zingmond D, Soohoo N, Silverman S. The role of socioeconomic status on hip fracture. Osteoporos Int. 2006;17(10):1562-8. DOI: 10.1007/s00198-006-0161-7

113. Quah C, Boulton C, Moran C. The influence of socioeconomic status on the incidence, outcome and mortality of fractures of the hip. J Bone Joint Surg Br. 2011;93(6):801-5. DOI: 10.1302/0301-620X.93B6.24936

114. Ensrud KE, MPh RCL, Orwoll ES, Genant HK, Cummings SR, Group SoOFR. Body size and hip fracture risk in older women: a prospective study. Am Journal Med. 1997;103(4):274-80. DOI: 10.1016/S0002-9343(97)00025-9

115. Pluijm SM, Koes B, de Laet C, Van Schoor NM, Kuchuk NO, Rivadeneira F, *et al.* A simple risk score for the assessment of absolute fracture risk in general practice based on two longitudinal studies. J Bone Miner Res. 2009;24(5):768-74. DOI: 10.1359/jbmr.081244

116. Rothem DE, Rothem L, Soudry M, Dahan A, Eliakim R. Nicotine modulates bone metabolism-associated gene expression in osteoblast cells. Journal Bone Miner Metab. 2009;27(5):555-61. DOI: 10.1007/s00774-009-0075-5

117. Kanis JA, Johansson H, Johnell O, Oden A, De Laet C, Eisman JA, *et al.* Alcohol intake as a risk factor for fracture. Osteoporos Int. 2005;16(7):737-42. DOI: 10.1007/s00198-004-1734-y

118. Waugh E, Lam M-A, Hawker G, McGowan J, Papaioannou A, Cheung A, *et al.* Risk factors for low bone mass in healthy 40–60 year old women: a systematic review of the literature. Osteoporos Int. 2009;20(1):1. DOI: 10.1007/s00198-008-0643-x

119. Dam T-T, Harrison S, Fink H, Ramsdell J, Barrett-Connor E. Bone mineral density and fractures in older men with chronic obstructive pulmonary disease or asthma. Osteoporos Int. 2010;21(8):1341-9. DOI: 10.1007/s00198-009-1076-x

120. Jørgensen N, Schwarz P, Holme I, Henriksen B, Petersen LJ, Backer V. The prevalence of osteoporosis in patients with chronic obstructive pulmonary disease—a cross sectional study. Respir Med. 2007;101(1):177-85. DOI: 10.1016/j.rmed.2006.03.029

121. Jørgensen N, Schwarz P. Osteoporosis in chronic obstructive pulmonary disease patients. Curr Opin Pulm Med. 2008;14(2):122-7. DOI: 10.1097/MCP.0b013e3282f4efb6

122. Kearney DM, Lockey RF. Osteoporosis and asthma. Ann Allergy Asthma Immunol. 2006;96(6):769-76. DOI: 10.1016/S1081-1206(10)61338-5

123. Melton LJ, Patel A, Achenbach SJ, Oberg AL, Yunginger JW. Long-term fracture risk following adult-onset asthma: a population-based study. Osteoporos Int. 2004;15(4):311-6. DOI: 10.1007/s00198-003-1504-2

124. Adinoff AD, Hollister JR. Steroid-induced fractures and bone loss in patients with asthma. New Engl J Med. 1983;309(5):265-8. DOI: 10.1056/NEJM198308043090502

125. Kim SY, Schneeweiss S, Liu J, Daniel GW, Chang C-L, Garneau K, *et al.* Risk of osteoporotic fracture in a large population-based cohort of patients with rheumatoid arthritis. Arthritis Res Ther. 2010;12(4):R154. DOI: 10.1186/ar3107

126. van Staa T, Geusens P, Bijlsma J, Leufkens H, Cooper C. Clinical assessment of the long-term risk of fracture in patients with rheumatoid arthritis. Arthritis Rheum. 2006;54(10):3104-12. DOI: 10.1002/art.22117

127. Wright NC, Lisse JR, Walitt BT, Eaton CB, Chen Z. Arthritis increases the risk for fractures-results from the women's health initiative. J Rheumatol. 2011;38(8):1680-8. DOI: 10.3899/jrheum.101196

128. Azhar A, Lim C, Kelly E, O'Rourke K, Dudeney S, Hurson B, *et al.* Cost induced by hip fractures. Ir Med J. 2008;101(7):213-5.

129. Liang C, Hu J, Li J, He Z, Gu N, Zhang Y. Increased risk of hip fracture related to cardiovascular disease: a meta-analysis. Int J Clin Exp Med. 2018;11(7):6501-8.

