# Measuring the economic cost of traumatic brain injury (TBI) in New Zealand

A cost-of-illness study

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# List of Abbreviations

| | |
|---|---|
| ACC | Accident Compensation Corporation |
| BIONIC | Brain Injury Outcomes New Zealand in the Community |
| CI | Confidence Interval |
| COI | Cost of Illness |
| CT | Computed Tomography |
| DALY | Disability Adjusted Life Year |
| DHB | District Health Board |
| GCS | Glasgow Coma Scale |
| GOS | Glasgow Outcome Score |
| ICD-10 | International Classification of Disease, tenth revision |
| MOH | Ministry of Health |
| NMDS | National Minimum Dataset |
| NHI | National Health Index |
| NICE | UK National Institute for Health and Clinical Excellence |
| NZ | New Zealand |
| PTA | Post Traumatic Amnesia |
| QALY | Quality Adjusted Life Year |
| SIGN | Scottish Intercollegiate Guidelines Network |
| TBI | Traumatic Brain Injury |
| WIES | Weighted Inlier Equivalent Separations |
| WHO | World Health Organization |
| YLD | Years of Life in Disability |
| YLL | Years of Life Lost |

# Attestation of Authorship

"I *Braden James Te Ao* hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Signature:  Date: 7/07/2015

# Co-Authored Works

## Publications from thesis in peer-reviewed journals

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**Te Ao B**, Brown P, Tobias M, Ameratunga S, Barker-Collo B, Theadom A, McPherson K, Starkey N, Dowell A, Jones K and Feigin V (2014). The cost of traumatic brain injury in New Zealand: evidence from a population based study. *Neurology; 83; 18:1645-1652.*

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## Public presentations from thesis

Te Ao B, Brown P, Tobias M, Taylor D, Feigin V. The cost of traumatic brain injury in New Zealand: preliminary results from a population-based incidence study. A presentation to ACC May 2013

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# Intellectual Property Rights

There are no intellectual property rights associated with this thesis.

# Ethical Approval

Ethical approval for the study was granted by the Multi Regional Health and Disability Ethics Committee of New Zealand (ref: **MEC/75/076EXP**).

# Confidential Material

No identifying material is contained in this thesis.

# Abstract

**Aim:**

To estimate:

1. The incidence, prevalence and disability adjusted life years (DALY) for traumatic brain injury (TBI) in New Zealand (NZ) in 2010 projected to 2020.
2. From a societal perspective the direct and indirect cost of traumatic brain injuries (TBIs) in New Zealand (NZ) in 2010 projected to 2020.

**Methods:**

A multi-state life table model was constructed using inputs for first-ever in a lifetime TBI incidence and severity distribution from the Brain Injury Outcomes New Zealand in the Community (BIONIC) study, TBI mortality data from the NZ Ministry of Health's Mortality Collection, and population data from Statistics New Zealand. The modelled estimate of prevalence was combined with the disability weights for TBI (by stage, and severity level) from the Global Burden of Disease 2010 study to obtain estimates of health loss (DALYs) for TBI. TBI incidence and prevalence were then projected to 2020.

An incidence-based, cost-of-illness model was developed using data from the BIONIC study. Details of TBI-related resource use during the first 12 months after injury were obtained for 725 cases using resource utilisation information from participant surveys and medical records. Total costs are presented in NZ dollars (NZ$) year 2010 value. Multivariate probabilistic uncertainty analyses were undertaken to provide information on the strength of the results.

**Findings:**

Approximately 11,300 first-ever incident traumatic brain injuries occurred in NZ in 2010, with 527,000 New Zealanders estimated to have ever experienced a TBI (prevalent cases). The estimated 20,300 DALYs attributable to TBI accounted for 27% of total injury-related health loss and 2.4% of DALYs from all causes. Of the total TBI attributable DALYs 71% resulted from fatal injuries. However, nonfatal outcomes still accounted for a substantial share of the burden (29%) with mild TBI making the greater contribution of non-fatal outcomes (56%).

Total first-year cost of all new TBI cases were estimated to be NZ$71 million with total prevalence costs of NZ$151 million. The average cost per new TBI case over a lifetime was NZ$8,824 (95% CI NZ$7,118-NZ$11,709), varying from NZ$6,908 (95% CI NZ$5,597-NZ$8,286) for mild cases to NZ$54,605 (95% CI NZ$24,359-NZ$97,371) for moderate/severe cases. Due to the unexpectedly large number of mild TBI (95% of all TBI cases) the total cost of treating these cases was nearly three times that of moderate/severe. The total lifetime cost of all TBI survivors in 2010 was NZ$218 million and is expected to increase to NZ$263.9 million in 2020.

**Conclusion:**

The burden of TBI in NZ is substantial and mild TBI contribute to major part of nonfatal outcomes. The results suggest that while the cost of treating TBI varies greatly with most severe TBI attracting maximal costs; the cost of all mild TBI cases accounts for a large proportion of the overall impact due to the increased incidence. There is an urgent need to develop effective interventions to reduce the incidence of lower cost mild injuries.

# CHAPTER ONE: Introduction

## Overview

Traumatic brain injury (TBI) is a leading cause of disability and death in New Zealand (NZ) (Feigin et al., 2013) and persons of all ages, ethnicity and incomes are affected. Brain injury has a significant impact not only on the individual (Aitken et al., 2009), but also on their immediate and extended family or whanau (Aitken et al., 2009), friends, and society (Mock, Quansah, Krishnan, Arrelo-Risa, & Rivara, 2004). This study will estimate the number of incident and prevalent cases of TBI identified within the Hamilton and Waikato region extrapolated to the NZ general population in 2010. This study will also estimate from a societal perspective the one-year and life-time direct (medical) and indirect (loss of productivity) costs of TBI in NZ in 2010 projected to 2020. Quantifying the economic impact of TBI in NZ may inform the magnitude of costs relative to other conditions, however it does not inform whether spending on healthcare for this group should increase or decrease on the basis of the likely benefit for more or less investment made. No reliable information on the economic burden of TBI exists in NZ or internationally. This study will provide essential information for health care services provided for TBI in NZ.

## Traumatic brain injury is an important public health issue

Internationally injuries are responsible for approximately five million deaths worldwide (Krug, Mercy, Dahlberg, & Zwi, 2002), over half of these due to TBI alone (Kraus, 1993). The incidence of TBI is high in developed countries. For instance, in the United Kingdom and North America 200-300 people per 100,000 are admitted to hospital with a TBI each year (Torner & Schootman, 1996). In-hospital incidence in NZ is higher, estimated at 600/100,000 (Barker-Colllo, Wilde, & Feigin, 2009). Despite the reported incidence in NZ being higher than for overseas populations, these rates are still likely to be a significant underestimate; excluding cases of mild TBI which account for approximately 70-90% of all TBIs (Von Holst & Kleiven, 2007), non-hospitalised TBIs or those TBIs that do not seek immediate medical attention (Maejima, 2001; McGarry et al., 2002; Tate, McDonald, & Lulham, 1998), and TBIs undiagnosed due to their being overshadowed by other conditions (e.g., internal injury, spinal cord injury, facial/hip fractures). Much research focus to date has been on the outcomes experienced by those having a moderate and severe TBI (Access Economics, 2009; Davis, Joshi, Tortella, & Candrilli, 2007). It is commonly accepted that these survivors experience significant disability and the highest usage of health resources. Less is known about the magnitude of mild TBI and its complications (Cassidy et al., 2004) despite a growing literature suggesting 70% to 90% of TBIs are mild (Maejima, 2001; Tate et al., 1998; Von Holst & Kleiven, 2007). A recent World Health Organization (WHO) systematic review reported the annual incidence of mild TBI is estimated to be over 600/100,000. Current evidence suggests mild TBI is of great interest and can lead to a significant and persistent difficulty (New Zealand Guidelines Group, 2006; Wrightson & Gronwall, 1998) such as post-concussion (Sotir, 2001; Yang, Tu, Hua, & Huang, 2007) and intracranial haematoma (Stein, Burnett, & Glick, 2006; Stein, Fabbri, & Servadei, 2008).

The risk of TBI is known to increase between 15 and 30 years of age, and TBI-related mortality peaks from 15 to 24 years of age (Torner & Schootman, 1996). Due to the high incidence of TBI at an early age and the long-term impact on employment, TBI-related disability has enormous personal, economic and social consequences across the lifespan (Donders & Warschausky, 2007; New Zealand Guidelines Group, 2005).