130. Edwards BJ, Sun M, Zhang X, Holmes HM, Song J, Khalil P, *et al.* Fractures frequently occur in older cancer patients: the MD Anderson Cancer Center experience. Support Care Cancer. 2018;26(5):1561-8. DOI: 10.1007/s00520-017-3962-7

131. Chen Z, Maricic M, Aragaki A, Mouton C, Arendell L, Lopez AM, *et al.* Fracture risk increases after diagnosis of breast or other cancers in postmenopausal women: results from the Women's Health Initiative. Osteoporos Int. 2009;20(4):527-36. DOI: 10.1007/s00198-008-0721-0

132. Wallander M, Axelsson KF, Lundh D, Lorentzon M. Patients with prostate cancer and androgen deprivation therapy have increased risk of fractures—a study from the fractures and fall injuries in the elderly cohort (FRAILCO). Osteoporos Int. 2019;30(1):115-25. DOI: 10.1007/s00198-018-4722-3

133. Kanis J, McCloskey E, Johansson H, Oden A, Ström O, Borgström F. Development and use of FRAX in osteoporosis. Osteoporos Int. 2010;21(2):407-13. DOI: 10.1007/s00198-010-1253-y

134. Siminoski K, Leslie WD, Frame H, Hodsman A, Josse RG, Khan A, *et al.* Recommendations for bone mineral density reporting in Canada. J Clin Densitom. 2005;56(3):178. DOI: 10.1016/j.jocd.2007.01.001

135. Park H, Satoh H, Miki A, Urushihara H, Sawada Y. Medications associated with falls in older people: systematic review of publications from a recent 5-year period. Eur J Clin Pharmacol. 2015;71(12):1429-40. DOI: 10.1007/s00228-015-1955-3

136. Barnes PJ, Adcock IM. How do corticosteroids work in asthma? Ann Intern Med. 2003;139:359-70.

137. Gonzalez AV, Coulombe J, Ernst P, Suissa S. Long-term use of inhaled corticosteroids in COPD and the risk of fracture. Chest. 2018;153(2):321-8. DOI: 10.1016/j.chest.2017.07.002

138. Lai S-W, Lin C-L, Liao K-F. Use of oral corticosteroids and risk of hip fracture in the elderly in a case-control study. Front Pharmacol. 2017;8:625. DOI: 10.3389/fphar.2017.00625

139. Seppala LJ, van de Glind EM, Daams JG, Ploegmakers KJ, de Vries M, Wermelink AM, *et al.* Fall-Risk-Increasing drugs: a systematic review and meta-analysis: III. others. J Am Med Dir Assoc. 2018;19(4):372. e1-. e8. DOI: 10.1016/j.jamda.2017.12.098

140. Lim LS, Fink HA, Kuskowski MA, Taylor BC, Schousboe JT, Ensrud KE. Loop diuretic use and increased rates of hip bone loss in older men: the Osteoporotic Fractures in Men Study. Arch Intern Med. 2008;168(7):735-40. DOI: 10.1001/archinte.168.7.735

141. Jamieson HA, Nishtala PS, Scrase R, Deely JM, Abey-Nesbit R, Hilmer SN, *et al.* Drug burden index and its association with hip fracture among older adults: a national population-based study. J Gerontol A Biol Sci Med Sci. 2018;74(7):1127-1133. DOI: 10.1093/gerona/gly176.

142. Nishtala PS, Chyou T-y. Zopiclone Use and Risk of Fractures in Older People: Population-Based Study. J Am Med Dir Assoc. 2017;18(4):e1-. e8. DOI: 10.1016/j.jamda.2016.12.085

143. Paganini-Hill A, Chao A, Ross RK, Henderson BEJE. Exercise and other factors in the prevention of hip fracture: the Leisure World study. Epidemiol. 1991:16-25. DOI: 10.1097/00001648-199101000-00004

144. Høidrup S, Sørensen TI, Strøger U, Lauritzen JB, Schroll M, Grønbæk MJAjoe. Leisure-time physical activity levels and changes in relation to risk of hip fracture in men and women. Am J Epidemiol. 2001;154(1):60-8. DOI: 10.1093/aje/154.1.60

145. Lagerros YT, Hantikainen E, Michaëlsson K, Ye W, Adami H-O, Bellocco R. Physical activity and the risk of hip fracture in the elderly: a prospective cohort study. Eur J Epidemiol. 2017;32(11):983-91. DOI: 10.1007/s10654-017-0312-5

146. Cawthon PM, Fullman RL, Marshall L, Mackey DC, Fink HA, Cauley JA, *et al.* Physical performance and risk of hip fractures in older men. J Bone Miner Res. 2008;23(7):1037-44. DOI: 10.1359/jbmr.080227

147. Nikander R, Kannus P, Dastidar P, Hannula M, Harrison L, Cervinka T, et al. Targeted exercises against hip fragility. Osteoporos Int. 2009;20(8):1321-8. DOI: 10.1007/s00198-008-0785-x

148. Nordström A, Karlsson C, Nyquist F, Olsson T, Nordström P, Karlsson MJ. Bone loss and fracture risk after reduced physical activity. J Bone Miner Res 2005;20(2):202-7. DOI: 10.1359/JBMR.041012

149. Karinkanta S, Kannus P, Uusi-Rasi K, Heinonen A, Sievänen H. Combined resistance and balance-jumping exercise reduces older women's injurious falls and fractures: 5-year follow-up study. Age Ageing. 2015;44(5):784-9. DOI: 10.1093/ageing/afv064

150. Trimpou P, Landin-Wilhelmsen K, Odén A, Rosengren A, Wilhelmsen L. Male risk factors for hip fracture—a 30-year follow-up study in 7,495 men. Osteoporos Int. 2010;21(3):409-16. DOI: 10.1007/s00198-009-0961-7

151. Russo CR. The effects of exercise on bone. Basic concepts and implications for the prevention of fractures. Clin Cases Miner Bone Metab. 2009;6(3):223.

152. Hart NH, Nimphius S, Rantalainen T, Ireland A, Siafarikas A, Newton RU. Mechanical basis of bone strength: influence of bone material, bone structure and muscle action. J Musculoskelet Neuronal Interact. 2017;17(3):114.

153. Doku AO, Moses MO, Acheampong IK, Gyamfi I, Agbavor C, Akwa LG, *et al*. Physiological, anthropometric parameters, and balance skill response of healthy bankers to fitness training. J Exerc Rehabil. 2019;15(2):242. DOI: 10.12965/jer.1836572.286

154. Rietsch K, Eccard JA, Scheffler C. Decreased external skeletal robustness due to reduced physical activity? Am J Hum Biol. 2013;25(3):404-10. DOI: 10.1002/ajhb.22389

155. Braun SI, Kim Y, Jetton AE, Kang M, Morgan DW. Prediction of bone mineral density and content from measures of physical activity and sedentary behavior in younger and older females. Prev Med Rep. 2015;2:300-5. DOI: 10.1016/j.pmedr.2015.04.012

156. Valimaki MJ, Karkkainen M, Lamberg-Allardt C, Laitinen K, Alhava E, Heikkinen J, *et al.* Exercise, smoking, and calcium intake during adolescence and early adulthood as determinants of peak bone mass. BMJ. 1994;309(6949):230-5. DOI: 10.1136/bmj.309.6949.230

157. Cooper C, Cawley M, Bhalla A, Egger P, Ring F, Morton L, *et al.* Childhood growth, physical activity, and peak bone mass in women. J Bone Miner Res. 1995;10(6):940-7. DOI: 10.1002/jbmr.5650100615

158. Andreoli A, Celi M, Volpe S, Sorge R, Tarantino U. Long-term effect of exercise on bone mineral density and body composition in post-menopausal ex-elite athletes: a retrospective study. Eur J Clin Nutr. 2012;66(1):69-74. DOI: 10.1038/ejcn.2011.104

159. Karlsson M, Nordqvist A, Karlsson C. Sustainability of exercise-induced increases in bone density and skeletal structure. Food Nutr Res. 2008;52(1):1872. DOI: 10.3402/fnr.v52i0.1872

160. Nguyen ND, Pongchaiyakul C, Center JR, Eisman JA, Nguyen TV. Identification of high-risk individuals for hip fracture: a 14-year prospective study. J Bone Miner Res. 2005;20(11):1921-8. DOI: 10.1359/JBMR.050520

161. Kanis J, Johnell O, Odén A, Johansson H, McCloskey E. FRAX™ and the assessment of fracture probability in men and women from the UK. Osteoporos Int. 2008;19(4):385-97. DOI: 10.1007/s00198-007-0543-5

162. Singer B, McLauchlan G, Robinson C, Christie J. Epidemiology of fractures in 15 000 adults: the influence of age and gender. Bone Joint Surg Br. 1998;80(2):243-8. DOI: 10.1302/0301-620X.80B2.0800243

163. Kattan MW, Marasco J. What is a real nomogram? Semin Oncol; 2010;37(1):23-6. DOI: 10.1053/j.seminoncol.2009.12.003

164. Pencina MJ, D'Agostino RB. Evaluating discrimination of risk prediction models: the C statistic. JAMA. 2015;314(10):1063-4. DOI: 10.1001/jama.2015.11082

165. Perkins NJ, Schisterman EF. The inconsistency of "optimal" cutpoints obtained using two criteria based on the Receiver Operating Characteristic curve. Am J Epidemiol. 2006;163(7):670-5. DOI: 10.1093/aje/kwj063