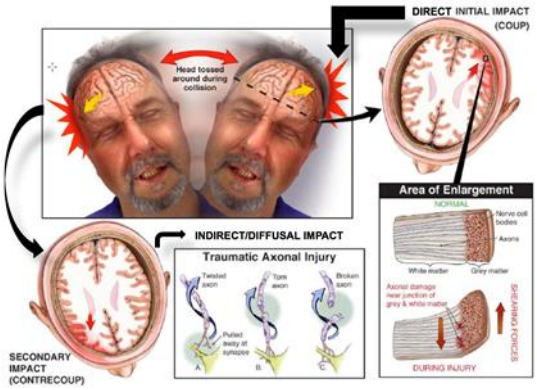
Previous studies have described differences in TBI incidence and outcomes by ethnicity or race (Hart, Whyte, Polansky, Kersey-Matusiak, & Fidler-Sheppard, 2005; Langlois, Rutland-Brown, & Thomas, 2005; Rutland-Brown, Wallace, Faul, & Langlois, 2005; Sherer et al., 2003). In particular, previous authors found greater risk of TBI and higher mortality after having a TBI among ethnic minority groups compared to European ethnicity (Frankowski & Whitman, 1985; Thurman, Dunn, Guerrero, & Sniezek, 1999; Whitman & Desai, 1984). The results from a study on functional outcomes and social integration a year after having a TBI suggests that while all experienced some impairment, minorities reported feeling isolated, less engaged in social integration, and less involved with friends and family (Rosenthal & Harrison-Felix, 1996). Another unfortunate consequence from having a TBI among minorities was low return to work and employment rates at one-year post injury. The result was also found for those who were employed prior to injury (Hodgkinson, Veerabangsa, Drane, & McCluskey, 2000; Livingston et al., 2005). Bazarian, McClung, Cheng, Flesher, and Schneider (2005) assessed ethnic disparities in emergency departments among those with mild TBI in the US. Their findings concluded that while incidence among ethnic minorities was higher than among white Americans, ethnic minorities often experienced longer waiting times to see a doctor and were less likely to be referred to other physicians upon discharge.

Significant ethnic disparity in TBI incidence has also been reported in NZ. For instance, Barker-Colllo et al. (2009) noted that in-hospital incidence for Maori and Pacific men were much higher than the non-Maori and non-Pacific population, suggesting that Maori and Pacific people share a disproportionate burden of TBI in NZ. The NZ TBI Guideline Development Group (New Zealand Guidelines Group, 2006) identified an urgent need to quantify the incidence and burden of TBI in NZ. This study will address one of the eight future research objectives identified by the Group (New Zealand Guidelines Group, 2006) by contributing to the knowledge of 'burden' by quantifying the incidence and prevalence of TBI for NZ and by estimating the direct and indirect cost of TBI.

## What is traumatic brain injury?

TBI is defined by the WHO and the NZ TBI guidelines (New Zealand Guidelines Group, 2006), as an acute brain injury resulting from mechanical energy to the head from external physical forces (Carroll & Holm, 2004). Operationally, TBI has been defined as including the presence of ≥1 of the following: (1) confusion or disorientation; (2) loss of consciousness; (3) post-traumatic amnesia; (4) other neurological abnormalities (e.g. focal signs, seizure) (Carroll & Holm, 2004). These indices of TBI are not due to drugs, alcohol or medications, caused by other injuries or treatment for other injuries (e.g. systemic injuries, facial injuries or intubation), or caused by other problems (e.g. psychological trauma or co-existing medical conditions) (Carroll & Holm, 2004).

*Figure 1: Illustration of brain impact*




TBI severity has been defined using the standard definitions outlined in Table 1 (Ponsford et al., 2004; Shores, Marosszeky, & Sandanam, 1986; Teasdale & Jennett, 1974). Mild TBI is defined as Glasgow Coma Scale (GCS) (13-15) and/or post-traumatic amnesia (PTA) (Ponsford et al., 2004) <24 hours; moderate TBI as GCS 9-12 and/or PTA one-six days; and severe TBI as GCS 8 or less and/or PTA seven or more days. If GCS and PTA severities differed, the more severe category is assigned. If no information on PTA is available, severity is based on the GCS score alone. All confirmed cases of TBI where a GCS score is not recorded are classified as mild.

*Table 1: Classification for severity of traumatic brain injury*

| **Severity of injury** | **Glasgow Coma Scale Score** | **Duration of Post Traumatic Amnesia** |
|---|---|---|
| Mild | 13-15 | <24 hours |
| Moderate | 9-12 | 1-6 days |
| Severe | <8 | 7 days or more |

## Economic burden

Previous studies have suggested that the economic burden of TBI is substantial, with known approximations in Europe for annual direct healthcare cost of €2.9 billion (Gustavsson, Svensson, & Jocobi, 2011). Similarly in the United States, the Centre for Disease Control and Prevention estimated direct and indirect costs of TBI totalling between US$56-60 billion (measured in 1995 dollar value). Given the long-term economic impact and burden of disability to family, work and society, average lifetime cost per person for TBI in the US is estimated to be US$396,000 (Faul, Wald, Rutland-Brown, Sullivent, & Sattin, 2007). The cost of TBI in Australia was estimated to be AU$8.6 billion, costs attributable to moderate and severe TBI was AU$3.7 billion and AU$4.8 billion respectively with the greatest portions borne by the individual (64.9%). Lifetime costs per case varied from AU$2.5 million for moderate and AU$4.8 million for severe TBI across Australia (Access Economics, 2009). One limitation of previous studies is that these focused on: i) more severe injuries and ii) hospital admissions only; this means that the cost of non-hospitalised cases and mild TBI has not been considered.

In NZ, the Accident Compensation Corporation (ACC) reported an annual payout over NZ$100 million (measured in 2005 dollar value) for post-acute TBI claimants (New Zealand Guidelines Group, 2005). Reported cost was inclusive of all new and on-going TBI cases. Cost figures described here may be an underestimate as it is widely accepted that many TBI cases are mild and sufferers either do not seek immediate medical attention or are misdiagnosed. As a consequence, these cases are unlikely to make an ACC claim and will not be identified by ACC statistics. Accurate total cost information for TBI is lacking both here in NZ and internationally. Previous studies have used national hospital data to identify the associated costs with TBI (Access Economics, 2009; Davis et al., 2007; Faul et al., 2007; McGarry et al., 2002). Despite current studies on the outcomes and costs of TBI, information on direct (including third-party payments) and indirect costs is limited.

### Why look at the costs associated with TBI?

There are a number of advantages linked with understanding the contribution of costs associated with TBI. Firstly, estimating the cost of TBI provides additional information in quantifying the magnitude and scope of the problem and potential savings from interventions aimed at reducing the incidence, or improving treatment for TBIs. Secondly, identifying the predictors of high costs, including differences by age, gender, ethnicity and severity of injury and/or other measures of socio-economic status, can help health care providers identify the sufferers who are most likely to be in need of extensive treatments. From an equity standpoint, evidence of differential access to services by subgroups within the population (i.e. that have greater access to services than others) provides information on the extent to which NZ is meeting the health needs of its disadvantaged populations. Here costs reflect the amount of resources used per individual, so therefore act as a "*proxy*" measure of health care utilisation. Good treatment requires people to have good access to care, so if TBI survivors do not have good access, as a consequence allows researchers to identify key leverage points indicating areas where public health could intervene. Lastly, by analysing the cost of TBI services, we then are able to evaluate potential interventions to inform policy.

Cost-of-illness estimates have value for public health decision makers interested in incorporating the economic impact of TBI along with morbidity, mortality, incidence and prevalence statistics when developing public policy. Cost-of-illness studies attempt to quantify the value of a disease to society. Cost components typically include the value of medical care resources used to treat a disease and the losses in productivity to society as a result of illness. A full economic evaluation of TBI is essential to advocate for more preventive resources, as well as for policy makers to inform changing allocation of scarce public resources (Bennett, Jacobs, & Schwartz, 1989; Spearman et al., 2001). The current study seeks to quantify the expected numbers of people likely to have TBI and to estimate direct and indirect costs at a population level. Although a full economic evaluation (i.e. cost effectiveness of TBI prevention strategies) will add great value to the debate; it is outside the current scope of the present study and will be the subject of a recommendation for further studies.

## Context and aims of the thesis

The Brain Injury Outcomes New Zealand in the Community (BIONIC) study was a population-based, (follow-up) TBI-incidence study which used known surveillance methods previously used for strokes in Auckland (Anderson, Carter, & Hackett, 2005; Bonita, Broad, & Beaglehole, 1993; Feigin, Lawes, & Bennett, 2003; Krishnamurthi et al., 2014). This thesis builds on the recent completion of the BIONIC study by exploring the economic burden of TBI in NZ. Three key areas were expanded on what has been previously reported: 1) to estimate the burden of disease attributable to TBI; and 2) assess healthcare and community resource use - data collected at one, six and twelve months post injury to estimate direct and indirect costs associated with TBI; and 3) investigate the success of known injury prevention measures to inform design and implementation for future interventions for people with TBI.

## Research aims and objectives

Using incidence data from the BIONIC study, in combination with self-reported health care use, electronic hospital records and official death records, this thesis will address the following questions:

1. What is the first-ever incidence and estimated prevalence of traumatic brain injury among all age groups in NZ in 2010?
2. What is the projected future first-ever incidence and prevalence of TBI in NZ in 2020?
3. What is the burden of disease for TBI in NZ measured in disability adjusted life years (DALYs) in 2010 projected to 2020?
4. What are the first-year and lifetime direct (medical) and indirect (productivity loss) costs of all TBI by severity in NZ in 2010?
5. What are the projected direct and indirect costs of all TBI in NZ in 2020?

It is hypothesised that the cost of mild TBI cases will account for a large proportion of the overall impact of TBI in NZ.