166. Albertsson DM, Mellström D, Petersson C, Eggertsen. Validation of a 4-item score predicting hip fracture and mortality risk among elderly women. Ann Fam Med. 2007;5(1):48-56. DOI: 10.1370/afm.602

167. Tanaka S, Yoshimura N, Kuroda T, Hosoi T, Saito M, Shiraki M. The Fracture and Immobilization Score (FRISC) for risk assessment of osteoporotic fracture and immobilization in postmenopausal women—A joint analysis of the Nagano, Miyama, and Taiji cohorts. Bone. 2010;47(6):1064-70. DOI: 10.1016/j.bone.2010.08.019

168. Negm AM, Ioannidis G, Jantzi M, Bucek J, Giangregorio L, Pickard L, *et al.* Validation of a one year fracture prediction tool for absolute hip fracture risk in long term care residents. BMC Geriatr. 2018;18(1):320. DOI: 10.1186/s12877-018-1010-1

169. Nguyen ND, Frost SA, Center J, Eisman JA, Nguyen TV. Development of prognostic nomograms for individualizing 5-year and 10-year fracture risks. Osteoporos Int. 2008;19(10):1431-44. DOI: 10.1007/s00198-008-0588-0

170. Hosmer DW, Lemeshow S, Sturdivant RX. Introduction to the Logistic Regression Model. In: Applied logistic regression. 3rd ed. Hoboken: Wiley; 2013. p. 1-33.

171. Peng C-YJ, Lee KL, Ingersoll GM. An introduction to logistic regression analysis and reporting. J Educ Res. 2002;96(1):3-14. DOI: 10.1080/00220670209598786

172. Harrell Jr FE. Cox proportional hazards regression model. In: Regression modeling strategies: with applications to linear models, logistic and ordinal regression, and survival analysis. Second ed. Cham: Springer; 2015. p. 475-517.

173. Bagdonavičius V, Levulienė R, Nikulin M. Goodness-of-fit criteria for the Cox model from left truncated and right censored data. J Math Sci. 2010;167(4):436-43. DOI: 10.1007/s10958-010-9929-6

174. Cox DR. Regression models and life-tables. J R Stat Soc Series B Stat Methodol. 1972;34(2):187-202. DOI: 10.1111/j.2517-6161.1972.tb00899.x

175. Szychowski JM, Roth DL, Clay OJ, Mittelman MS. Patient death as a censoring event or competing risk event in models of nursing home placement. Stat Med. 2010;29(3):371-81. DOI: 10.1002/sim.3797

176. Fine JP, Gray RJ. A proportional hazards model for the subdistribution of a competing risk. J Am Stat Assoc. 1999;94(446):496-509. DOI: 10.1080/01621459.1999.10474144

177. Scrucca L, Santucci A, Aversa F. Competing risk analysis using R: an easy guide for clinicians. Bone Marrow Transplant. 2007;40(4):381. DOI: 10.1038/sj.bmt.1705727

178. Gooley TA, Leisenring W, Crowley J, Storer BE. Estimation of failure probabilities in the presence of competing risks: new representations of old estimators. Stat Med. 1999;18(6):695-706. DOI: 10.1002/(SICI)1097-0258(19990330)18:6<695::AID-SIM60>3.0.CO;2-O

179. Berry SD, Ngo L, Samelson EJ, Kiel DP. Competing risk of death: an important consideration in studies of older adults. J Am Geriatr Soc. 2010;58(4):783-7. DOI: 10.1111/j.1532-5415.2010.02767.x

180. Adams ST, Leveson SH. Clinical prediction rules. BMJ. 2012;344:d8312. DOI: 10.1136/bmj.d8312

181. Bellazzi R, Zupan B. Predictive data mining in clinical medicine: current issues and guidelines. Int J Med Inform. 2008;77(2):81-97. DOI: 10.1016/j.ijmedinf.2006.11.006

182. Austin PC, Tu JV, Lee DS. Logistic regression had superior performance compared with regression trees for predicting in-hospital mortality in patients hospitalized with heart failure. J Clin Epidemiol. 2010;63(10):1145-55. DOI: 10.1016/j.jclinepi.2009.12.004

183. Anderson D, Burnham K. Model selection and multi-model inference. 2nd ed. New York: Springer-Verlag; 2004. p.29-31.

184. Kohavi R. A study of cross-validation and bootstrap for accuracy estimation and model selection. IJCAI (U S); 1995: Montreal, Canada.