## Study design

Economic evaluations are increasingly used to inform health care decisions and health policy making. Economic analysis of health care services is a way to assess whether the efficiency of the health care service represents good value for money (Barton, Bryan, & Robinson, 2004; Briggs, Nixon, Dixon, & Thompson, 2005). Current research utilised prospective and population level data to develop a cost of illness model for TBI in NZ. Data for this study will primarily be sourced from the incidence data from the study titled *Traumatic brain injury in NZ: a population-based incidence and outcomes* (09/063A Feigin et al BIONIC study). Health services costs post TBI will be obtained from the costing department Waikato District Health Board and the National Minimum Dataset including all hospital admissions.

The study will confirm TBI hospitalisation using ICD-10 codes (e.g. S06.0-S06.9). The methodology involves linking electronic medical records with self-reported health care service use, using statistical risk analysis modelling and Monte Carlo simulations. Detailed information on costs, mortality and morbidity will be examined as a function of severity of TBI. Per-patient costs will be estimated for resource utilisation during 12 months after injury. Multi-level analysis will be employed to identify predictors of high cost TBIs as a function of age, gender and severity of injury.

## Study rationale

This study is unique in NZ, being one of only a few economic evaluations ever to be completed. The economic cost of TBI in NZ study will collate accurate and nationally representative estimates of the cost burden of TBI (Tilford, Aitken, Goodman, & Adelson, 2007). The proposed research is most relevant to evidence-based planning, health-service utilisation, and improving outcomes following TBI. The approach taken in the current thesis is from a health services research perspective. Which draws from areas relating to public health and health economics, by examining utilisation and cost of healthcare as well as looking at ways to improve the organisation of services or prevention strategies.

The contribution of applying health economic tools helps us to understand how people make decisions about their health and health care. Topics such as whether or not to engage in protective health behaviours, when to visit a doctor, and how health care should be financed and organised to get the best results are all within the realm of health economics. But health economics is also concerned with understanding and identifying efficiency in the delivery and organisation of health services, including whether procedures or interventions are cost effective. This is information that health funders and consumers of health care (both nationally and internationally) require, to demonstrate that public health services represent good value for money. When deciding whether to introduce new interventions, or to identify the best alternative between interventions, it is important to consider the cost and resources that will be required and the outcomes that can be expected. Applying health economic concepts to a research inquiry provides a rigorous and evidence-based platform to explore options to improve health care delivery. The options are then weighed up in terms of effectiveness, cost effectiveness and the impact on patient flow through the health system.

## Point of difference for the current study

While the current study uses data from the BIONIC study, the methodology underlying this thesis is independent of the BIONIC study. That is, this PhD reports on the economic analysis of the BIONIC study. The current PhD fellowship addresses a novel aspect of examining trends in economic burden for TBI by severity for the reference year 2010 and estimating economic burden of TBI in NZ projected to 2020. The work reported here, including the intellectual content, study design, data collection, data analysis and interpretation of results have been conducted under the direction of Professors Valery Feigin, the Principal Investigator of the BIONIC study and Paul Brown, a Health Economist with primary responsibility for overseeing and supervising the health services research aspects of the BIONIC study.

## Structure and organisation of the thesis

The structure of the thesis is as follows: The first chapter provides an overview of the significance of TBI among people of all ages and severity as a public health issue. This provides the reader with an understanding of the importance of the thesis. Chapter two is presented in two parts: the first provides a review of published literature examining key concepts of cost-of-illness studies, and the second provides a summary of previous cost-of-TBI studies. The goal is to highlight the methods used in previous studies to quantify the economic cost of TBI. Chapter three reports the estimates of TBI incidence and prevalence, controlling for mortality in NZ using multi-life table methods. In Chapter four

the direct (medical) and indirect (productivity lost) cost of TBI is outlined. Chapter five presents the results of the health disparities analyses, identifying key areas for public health to intervene. In the final chapter (six), the main findings of the research are summarised, the strengths and limitations of the current investigation are discussed and implications for future health services research are presented.

# CHAPTER TWO: Methodological issues for guiding cost-of-illness studies for traumatic brain injury: a literature review

## Introduction

New Zealand is similar to other middle and high income countries, where traumatic brain injury (TBI) is the leading cause of disability and death in young adults (Feigin et al., 2013; Mock et al., 2004). Although the cost of treating TBI is significant, few studies have summarised the cost to society of treating TBI and the burden TBI places on the health care system and families. This is partly due to the lack of accurate population level data about resource use and health impact of TBI (Theadom et al., 2012). As a result, many decisions allocating resources to injury prevention may not be underpinned by evidence that the intervention works or represents 'value-for-money' (Barton et al., 2004).

Assessing the economic burden (economic and health outcomes) of TBI on society provides information on the scope of the problem and potential cost savings from interventions aimed at reducing the incidence or severity, or improving treatment for TBIs (Kreutzer, 2001; Vitaz, McIlvoy, Raque, Spain, & Shields, 2001). A review of cost-of-illness literature of TBI is one of many important factors that is needed to aid best informed decision making. Cost of illness studies provides essential information required to enable an evaluate the effectiveness of interventions, to advocate for more preventative resources, as well as for policy makers to inform changing allocation of scarce public resources. If the economic impact of TBI can be quantified and compared relative to other diseases, it can provide another evidence-based argument for allocating resources (Kolakowsky-Hayner, Miner, & Kreutzer, 2001; Thurman et al., 1999).

This chapter aims to review relevant published literature to analyse the methods used. First a general description of the cost-of-Illness (COI) methods used from different studies is provided to inform appropriate COI methodology. Secondly, the direct and indirect cost estimates reported from previous COI studies for TBI are presented as a baseline comparison for the present study.

## Methods

### Cost-of-illness study

The main aim of COI studies is to provide a snapshot of the costs associated with treating a disease condition (in this case brain injuries) (Hodgson & Meiners, 1982). One important methodological aspect is to collect accurate disease identification, resource consumption, as well as detailed information on TBI survivorship and the pathways of care post TBI. These aspects are needed in order to understand equity and efficiency issues for TBI sufferers. Tracking the cost-of-care post TBI requires both an accurate identification of TBI and ideally longitudinal data on health service utilisation post TBI. COI studies provide estimates that describe resource consumption characterised by the disease condition being assessed. The economic impact of TBI refers to the value (measured in dollars) of medical care resources used to treat the condition, indirect costs are also included, such as losses in productivity to society as a result of illness (Koopmanschap & Rutten, 1993; Rice, 2000). Cost categories include: hospital treatment, outpatient and other medical expenses, long-term cost of care (i.e. caregiver and support services) and

loss of wages and income as a result of having a TBI. The goal is to identify the "***additional***" (including lifetime costs) or "***marginal***" costs associated with the condition (i.e. not total costs, only costs due to TBI) (Rice, 1967). Cost of illness data is an essential tool that will aid decision makers on (1) advocating for more specialised resources or health prevention programmes; and (2) their use as an evidence-based, priority-setting measure when determining budget or resource allocation within societies managing economic constraints.

### Defining the disease condition and population

This is widely dependant on how a disease condition is defined; conditions could be defined by clinical guideline criteria or be diagnosis-based using the international classification of disease manual. For the purpose of the current thesis, TBI will be defined using the WHO definition (Holder, Krug, Lund, Gururaj, & Kobusingye, 2001) (see chapter one).

### Epidemiological approach

There are two main epidemiological approaches used in most COI studies. The first approach is to estimate the total cost of a disease in a given year (prevalence approach). The second approach commonly used is to estimate the lifetime costs of cases first diagnosed in a given year (incidence approach). The prevalence-based approach seeks to sum together all costs (direct and indirect) for all who suffered a given disease condition (including first-ever and recurrent events) measured at one point in time, regardless of when the disease first occurred. It provides a cross-sectional view of the costs associated with a given condition. A prevalence-based approach COI study would be useful for answering research questions like "how much do we spend each year to treat individuals with TBI in Auckland, New Zealand?" On the other hand an incidence-based costing approach measures the number of new cases of TBI and the costs associated with treatment, as well as other financial and non-financial costs (such as, productivity losses, loss of quality of life) over the person's lifetime, due to TBI. An incidence-approach method for estimating the cost of illness for TBI will be best suited to link into further cost-effectiveness analyses (CEA) of current TBI interventions, due to the availability of data.

### Perspective of the analysis and costs assessed

The perspective of the study is the viewpoint used to examine the costs associated with a disease condition. For instance, if the study reports the results from the perspective of the health system or funder (Gold, Siegel, Russell, & Weinstein, 1996), then it would include the direct health care costs associated with the condition (e.g. hospitalisations, doctor visits, medications, and auxiliary treatments). A societal perspective (Byford & Raftery, 1998) includes the direct costs, but also includes indirect costs such as lost wages, out-of-pocket expenses, and other caregiver costs. Thus the societal perspective includes a wider range of costs (both direct medical and indirect costs such as productivity loss) and outcomes (in some cases measured as either life expectancy, clinical outcome or some sort of health preference measure (quality adjusted life years or disability adjusted life years).

### Estimating resource use consumption

Methods estimating resource use consumption often vary depending on the design of the study and the availability of data. For instance, a prospective cohort study is a longitudinal study following a population of interest forward in time, with the goal of assessing exposure in the present tense. With

appropriate ethical approvals, individual information can be linked (using a health tracker) and matched between datasets. While a retrospective cohort study is of similar nature, it often follows a cohort using historical data (i.e. back in time). One clear difference involves a limitation of the data. Because individual consent is often required to link data from different healthcare providers, reported health service usage is often limited to a single organisation (i.e. hospital admissions). In order to accurately analyse individual level health service information, prospective cohort databases are able to be linked and matched to national (i.e. Ministry of Health) or regional databases (i.e. District Health Boards) for each individual by personal identification number. Another source often used in previous literature is case report forms or patient and caregiver surveys. Collected information via prospective questionnaires includes the type of service used, frequency of use, duration of time and who paid for the service. However, survey responses are often susceptible to recall and memory bias (Thorn et al., 2013).

### Valuation of unit costs

Generally there are two universal approaches to examine costs. First is a top-down approach which uses aggregate estimates for specific diseases (Drummond, Sculpher, Torrance, OBrien, & Stoddart, 2005). With a top-down approach costs are typically calculated by health expenditure by the proportion of health services use as observed by a given disease condition. For instance, this approach involves estimating per-person costs by averaging total expenditure divided by the number of people with a specific disease. The second is to use a bottom-up approach and unlike the previous approach it estimates costs based on individual units consumed by the individual (Drummond et al., 2005). An example of a bottom-up cost approach involves recording resource use for each individual and calculating costs per resources used; this does not include a valuation of resources unused. The aim of valuing unit costs is to ascertain the value (measured in dollars) which reflects the true opportunity cost of those resources being consumed. There is some uncertainty for unit costs due to varying unit costs between hospitals or health care providers since cost estimates are determined by the manufacturer. Methods for dealing with uncertainty will be further described (see sensitivity analysis).

Direct costs include both costs to the health system (service usage), and out-of-pocket expenses. The source of cost information will vary from study to study; but in most cases, these costs are sourced from health care providers (medical records) or health insurance organisations. One way to estimate costs is using a resource-based costing approach. This approach multiplies health services usage by a market price for those services. Unit prices for resources utilised by an intervention (i.e. TBI rehabilitation) should be sourced from the most accurate and up-to-date sources for each provision of service. The costs of health services are measured in real prices for the reference year.

Indirect costs are often assessed using three methodological approaches: human-capital approach (Koopmanschap & Martin Van Ineveld, 1992; Koopmanschap & Rutten, 1993), friction approach (Koopmanschap & Rutten, 1996), or the willingness-to-pay approach (Gafni, 1991). Estimating productivity loss will include loss of employment due to lower re-employment after the disease condition and/or premature death. The human-capital approach (HCA) can be justified here as it provides a measure of the cost of a disease. HCA reflects earning and productivity. Cost of productivity will be approximated using estimates of annual living wages sourced from governmental departments

combined with a probability of loss of earnings. HCA takes an individual's perspective where loss of productivity is calculated by summing any hours not worked (up to retirement age) as hours lost. The frictional approach, on the other hand, assumes a short absence from employment (i.e., sick leave, entitled leave with or without pay). Friction cost method takes the employer perspective and only considers hours not worked until the individual is replaced with another employee. There is on-going debate around which methods to use for valuing indirect costs. For instance some authors favour friction cost method as an alternative to human capital approach, as it takes "worker replacement" into account (Birnbaum, 2005; Koopmanschap & Martin Van Ineveld, 1992). While other authors argue that friction cost approach based on implausible assumptions and not supported by neoclassical economic theory (Johannesson & Karlsson, 1997). The willingness-to-pay approach is often used to determine the value of people's (consumers) willingness and ability to pay (for health services or treatment) in order to avoid health risks (Gafni, 1991). Such techniques involves assessing personal preferences and understanding their protective health behaviours about reducing risk of having a TBI or avoiding early mortality. A critique of this costing method is that it may tend to overstate estimates (Johannesson, 1996).

Historic costs obtained from literature, will be inflated using the consumer price index (CPI) of the source country. This enables all costs to be standardised to a common year. When cost source year is not presented, the year prior to the publication will be used to adjust cost. International cost estimates will be exchanged to NZ value in 2010 dollars using purchasing power parities (see OECD website http://www.oecd.org/std/prices-ppp/).

### Discounting costs

To ensure the cost results occurring beyond one year reflect the present value of costs and or benefits accruing over the time horizon of the analysis, future costs should be discounted to account for the time preference. In practice the discount rate reflects the long-term bond rate set by the economy. While there are a number of discount rates quoted in previous studies, authors should justify their rates. For example, a common discount rate of 3% is recommended by a consensus panel of health economists in the USA for cost-effectiveness analysis (Phillips & Chen, 2002).

### Sensitivity analysis

Sensitivity analyses are recommended to address uncertainties in the present data and/or methodology. To account for uncertainty, sensitivity analysis will explore the robustness of the results by varying key variables. The different forms of sensitivity analysis often include one-way or multi-sensitivity and probabilistic (Barton et al., 2004; Briggs, Sculpher, & Claxton, 2006). As stated by Briggs and Gray (1999) one-way sensitivity analysis examines the impact of each variable in the study. Single variables are tested by varying across plausible ranges of values, for example a high cost unit for neuroimaging vs low cost unit. Likewise a multi-sensitivity analysis involves varying a number of variables simultaneously and is usually used to generate best- and worst-case scenarios of the study being evaluated (Briggs & Gray, 1999). Similarly probabilistic sensitivity analysis examines a series of variables simultaneously but is based on a large number of Monte Carlo simulations according to a statistical distribution for

parameters. For example, gamma distribution is the predefined distribution for cost variables as it re-samples plausible values from 1 to infinity (Briggs, 2004).

### Presentation of results

Like many other studies, the results should be consistent with documented data collection and methods reported in the study. For COI studies, it is important that cost data be disaggregated by subgroup and health care category (see Table 4 and *appendix two* for a quality checklist of reviewed articles). In addition COI should also test for uncertainty of cost and or health benefits.

## Literature review

### Data sources and search terms

A review of previous literature was intended to assess available information on economic analysis for TBI. Synonyms relating to TBIs (e.g. head injury, head trauma, brain injury, traumatic brain injury, brain trauma and brain concussion) were combined with selected search terms from the Scottish Intercollegiate Guideline Network (SIGN) search filter for economic evaluations aimed at restricting results to economic and cost-related studies (see *appendix one* for the search strategy). Computerised searches used a general health search engine of the EBSCO Health database; this collection of databases included: Biomedical Reference Collection: Basic, CINAHL Plus with Full Text (1937-present), Health Business Elite (1922-present), Health Source-Consumer Edition, Health Source: Nursing/Academic Edition, MEDLINE, Psychology and Behavioural Sciences Collection, SPORTDiscuss with Full Text and Dentistry and Oral Science Source. Further keyword searches were conducted using the centre for review and dissemination NHS Economic Evaluation Database (NHS EED).

All resources were searched for recent studies published between 2000 to May 2014 and restricted to English language articles. Reference sections of publications found were scanned to find further relevant literature. Hand-searching was also conducted of the table of contents of the following journals: Injury; Injury Prevention, Journal of Neurotrauma, Journal of Trauma, Journal of Trauma, Injury, Infection and Critical Care, and Brain Injury. In addition in an attempt to obtain unpublished reports or documents, database searches were conducted. Each report was independently reviewed by screening titles and abstracts using a pre-defined inclusion and exclusion criteria (see *appendix three and four*). A full text review was then conducted and a decision made regarding study eligibility. A thorough analysis of each article was performed to extract data from included studies. Primary studies that reported acute and post-acute costs relating to TBI were included.

All COI studies that performed an analysis of cost and outcome were incorporated. These included whether the study provided the measure of effect as either quality adjusted life years (QALYs) or life expectancy as the effect measures or no outcomes. Studies that reported acute, rehabilitation, community support and on-going costs associated with head injuries/brain injuries (TBI) were also included. Other economic evaluation studies, for example those that performed a comparative analysis of both costs and effects of at least two competing strategies, were excluded. Where possible, all studies which included adults and/or children of any age diagnosed with TBI with mild (i.e. GCS 13-15), moderate (i.e. GCS 9-12) and severe (i.e. GCS 8) injuries were included.

### Data collection and analysis

The methodological assessment of the selected studies was assessed using the quality checklist for health economic studies adopted from Drummond (Drummond et al., 2005) and used in previous cost-of-illness reviews (Costa et al., 2012; Molinier et al., 2008). The criteria derived from Drummond used to assess the quality of included studies were: definition of illness, epidemiological sources, unit costs, sources of cost, costing, adjustments for timing of cost, allowance for uncertainty and presentation of results (see *appendix two*). All articles meeting the inclusion criteria were reviewed and summary information was extracted. The review and extraction of summary information was independently completed. From each study the following variables were extracted: author(s), country setting of the study, type of health care system, year of costs, type of currency, perspective of the analysis, study design, sample size, follow up and baseline results.

All reported costs from the literature were reported in US dollar currency and adjusted to NZ dollars using the purchasing power parity (PPP). This enables all costs to be standardised to a common currency. When cost source year was not presented, the year prior to the publication was used to adjust cost to US value in 2010 dollars. Meta-analysis was not carried out due to the heterogeneity of the eligible studies.