185. Bleeker S, Moll H, Steyerberg E, Donders A, Derksen-Lubsen G, Grobbee D, *et al.* External validation is necessary in prediction research: A clinical example. J Clin Epidemiol. 2003;56(9):826-32. DOI: 10.1016/S0895-4356(03)00207-5

186. Harrell Jr FE, Lee KL, Matchar DB, Reichert TA. Regression models for prognostic prediction: advantages, problems, and suggested solutions. Cancer Treat Rep. 1985;69(10):1071-7.

187. Harrell Jr FE, Lee KL, Mark DB. Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med. 1996;15(4):361-87. DOI: 10.1002/(SICI)1097-0258(19960229)15:4<361::AID-SIM168>3.0.CO;2-4

188. Moons KG, van Es G-A, Michel BC, Büller HR, Habbema JDF, Grobbee DE. Redundancy of single diagnostic test evaluation. Epidemiol. 1999:276-81. DOI: 10.1097/00001648-199905000-00015

189. Steyerberg EW, Harrell Jr FE, Borsboom GJ, Eijkemans M, Vergouwe Y, Habbema JDF. Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. J Clin Epidemiol. 2001;54(8):774-81. DOI: 10.1016/S0895-4356(01)00341-9

190. Riley RD, Ensor J, Snell KI, Debray TP, Altman DG, Moons KG, *et al.* External validation of clinical prediction models using big datasets from e-health records or IPD meta-analysis: opportunities and challenges. BMJ. 2016;353:i3140. DOI: 10.1136/bmj.i3140

191. Ministry of Health. [Internet]. Wellington: Ministry of Health. National Health Index overview; 2018 [cited 2019 Apr 13]; [about 3 screens]. Available from: https://www.health.govt.nz/our-work/health-identity/national-health-index/national-health-index-overview

192. Schluter PJ, Ahuriri-Driscoll A, Anderson TJ, Beere P, Brown J, Dalrymple-Alford J, *et al.* Comprehensive clinical assessment of home-based older persons within New Zealand: an epidemiological profile of a national cross-section. Aust N Z J Public Health. 2016;40(4):349-55. DOI: 10.1111/1753-6405.12525

193. Meehan B, Millar N. Regulating the quality of long-term aged care in New Zealand. Regulating Long-Term Care Quality: An International Comparison: Cambridge University Press; 2014. p. 357-81. DOI: 10.1017/CBO9781107323711.018

194. Eleftheriades C, Wittenberg R. A critical review of international practice on assessment and eligibility in adult social care: Lessons for England. Oxford: Centre for Health Service Economics & Organisation (CHSEO); 2013.

195. Morris JN, interRAI. InterRAI Home Care (HC) Assessment Form and User's Manual: interRAI; 2010.

196. Morris JN, Belleville-Taylor P. interRAI clinical assessment protocols (CAPs) for use with community and long-term care assessment instruments: InterRAI; 2010.

197. Morris JN. Falls CAP. InterRAI Clinical Assessment Protocols (CAPs) for Use with Community and Long-term Care Assessment Instruments: interRAI; 2010. p. 101-8.

198. Hirdes JP, Frijters DH, Teare GF. The MDS-CHESS Scale: A new measure to predict mortality in institutionalized older people. J Am Geriatr Soc. 2003;51(1):96-100. DOI: 10.1034/j.1601-5215.2002.51017.x

199. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977:159-74. DOI: 10.2307/2529310

200. Hirdes JP, Ljunggren G, Morris JN, Frijters DH, Soveri HF, Gray L, *et al.* Reliability of the interRAI suite of assessment instruments: a 12-country study of an integrated health information system. BMC Health Serv Res. 2008;8(1):277. DOI: 10.1186/1472-6963-8-277

201. Ministry of Health. [Internet]. Wellington: Ministry of Health. National Minimum Dataset (hospital events); 2019 May 29 [cited 2019 Oct 3]; [about 4 screens]. Available from:

https://www.health.govt.nz/nz-health-statistics/national-collections-and-surveys/collections/national-minimum-dataset-hospital-events

202. Ministry of Health. [Internet]. Wellington: Ministry of Health. Mortality Collection; 2019 May 30 [cited 2019 Oct 3]; [about 4 screens]. Available from: https://www.health.govt.nz/nz-health-statistics/national-collections-and-surveys/collections/mortality-collection

203. Poutasi K. Ethnicity data protocols for the health and disability sector. [Internet]. Wellington: Ministry of Health; 2004. [cited 2019 Aug 26]. Available from: https://www.fmhs.auckland.ac.nz/assets/fmhs/faculty/tkhm/tumuaki/docs/ethnicity-data-protocols.pdf

204. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, *et al.* The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. PLoS Med. 2015;12(10):e1001885. DOI: 10.1371/journal.pmed.1001885

205. Vandenbroucke JP, Von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, *et al.* Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med. 2007;4(10):e297. DOI: 10.1371/journal.pmed.0040297