## Results

### Overview of eligible studies identified

Twelve articles met the criteria and were identified using the search strategy (see figure 2). Of these, ten studies were conducted in the United States (Ettaro, Berger, & Songer, 2004; Farhad et al., 2013; Faul et al., 2007; Leibson et al., 2012; McGarry et al., 2002; Rockhill, Fann, Fan, Hollingworth, & Katon, 2010; Rockhill et al., 2012; Schootman, Buchman, & Lewsi, 2003; Stroupe et al., 2013; Vangel, Rapport, Hanks, & Black, 2005); one was carried out in Canada (Chen et al., 2012) and one study in China (Yang et al., 2007). All studies varied in sample size ranging from 63 (Vangel et al., 2005) to 254,500 participants (Schootman et al., 2003). Methodological assessments of selected studies are shown in Table 2; five studies scored "yes" in points assessed (Chen et al., 2012; Faul et al., 2007; Leibson et al., 2012; Rockhill et al., 2012; Schootman et al., 2003).

### Defining the disease condition

TBI was defined using clinical diagnosis codes in eleven studies (Chen et al., 2012; Ettaro et al., 2004; Farhad et al., 2013; Leibson et al., 2012; McGarry et al., 2002; Rockhill et al., 2012; Vangel et al., 2005; Yuan et al., 2012). Of these, three studies gave a detailed definition using the Centres for Disease Control and Prevention case definition (Faul et al., 2007; Rockhill et al., 2010; Schootman et al., 2003). However one study did not define TBI at all (Stroupe et al., 2013).

*Figure 2: Literature search and selection process*

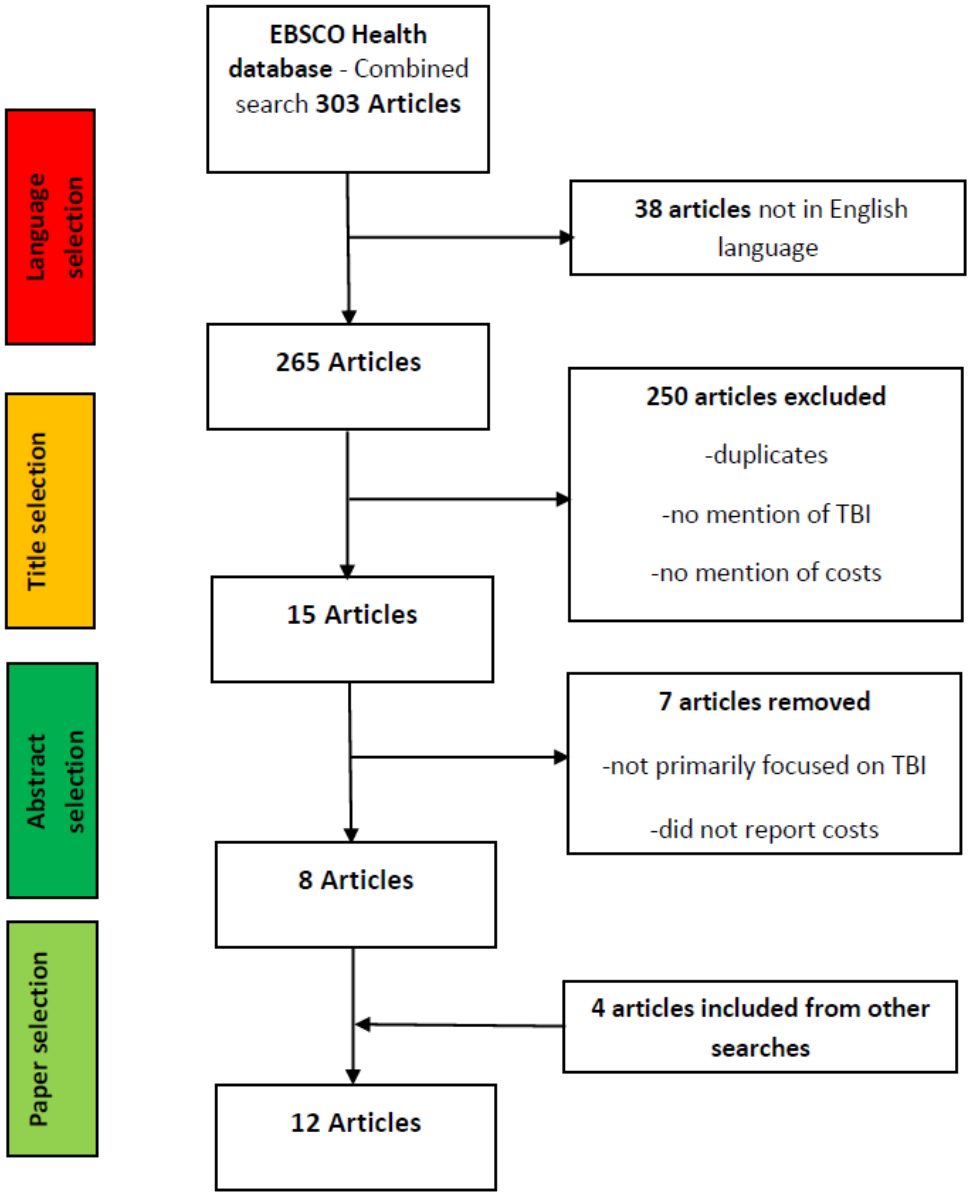


*Table 2: Overview of methodological aspect of study*

| | ALL STUDIES | | | McGarry et al. 2002 | | | Schootman et al. 2003 | | | Ettaro et al. 2004 | | | Vangel et al. 2005 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No |
| Was a clear definition of the illness given? | 9 | 3 | 0 | Yes | | | Yes | | | Yes | | | | Partially | |
| Were epidemiological sources carefully described? | 8 | 4 | 0 | Yes | | | Yes | | | | Partially | | | Partially | |
| Were costs sufficiently disaggregated? | 9 | 2 | 1 | | Partially | | Yes | | | | Partially | | Yes | | |
| Were activity data appropriately assessed? | 11 | 1 | 0 | Yes | | | Yes | | | Yes | | | Yes | | |
| Were the sources of all cost values analytically described? | 10 | 2 | 0 | Yes | | | Yes | | | Yes | | | Yes | | |
| Were unit costs appropriately valued? | 2 | 7 | 3 | | | No | Yes | | | | Partially | | | Partially | |
| Were the methods adopted carefully explained? | 10 | 0 | 0 | Yes | | | Yes | | | Yes | | | Yes | | |
| Were costs discounted? | 1 | 1 | 10 | | | No | | | No | | | No | | | No |
| Were the major assumptions tested in a sensitivity analysis? | 3 | 1 | 8 | | | No | | | No | | | No | Yes | | |
| Was the presentation of study results consistent with the methodology of study? | 11 | 1 | 0 | | Partially | | Yes | | | Yes | | | Yes | | |
| Total score by study | 74 | 22 | 22 | 5 | 2 | 3 | 8 | 0 | 2 | 5 | 3 | 2 | 6 | 3 | 1 |

| | Faul et al. 2007 | | | Rockhill et al. 2010 | | | Chen et al. 2012 | | | Leibson et al. 2012 | | | Yuan et al. 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No |
| Was a clear definition of the illness given? | Yes | | | Yes | | | Yes | | | Yes | | | | Partially | |
| Were epidemiological sources carefully described? | Yes | | | | Partially | | Yes | | | Yes | | | | Partially | |
| Were costs sufficiently disaggregated? | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Were activity data appropriately assessed? | Yes | | | Yes | | | Yes | | | Yes | | | | Partially | |
| Were the sources of all cost values analytically described? | Yes | | | Yes | | | Yes | | | Yes | | | | Partially | |
| Were unit costs appropriately valued? | | Partially | | | Partially | | Yes | | | | Partially | | | | No |
| Were the methods adopted carefully explained? | Yes | | | Yes | | | Yes | | | Yes | | | | Partially | |
| Were costs discounted? | | | No | | Partially | | | | No | | | No | | | No |
| Were the major assumptions tested in a sensitivity analysis? | Yes | | | | | No | Yes | | | | | No | | | No |
| Was the presentation of study results consistent with the methodology of study? | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Total score by study | 8 | 1 | 1 | 6 | 3 | 1 | 9 | 0 | 1 | 7 | 1 | 2 | 2 | 5 | 3 |

| | Rockhill et al. 2012 | | | Farhad et al. 2013 | | | Stroupe et al. 2013 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Yes | Partially | No | Yes | Partially | No | Yes | Partially | No |
| Was a clear definition of the illness given? | Yes | | | Yes | | | | Partially | |
| Were epidemiological sources carefully described? | Yes | | | Yes | | | Yes | | |
| Were costs sufficiently disaggregated? | Yes | | | | | No | Yes | | |
| Were activity data appropriately assessed? | Yes | | | Yes | | | Yes | | |
| Were the sources of all cost values analytically described? | Yes | | | | Partially | | Yes | | |
| Were unit costs appropriately valued? | | Partially | | | | No | | Partially | |
| Were the methods adopted carefully explained? | Yes | | | | Partially | | Yes | | |
| Were costs discounted? | Yes | | | | | No | | | No |
| Were the major assumptions tested in a sensitivity analysis? | | Partially | | | | No | | | No |
| Was the presentation of study results consistent with the methodology of study? | Yes | | | Yes | | | Yes | | |
| Total score by study | 8 | 2 | 0 | 4 | 2 | 4 | 6 | 2 | 2 |

### Perspective of the analysis and costs assessed

Characteristics of the COI studies in TBI are presented in table 3. Eleven studies were conducted from a health system/health funder perspective (Chen et al., 2012; Ettaro et al., 2004; Farhad et al., 2013; Leibson et al., 2012; McGarry et al., 2002; Rockhill et al., 2010; Rockhill et al., 2012; Schootman et al., 2003; Stroupe et al., 2013; Vangel et al., 2005; Yuan et al., 2012). Most of these were carried out in the US. Acute hospitalisation costs was mostly considered among the included studies; direct costs also included rehabilitation, outpatient, medication, physician or specialist, home care or out of pocket. Many of these studies examined costs over a short timeframe; four studies had follow up post 12-months (Chen et al., 2012; Faul et al., 2007; Rockhill et al., 2010; Rockhill et al., 2012). Only one study conducted their analysis from a societal viewpoint (Faul et al., 2007) thus quantifying both direct medical and indirect costs. Interestingly, no studies quantified informal care costs associated with TBI survivors.

### Estimating resource consumption

All studies calculated prevalence-based health care costs. No study conducted an incidence-based analysis. Prevalence results were estimated primarily from hospital databases or medical billing records; while three studies combined national data with patient surveys at follow up (Rockhill et al., 2010; Rockhill et al., 2012). Eight studies utilised a retrospective cohort study design (Chen et al., 2012; Ettaro et al., 2004; Farhad et al., 2013; Leibson et al., 2012; McGarry et al., 2002; Schootman et al., 2003; Stroupe et al., 2013; Vangel et al., 2005). Three studies used a prospective cohort design (Rockhill et al., 2010; Rockhill et al., 2012; Yuan et al., 2012) and one study conducted a decision analysis (Faul et al., 2007). Of the included studies most undertook a bottom-up approach to gather activity data and to measure resource use consumption. One study however used a top-down approach and used aggregated cost figures and assumptions sourced from literature by severity of disability (Faul et al., 2007).

### Valuation of unit costs

Total annual costs of TBI are shown in table 4. Direct costs were estimated from published literature (Faul et al., 2007) and hospital billing charges (Chen et al., 2012; Leibson et al., 2012; Rockhill et al., 2010; Rockhill et al., 2012). Only one study gave micro-level cost units per health resource consumption. The majority of direct costs occurred during the acute hospitalisation phase; estimates ranged from US$1,054 (Rockhill et al., 2010) to US$62,804 (Vangel et al., 2005) (see table 4). Over half of the studies reviewed estimated annual costs per person. For instance, Rockhill et al. (2012) estimated the one year cost of TBI in the US to be over US$7,377 per person, while Leibson et al. (2012) estimated the cost to be US$27,187 per patient (US$2007). Similarly in Canada, Chen et al. (2012) reported annual cost per person at CAN$32,132 (CAN$2007) while a study in China estimated acute costs to be US$1,715. One study estimated indirect costs using the human-capital approach methodology. Faul et al. (2007) reported that the associated indirect cost of TBI in the US was estimated to be US$330,827 (US$2002).

### Discounting costs

Only two studies reported a discount rate of 3% for occurring costs beyond one year post TBI (Rockhill et al., 2010; Rockhill et al., 2012). One study in the US conducted their research using decision modelling

techniques and projected costs over the lifetime of the cohort; but the authors did not account for present net value of costs occurring in the future (Faul et al., 2007).

### Sensitivity analysis

Although three studies declared their main assumption and limitation of their data (Chen et al., 2012; Faul et al., 2007; Vangel et al., 2005); surprisingly none of these studies conducted a sensitivity analysis (i.e. using either one way, multi or probabilistic) to test the robustness of the estimates.

### Presentation of results

Six studies presented aggregated hospitalisation cost (Ettaro et al., 2004; Farhad et al., 2013; Leibson et al., 2012; McGarry et al., 2002; Schootman et al., 2003; Yuan et al., 2012). From their results it was hard to differentiate the rehabilitation proportion of costs. Other studies (six) presented disaggregated direct and indirect costs (Chen et al., 2012; Faul et al., 2007; Rockhill et al., 2010; Rockhill et al., 2012; Stroupe et al., 2013; Vangel et al., 2005); with four articles describing their dissemination (Chen et al., 2012; Rockhill et al., 2010; Rockhill et al., 2012; Vangel et al., 2005). All studies reported per-patient cost estimates.

*Table 3: Cost-of-illness study characteristics in TBI*

| Study | Country | Type of healthcare system | Year of valuation* | Currency | Perspective | Design of cost analysis | Sample size | Follow-up (months) | Total annual cost per patient (NZ$2010)** |
|---|---|---|---|---|---|---|---|---|---|
| McGarry et al. 2002 | USA | Private | 1999 | USD | Health funder | Retrospective, multicentre | 8,717 | NS | $35,649 |
| Schootman et al. 2003 | USA | Private | 1996 | USD | Health funder | Retrospective, multicentre | 254,500 | NS | $43,957 |
| Ettaro et al. 2004 | USA | Private | 1999 | USD | Health Funder | Retrospective | 377 | NS | $36,068 |
| Vangel et al. 2005 | USA | Private | 2004 | USD | Health funder | Retrospective | 63 | 19 | $1,323,098 |
| Faul et al. 2007 | USA | Private | 2002 | USD | societal | Decision model | 23,265 | 12 | $715,798 |
| Rockhill et al. 2010 | USA | Private | 2008 | USD | Health funder | Prospective, multicentre | 489 | 12 | $5,534 |
| Chen et al. 2012 | Canada | Public social | 2007 | CAD | Healthcare system | Retrospective | 11,970 | 12 | $54,627 |
| Leibson et al. 2012 | USA | Private | 2007 | USD | Health funder | Retrospective | 93 | 12 | $42,596 |
| Yuan et al. 2012 | China | Public social insurance | 2004 | USD | Health funder | Prospective, multicentre | 13,007 | NS | $2,951 |
| Rockhill et al. 2012 | USA | Private | 2009 | USD | Healthcare system | Prospective, multicentre | 2,808 | 12 | $11,170 |
| Farhad et al. 2013 | USA | Private | 2007 | USD | Health funder | Retrospective | 49,680 | NS | $33,623 |
| Stroupe et al. 2013 | USA | Private | 2008 | USD | Health funder | Retrospective | 31,627 | NS | $14,507 |

* Currency was inflated to 2010 dollar value, before **currency exchange USD to NZD using PPP

*Table 4: Total annual costs disaggregated*

| Study | Total annual cost per patient | Acute hospitalisation | Rehabilitation | Outpatient | Medication | Physician or Specialist | Home help | Out of pocket | Informal care costs | Indirect costs |
|---|---|---|---|---|---|---|---|---|---|---|
| McGarry et al. 2002 | NA | $18,279 | NS | NA | NA | NA | NA | NA | NA | NA |
| Schootman et al. 2003 | NA | $21,241 | NA | NA | NA | NA | NA | NA | NA | NA |
| Ettaro et al. 2004 | NA | $18,494 | NA | NA | NA | NA | NA | NA | NA | NA |
| Vangel et al. 2005 | $795,635 | $62,804 | NS | $193,475 | $54,950 | $21,434 | $140,047 | NS | NA | NA |
| Faul et al. 2007 | $396,331 | $60,887 | $4,618 | NS | NS | NS | NS | NS | NS | $330,827 |
| Rockhill et al. 2010 | $3,666 | $1,054 | NS | $102 | $267 | $1,900 | $2,943 | $314 | NA | NA |
| Chen et al. 2012 | $32,132 | $19,083 | $5,363 | $3,535 | NS | $3,242 | $722 | NS | NA | NA |
| Leibson et al. 2012 | $27,187 | NS | NS | NS | NS | NS | NS | NS | NA | NA |
| Yuan et al. 2012 | NA | $1,715 | NA | NA | NA | NA | NA | NA | NA | NA |
| Rockhill et al. 2012 | $7,377 | $2,941 | NS | $168 | $925 | $2,632 | $4,704 | $712 | NA | NA |
| Farhad et al. 2013 | NA | $21,460 | NS | NS | NS | NS | NA | NA | NA | NA |
| Stroupe et al. 2013 | $9,610 | $1,353 | NS | $7,746 | $511 | NS | $242 | NS | NA | NA |

NS not specified; NA not applicable; costs measured in US$ 2010

## Discussion

The purpose of this chapter was to review current literature on the cost of TBI, including the methods used to analyse the costs. The review of literature identified twelve COI studies on TBI, according to the methodological assessment tool *(*see Table 2*)* with five studies scoring "Yes" on the majority of the points assessed (Chen et al., 2012; Faul et al., 2007; Leibson et al., 2012; Rockhill et al., 2012; Schootman et al., 2003). This review found that COI studies on TBI were scarce and few were conducted of high quality health economic methodology. The review confirms that TBI is associated with significant direct medical costs and the indirect cost component accounts for the largest proportion (Faul et al., 2007).