206. IBM Corporation. IBM SPSS Statistics for Windows. 22.0 ed. Armonk (NY): IBM Corporation; 2013.

207. StataCorp. Stata IC 15.0 ed. College Station (TX): StataCorp LP; 2017.

208. Schluter PJ, Ward C, Arnold EP, Scrase R, Jamieson HA. Urinary incontinence, but not fecal incontinence, is a risk factor for admission to aged residential care of older persons in New Zealand. Neurourol Urodyn. 2017;36(6):1588-95. DOI: 10.1002/nau.23160

209. Morris JN, Belleville-Taylor P. interRAI clinical assessment protocols (CAPs) for use with community and long-term care assessment instruments: InterRAI; 2010.

210. Statistics New Zealand. Stats NZ. [Internet]. Wellington: Statistics New Zealand; 2013. [cited 2018 Aug 30]; [about 5 screens]. Available from: http://www stats govt nz/Census/2013-census/profile-and-summary-reports/quickstats-about-national-highlights/cultural-diversity.aspx

211. Schluter PJ, Bridgford P, Cook L, Hamilton G. Improving the evidence-base for access to primary health care in Canterbury: a panel study. Aust N Z J Public Health. 2014;38(2):171-6. DOI: 10.1111/1753-6405.12155

212. Thornley C, Tobias M, Bonne M. Priorities for Māori and Pacific Health: Evidence from Epidemiology. [Internet]. Wellington: Ministry of Health; 2001. [cited 2019 Oct 29] p. 1-28. Available from: http://www.moh.govt.nz/notebook/nbbooks.nsf/0/A31842D91480064FCC256A55007A980A/$file/PrioritiesForMaoriandPacificHealth.pdf

213. Norman KJ, Hirdes JP. Evaluation of the predictive accuracy of the interRAI Falls Clinical Assessment Protocol, Scott Fall Risk Screen, and a supplementary falls risk assessment tool used in residential long-term care: a retrospective cohort study. Canadian Journal on Aging/La Revue canadienne du vieillissement. 2020:1-12. DOI: 10.1017/S0714980820000021

214. Sun G-W, Shook TL, Kay GL. Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. J Clin Epidemiol. 1996;49(8):907-16. DOI: 10.1016/0895-4356(96)00025-X

215. Boonen S, Dequeker J, Pelemans W. Risk factors for falls as a cause of hip fracture in the elderly. Acta Clin Belg. 1993;48(3):190-4. DOI: 10.1080/17843286.1993.11718306

216. LaMorte WW. The Criterion of positivity [Internet]. Boston: Boston University School of Public Health; 2016 [cited 2018 1 August 2018]; [about 4 screens]. Available from: http://sphweb.bumc.bu.edu/otlt/MPH-modules/EP/EP713_Screening/EP713_Screening4.html

217. Rothman KJ. Clinical epidemiology. In: Greenland S, Lash TL, Ovid Technologies I, Modern epidemiology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2008. p. 642-53.

218. Rothman K, Greenland S, Lash T. Modern epidemiology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2008. p. 345-381.

219. Hosmer DW, Lemeshow S, Sturdivant RX. Assessing the fit of the model. Applied logistic regression. 3rd ed. Hoboken, N.J.: Wiley; 2013. p. 153-222.

220. Rapp K, Becker C, Cameron ID, König H-H, Büchele G. Epidemiology of falls in residential aged care: analysis of more than 70,000 falls from residents of Bavarian nursing homes. J Am Med Dir Assoc. 2012;13(2):187. e1-. e6. DOI: 10.1016/j.jamda.2011.06.011

221. Wright NC, Saag KG, Curtis JR, Smith WK, Kilgore ML, Morrisey MA, *et al.* Recent trends in hip fracture rates by race/ethnicity among older US adults. J Bone Miner Res. 2012;27(11):2325-32. DOI: 10.1002/jbmr.1684

222. Barrett-Connor E, Siris ES, Wehren LE, Miller PD, Abbott TA, Berger ML, *et al.* Osteoporosis and fracture risk in women of different ethnic groups. J Bone Miner Res. 2005;20(2):185-94. DOI: 10.1359/JBMR.041007

223. Hubbard RE, Lang IA, Llewellyn DJ, Rockwood K. Frailty, body mass index, and abdominal obesity in older people. J Gerontol A Biol Sci Med Sci. 2009;65(4):377-81. DOI: 10.1093/gerona/glp186

224. Nilsson B. Spinal Osteoporosis and Femoral Neck Fracture. Clin Orthop Relat Res. 1970;68:93-5. DOI: 10.1097/00003086-197001000-00015

225. Reid IR, Plank LD, Evans MC. Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. J Clin Endocrinol Metab. 1992;75(3):779-82. DOI: 10.1210/jcem.75.3.1517366

226. Albala C, Yanez M, Devoto E, Sostin C, Zeballos L, Santos JL. Obesity as a protective factor for postmenopausal osteoporosis. 1996;20(11):1027-32.