The main finding from the review indicated that the annual per-person cost associated with TBI ranged between NZ$2,951 to NZ$1,323,098 (see *table 3*). These results indicate that although the cost of TBI is substantial there was also considerable variability (in methods used and sample size). However, it is difficult to make a clear definitive statement about these costs as each study adopted different methodological approaches and were taken over different time periods. Many previous studies were conducted over short timeframes (i.e. less than 12 months of observation) and only assessed acute hospitalisation costs. Very few studies assessed health care utilisation and cost up to 12 months post injury (Chen et al., 2012; Leibson et al., 2012; Rockhill et al., 2010; Rockhill et al., 2012). One important aspect that is lacking in previous studies is data on the resource utilisation for TBI over the past 12 months. Lifetime direct and indirect economic impact with TBI is hugely unknown; this is partly due to the lack of accurate longitudinal data.

Secondly, the type of health care system of each country may possibly explain the influence of higher treatment costs. For instance, ten of the studies were conducted in a country that is predominately a market-driven economy. The US as opposed to Canada and China has a private health system, where the environment is shaped by competitive "fee for service" type arrangements. By contrast, in a public health system treatment costs are contained and often regulated by government, which in turn may drive costs down (less market competition). Moreover countries differ significantly in health care costs, and this is reflected in the costs of TBIs.

Thirdly, previous COI reviews (Costa et al., 2012; Molinier et al., 2008) stated that comparing international cost estimates is problematic due to differences in the dollar value of each currency. The reported costs were inflated to the US dollar 2010 value using consumer price indices and then converted to NZ dollar 2010 value using purchasing power parity which attempts to make dollar values equivalent.

Fourthly, it was noted that among the majority of the studies reviewed, included TBI who were admitted into hospital and identified using medical diagnosis codes. One study did not state how TBI was defined at all (Stroupe et al., 2013). This is problematic as TBIs are often missed and overshadowed by other injuries (Ribbers, 2007; Stephenson, Henley, Harrison, & Langley, 2004; Stephenson, Langley, & Cryer, 2005) This review also found that previous literature often excluded those with TBI who were not hospitalised or did not seek immediate attention (Feigin et al., 2013) for their injury. The reason for the exclusion is unclear, but may be due to the limitation of sources of available information (e.g. admission

registries and hospital admission data) for identifying cases. It is clear that any further population-based TBI incidence studies must reflect appropriate methodology for instance utilising hot-pursuit methods (Theadom et al., 2012). Identifying additional cases of TBI through cross checks of general practitioner databases and hospital admissions are more like to find cases who did not seek immediate medical attention but saw a medical professional later due to the consequences associated with TBI (Cassidy et al., 2004; Feigin et al., 2013). The omission of the mild TBI cases and those who do not seek immediate medical attention may lead to a overestimation of the cost per person.

In conclusion, internationally the cost of treating TBI varies greatly. This review has demonstrated the high cost TBI sufferers can incur and there are differences between treatments received. The economic burden for TBI is high, but substantial cost savings and improvements in outcomes may be achieved by targeting high cost individuals. Given that New Zealand has a unique healthcare system and social insurance scheme for those who have sustained TBI. It is important for New Zealand health planners and policy makers to understand what the cost of TBI is to New Zealand society

# CHAPTER THREE: Estimating the incidence, prevalence and disability-adjusted life years for TBI in New Zealand 2010: A burden of injury study

The main findings of the results reported in this chapter have been published. The details of the publication are:

1. **Te Ao B**, Tobias M, Ameratunga S, McPherson K, Theadom A, Dowell A, Starkey N Jones K, Barker-Collo S, Brown P, Feigin V, on behalf of the BIONIC Study Group. (2015). Burden of traumatic brain injury in New Zealand: incidence, prevalence and disability-adjusted life years. Neuroepidemiology 44:255-261 (see *appendix five*)

## Introduction

Traumatic brain injury (TBI) is a major cause of disability and death in New Zealand (NZ) (Feigin et al., 2013). In addition to these long term impacts on personal and whanau/family wellbeing, TBI has major economic consequences for society (Te Ao et al., 2014). Robust information on the population-based epidemiology and health impact of TBI should guide health policy, including the allocation of resources to prevention, treatment and rehabilitation (Arciniegas, 2011; Tobias, Cheung, Carter, Anderson, & Feigin, 2007). However, previous attempts to measure the impact of TBI suffer from major methodological limitations. For instance, many studies have focused solely on injuries admitted to hospital (Corrigan, Selassie, & Orman, 2010). Case ascertainment often relies on clinical diagnosis codes (McGarry et al., 2002; Ribbers, 2007) yet TBI is often overshadowed by other injuries (e.g. internal injury, spinal cord injury, facial/hip fractures) (McGregor & Pentland, 1997). Estimates based on routinely collected data may fail to identify a substantial proportion of TBI, especially mild cases. Approximately, 70-95% of injuries are classified as mild severity (Cassidy et al., 2004; Feigin et al., 2013) managed in the community by primary care providers and are not hospitalised (Leibson et al., 2012; Tate et al., 1998).

The recently completed Brain Injury Outcomes New Zealand in the Community (BIONIC) study was the first to assess the incidence of TBI across all age groups and in rural and urban populations in New Zealand (NZ) (Feigin et al., 2013). The authors found that when community cases were included, the incidence of TBI especially mild TBI, was far greater in NZ than previously estimated (Feigin et al., 2013). This chapter presents an assessment of the epidemiology of TBI in NZ to provide important information for assessing demands on our health system.

The current study combines regional brain injury incidence rates from the BIONIC study with current mortality statistics and NZ population data to construct a multi state life tables model to estimate national incidence, prevalence and disability adjusted life years (DALY) for TBI in NZ in 2010. The DALY is an integrated measure of health loss that combines both fatal and non-fatal outcomes into a single metric (Murray, Vos, & Lozano, 2012). The constructed model outputs estimates of TBI incidence and prevalence for the study community (Hamilton Waikato), which was extrapolated to the NZ national population.

## Public health surveillance

According to the Centre of Disease Control and Prevention, public health surveillance is defined as the on-going, systematic collection, analysis, interpretation and dissemination of data regarding a health-related event for use in public health action to reduce morbidity and mortality and to improve health (Centre for disease control and prevention, 2002). For the purpose of this analysis, health-related events were interpreted to include both disease and injury. The two main aims of surveillance are to provide information to support firstly, control measures and secondly, prevention strategies (Baker, 2010). Both options depend on the input quality of identifying an accurate description of events to support evidence-based policy. Epidemiology is the study of disease within a community. Currently in NZ there are a number of examples of data sources useful for monitoring the health of populations.

Within the BIONIC study, brain injury identification utilised a methodology that captures the TBI cases that may currently be missed by existing databases (i.e. hospital records) including: (1) people who die as a result of TBI prior to being admitted for medical attention (e.g. autopsy records); (2) people who obtain medical attention following an accident, but where TBI is not recorded and/or is overshadowed by other injuries (e.g., orthopaedic injuries); (3) people who do not seek immediate medical attention post TBI (about 5% of cases) (Annegers, Grabow, Kurland, & Laws, 1980) but access services at a later time for TBI-related sequelae; and (4) people who do not wish to make an Accident Compensation Corporation (ACC) claim (e.g. those with very minor TBI or who access private insurance instead). Finally, existing databases tend to restrict case definitions to particular diagnoses based on the ICD-10 coding systems. ICD-10 codes include injuries to the head which do not reflect a brain injury (e.g. superficial injury of the head, open wound of the head, injury of the eye/orbit). Thus, the data reflects head injury and not necessarily brain injury.

## Rationale for the study

The incidence and prevalence of TBI injury across all ages in New Zealand has not been well described. Therefore a multi-state life table model using data from a population-based TBI incidence study and national mortality was conducted. The aim of the study was to provide health funders and planners with internally consistent estimates of TBI incidence and prevalence in 2010 based on BIONIC. Projections of TBI incidence and prevalence to 2020, based on the estimates for 2010 and population (age structure) projections to 2020 produced by Statistics New Zealand were also generated. The research questions this study addresses are:

1. What is the first-ever incidence and estimated prevalence of traumatic brain injury among all age groups in New Zealand in 2010?
2. What is the projected first-ever future incidence and prevalence of traumatic brain injury in New Zealand in 2020?
3. What is the burden of injury for TBI measured in disability adjusted life years?