227. Greco E, Fornari R, Rossi F, Santiemma V, Prossomariti G, Annoscia C, *et al.* Is obesity protective for osteoporosis? Evaluation of bone mineral density in individuals with high body mass index. Int J Clin Pract. 2010;64(6):817-20. DOI: 10.1111/j.1742-1241.2009.02301.x

228. Kanis JA, Johnell O, Odén A, Johansson H, De Laet C, Eisman J, *et al.* Smoking and fracture risk: a meta-analysis. Osteoporos Int. 2005;16(2):155-62. 10.1007/s00198-004-1640-3

229. Melhus H, Michaëlsson K, Holmberg L, Wolk A, Ljunghall S. Smoking, antioxidant vitamins, and the risk of hip fracture. J Bone Miner Res. 1999;14(1):129-35. DOI: 10.1359/jbmr.1999.14.1.129

230. Morris JN. InterRai long-term care facilities (LTCF) assessment form and user's manual: interRai; 2010. p. 118-23.

231. Garvan Institute of Medical Research. [Internet]. Sydney: Garvan Institute of Medical Research; 2013. Your questions answered [cited 2020 May 23]; [about 6 screens]. Available from: https://www.garvan.org.au/bone-fracture-risk/your-questions-answered

232. Sato Y, Kaji M, Tsuru T, Oizumi K. Risk factors for hip fracture among elderly patients with Parkinson's disease. J Neurol Sci. 2001;182(2):89-93. DOI: 10.1016/S0022-510X(00)00458-5

233. Johnell O, Melton III LJ, Atkinson EJ, O'Fallon WM, Kurklnd LT. Fracture risk in patients with parkinsonism: a population-based study in Olmsted County, Minnesota. Age Ageing. 1992;21(1):32-8. DOI: 10.1093/ageing/21.1.32

234. Chen Y-Y, Cheng P-Y, Wu S-L, Lai C-HJP. Parkinson's disease and risk of hip fracture: an 8-year follow-up study in Taiwan. Parkinsonism Relat Disord. 2012;18(5):506-9. DOI: 10.1016/j.parkreldis.2012.01.014

235. Lyell V, Henderson E, Devine M, Gregson C. Assessment and management of fracture risk in patients with Parkinson's disease. Age Ageing. 2015;44(1):34-41. DOI: 10.1093/ageing/afu122

236. Pouwels S, Bazelier M, De Boer A, Weber WJ, Neef C, Cooper C, *et al.* Risk of fracture in patients with Parkinson's disease. Osteoporos Int. 2013;24(8):2283-90. DOI: 10.1007/s00198-013-2300-2

237. Miller IN, Cronin-Golomb A. Gender differences in Parkinson's disease: clinical characteristics and cognition. Move Disord. 2010;25(16):2695-703. DOI: 10.1002/mds.23388

238. Sathiyakumar V, Greenberg SE, Molina CS, Thakore RV, Obremskey WT, Sethi MK. Hip fractures are risky business: an analysis of the NSQIP data. Injury. 2015;46(4):703-8. DOI: 10.1016/j.injury.2014.10.051

239. Fields AC, Dieterich JD, Buterbaugh K, Moucha CS. Short-term complications in hip fracture surgery using spinal versus general anaesthesia. Injury. 2015;46(4):719-23. DOI: 10.1016/j.injury.2015.02.002

240. Bohl DD, Sershon RA, Saltzman BM, Darrith B, Della Valle CJ. Incidence, risk factors, and clinical implications of pneumonia after surgery for geriatric hip fracture. J Arthroplast. 2018;33(5):1552-6. DOI: 10.1016/j.arth.2017.11.068

241. Spector T, Cooper C, Lewis AF. Trends in admissions for hip fracture in England and Wales, 1968-85. BMJ. 1990;300(6733):1173. DOI: 10.1136/bmj.300.6733.1173

242. Ashok P, Kharche JS, Raju R, Godbole G. Metabolic equivalent task assessment for physical activity in medical students. Natl J Physiol Pharm Pharmacol. 2017;7(3):236. DOI: 10.5455/njppp.2017.7.0825604092016

243. Schluter PJ, Audas R, Kokaua J, McNeill B, Taylor B, Milne B, *et al.* The efficacy of preschool developmental indicators as a screen for early primary school-based literacy interventions. Child Dev. 2018. DOI: 10.1111/cdev.13145

244. Canterbury District Health Board. Assessing "close in age and need" guidelines. Christchurch: Canterbury District Health Board; 2015 Oct 20. Report No: 235753.

245. Varian H. Bootstrap tutorial. Math J. 2005;9(4):768-75.

Appendix A RECORD Statement

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Title page Abstract	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the	Title page and abstract

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
				study, this should be clearly stated in the title or abstract.	
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Chapter 1		
Objectives	3	State specific objectives, including any prespecified hypotheses	1.6, 4.1, 5.1, 6.1, 7.1		
Methods					
Study Design	4	Present key elements of study design early in the paper	Chapter 1		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4.2.1, 5.2.1, 6.2.1, 7.2.1		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the	3.3, 4.3.1, 7.3.1	RECORD 6.1: The methods of study population selection (such as codes or	3.3, 4.3.1, 7.3.1

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching		algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		criteria and the number of controls per case			
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	4.2.2, 5.2.2, 6.2.2, 7.2.2	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	3.3
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	3.2		
Bias	9	Describe any efforts to address potential sources of bias	3.6		
Study size	10	Explain how the study size was arrived at	4.3.1, 7.3.1		

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	3.3		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed	4.2.3, 5.2.3, 6.2.3, 7.2.3		

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		Cross-sectional study - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses			
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	3.2
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods	3.2, 4.3.1

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
				of linkage quality evaluation should be provided.	
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	4.3.1, 7.3.1	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.*, study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	4.3.1, 7.3.1
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders	4.3.2, 5.3.1, 6.3.2, 7.3.2		

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		(b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures	5.3.2, 5.3.3, 5.3.4, 6.3.1, 6.3.3, 7.3.3, 7.3.4		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence	5.3.2, 5.3.3, 5.3.4, 6.3.1, 6.3.3, 7.3.3, 7.3.4		

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	5.3.2, 5.3.3, 5.3.4, 6.3.1, 6.3.3, 7.3.3, 7.3.4		
Discussion					
Key results	18	Summarise key results with reference to study objectives	8.1		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision.	8.3	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the	8.3

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		Discuss both direction and magnitude of any potential bias		specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8.2		
Generalisability	21	Discuss the generalisability (external validity) of the study results	8.3		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable,	N/A		

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
		for the original study on which the present article is based			
Accessibility of protocol, raw data, and programming code				RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	N/A

Appendix B Ethics Permission Letter

Health and Disability Ethics Committees

Health and Disability Ethics Committees
Ministry of Health
133 Molesworth Street
PO Box 5013
Wellington
6011

0800 4 ETHICS
hdecs@moh.govt.nz

13 June 2017

Dr Hamish Jamieson
The Princess Margaret Hospital
Cashmere Rd
Christchurch 8140

Dear Dr Jamieson

Re:	**Ethics ref:**	**14/STH/140/AM07**
	Study title:	Understanding health conditions and outcomes in older people

I am pleased to advise that this amendment has been *approved* by the Southern 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,

Ms Raewyn Idoine
Chairperson
Southern Health and Disability Ethics Committee

Encl: appendix A: documents submitted
appendix B: statement of compliance and list of members

Appendix A
Documents submitted and approved

Document	Version	Date
Protocol	1	25 May 2017
Covering letter	1	25 May 2017
Post Approval Form	AM07	29 May 2017

Appendix B
Statement of compliance and list of members

Statement of compliance

The Southern Health and Disability Ethics Committee:

- is constituted in accordance with its Terms of Reference
- operates in accordance with the *Standard Operating Procedures for Health and Disability Ethics Committees*, and with the principles of international good clinical practice (GCP)
- is approved by the Health Research Council of New Zealand's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990
- is registered (number 00008713) with the US Department of Health and Human Services' Office for Human Research Protection (OHRP).

List of members

Name	*Category*	*Appointed*	*Term Expires*
Ms Raewyn Idoine	Lay (consumer/community perspectives)	27/10/2015	27/10/2018
Dr Devonie Eglinton	Non-lay (intervention studies)	13/05/2016	13/05/2019
Dr Sarah Gunningham	Non-lay (intervention studies)	27/10/2015	27/10/2018
Assc Prof Mira Harrison-Woolrych	Non-lay (intervention studies)	27/10/2015	27/10/2018
Dr Fiona McCrimmon	Lay (the law)	27/10/2015	27/10/2018
Dr Nicola Swain	Non-lay (observational studies)	27/10/2015	27/10/2018
Dr Mathew Zacharias	Non-lay (health/disability service provision)	27/10/2015	27/10/2018

Unless members resign, vacate or are removed from their office, every member of HDEC shall continue in office until their successor comes into office (HDEC Terms of Reference)

http://www.ethics.health.govt.nz