# Methods

## Definitions

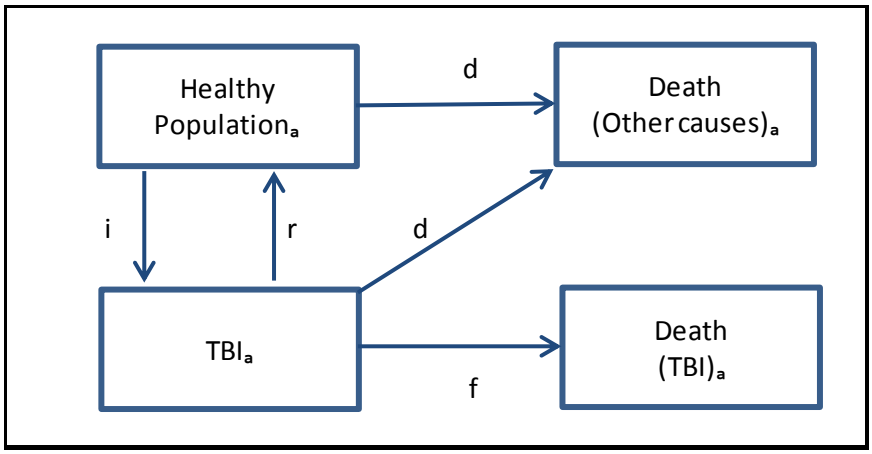
TBI was defined according to the World Health Organisation (WHO) (New Zealand Guidelines Group, 2005, 2006; Ribbers, 2007) recommendations as an acute brain injury resulting from mechanical energy

to the head from external physical forces which resulted in the presence of one or more of the following(Carroll & Holm, 2004):

1. confusion or disorientation;
2. loss of consciousness;
3. post-traumatic amnesia;
4. other neurological abnormalities (e.g. focal signs, seizure) (Carroll & Holm, 2004).

These indices of TBI were not due to drugs, alcohol or medications, caused by other injuries or treatment for other injuries (e.g. systemic injuries, facial injuries or intubation), or caused by other problems (e.g. psychological trauma or co-existing medical conditions) (Carroll & Holm, 2004).

*Figure 3: The conceptual disease model (adopted and modified from Barendregt, Oortmarssen, Vos, and Murray (2003))*




***Healthy Population*:** number of healthy people (i.e. without the disease/injury under consideration); ***TBI*:** the number of diseased/injured people; ***Death (TBI):*** number of people dead from the disease/injury; and ***Death (Other causes):*** number of people dead from all other causes, with (a) an age subscript. There are four transition hazards: **i:** incidence, **r:** remission, **f:** case fatality, and **d:** other-cause mortality.

### Brain Injury Outcomes New Zealand in the Community (BIONIC) Study

The methodology of the BIONIC study has been described elsewhere (Barker-Collo & Feigin, 2009; Theadom et al., 2012). Incidence estimates were obtained from the BIONIC study. This is a large prospective population-based TBI register covering the total population of the Hamilton and Waikato districts of New Zealand (approximately 170,000 rural and urban residents). Hamilton and Waikato population has demographic and social characteristics that are reflective of the NZ population according to the 2006 NZ census data. All cases (n=1369) of TBI were ascertained over a 12-month period between 1 March 2010 to 28 February 2011, using prospective and retrospective surveillance. Complete case ascertainment was assured by using multiple overlapping sources of information for all new hospitalised and non-hospitalised TBI cases (fatal and non-fatal). Hot pursuit methods were used to identify additional cases of TBI through cross-checks of general practitioner databases and hospital admissions. Regional TBI incidence estimates and the definition of TBI severity utilised are reported elsewhere (Feigin et al., 2013). Our focus is on estimates of first-ever in a lifetime TBI incidence (N = 521), (as a measure of true incidence), this is different from the injury rates (incidence and recurrent TBI)

previously reported. TBI mortality was defined as deaths registered in the NZ Ministry of Health's Mortality Collection (2010-2011) as resulting from a TBI (ICD10 S06.0-S06.9). Deaths from causes other than TBI are described as "other cause" mortality (see Figure 3). All-cause deaths and population denominator data were obtained from Statistics NZ.

The BIONIC study utilised a methodology that was built upon WHO's Injury Surveillance Guidelines (Holder et al., 2001) and has since recommended a number of conditions be considered (Barker-Collo & Feigin, 2009). This study addresses two points of their recommendation that is to: (i) present first-ever TBI events for both sexes separately; and (ii) present data by five-year age groups available for comparison with other studies.

### Current 2010 and projected 2020 estimates

The BIONIC study is the first worldwide to meet the criteria for an 'ideal' TBI incidence study (Feigin et al., 2013). First-ever TBI incidence rates were derived from the BIONIC study. Age and sex structures of the NZ population census data for 2006 for Hamilton city (urban residents) and Waikato district (rural residents) were used as denominators to calculate age and sex-specific TBI incidence. Age and sex-specific TBI incidences from Hamilton, Waikato region (BIONIC) were then applied to the general NZ population. Due to the low deaths recorded from BIONIC, TBI-related mortality rates obtained from the national mortality collection were used instead. TBI mortality was identified using ICD10 S06.0-S06.9, the codes which correlate strictly to brain injuries (Access Economics, 2009).

Given these estimates of first-ever TBI incidence and mortality, the multi-state life tables could be constructed using DISMOD II software (Barendregt et al., 2003; Barendregt & Ott, 2005; Chung, Cheong, Park, & Kim, 2008) (see *appendix six* for input variables in DISMOD II). DISMOD II was recently developed by the WHO (Barendregt et al., 2003) and has been previously used in the Global Burden of Disease (GBD) studies for estimating the epidemiology of a disease. It is based on a series of algorithms to quantify age-specific incidence, prevalence and mortality (Barendregt & Ott, 2005; Mathers, Vos, Lopez, & Ezzati, 2001). In DISMOD II, remission rate refers to a proportion of individuals with TBI recovering to a normal state, and "0" (zero) was applied as suggested in the GBD in consideration of the irreversible nature of TBI (World Health Organization, 2006) whether or not residual clinically apparent sequelae occur. Prevalence was computed based on incidence from the BIONIC study, and mortality from the New Zealand Health Information Service. The theoretical background and the application of multi-state life tables for epidemiology are discussed elsewhere (Barendregt et al., 2003). The incidence, prevalence, and mortality rates output of the model were then used to estimate the level of TBI burden in the population for 2010. In turn, the expected number of future TBIs can be estimated by combining BIONIC incidence data with NZ population projection estimates by age and gender for 2020. A cohort-based approach was used to project the TBI burden to 2020, using NZ population (census year 2006) under the strong assumptions that age/sex-specific incidence and excess mortality rates remained stable.

The model was built by first smoothing the input data using a "moving average" interpolation whereby to smooth shape continuities between adjacent 5 year age groups to prevent difficulties in modelling

prevalence. The incidence estimates were considered more reliable than the cause-specific mortality estimates, which were derived from routine cause of death coding (Ribbers, 2007). Accordingly, the DISMOD modelling was carried out anchoring on incidence, so giving less 'weight' to the excess mortality estimates. Remission was zero by definition (since at this stage we are modelling the prevalence of survivors of first ever in lifetime TBI, irrespective of disability level). DISMOD software was used to produce internally consistent estimates of incidence, prevalence, duration and related mortality. Annual crude incidence (all first-ever events) of TBI rates are presented as rates per 100,000 per person per year. Direct standardisation was employed to age standardise the rate to the world population, using the WHO's standard population (World Health Organization, 2000). 95% uncertainty intervals were computed using the $2.5^{th}$ and $97.5^{th}$ percentile of the distribution.

### Quality adjusted life years vs. disability adjusted life years

Both quality adjusted life years (QALY) and disability adjusted life years (DALY) are measures of burden of disease by aggregating mortality and morbidity into a single metric. One difference in these two measures is the way health states are weighted and collected. QALYs are derived from " individual preference based" health related quality of life instruments (such as the EQ-5D or SF-6D), where quality of life weighting are directly collected by the individuals (Polinder et al., 2011). Unlike DALYs, weights are elicited from clinical experts. Even though QALYs are collected directly from the individual, DALYs were used in this current study (Gabbe et al., 2013). The rationale for using DALYs, is so it can be compared against international literature such as the Global Burden of Disease studies (Murray et al., 2012).

### Quantifying disability-adjusted life years (DALYs)

Population burden of TBI was measured in disability-adjusted life years (DALYs) (Murray et al., 2012; Salomon, Vos, & Hogan, 2012). DALYs can be expressed as the sum of the "years of life lost" (YLL) and "years lived with disability" (YLD). As TBI is often associated with high levels of physical impairment DALYs might be more suited as an important component of DALYs is the concept of "social weighting", which has a heavy reliance on life expectancy (Moodie et al., 2004). When quantifying a disease burden the DALY would incorporate a years of life lost component, which would be acquired from life tables often with weights for dying at each age based on the "social value" of dying at that age. In addition to this, one would also quantify a years lived with disability component acquired by weighting years lived with a particular disease, elicited through some kind of preference-based method (such as "time trade off"(Attema, Edelaar-Peeters, Versteegh, & Stolk, 2013), "standard gamble" (Gafni, 1994)). At present there is no known reported standard assessment tool to measure DALYs (i.e. survey instrument). Years of life lost was calculated by multiplying the number of deaths from TBI by the remaining life expectancy at age of occurrence in five-year age bands. Remaining life expectancy at each age was taken from the GBD 2010 standard life table YLDs were calculated by multiplying the prevalence of the condition by severity level in each five-year age band by the relevant disability weight, taken from the GBD 2010. At 12 months post-TBI, the proportion of participants identified as having no, mild, or moderate/severe disability (defined by the Glasgow Outcome Score (Jennett & Bond, 1975)) was sourced from the BIONIC dataset and used to determine the probability of residual disability (i.e., after 12 months). If an

individual had residual disability (including mild or moderate/severe TBI) at 12 months, this was assumed to persist for a lifetime. Disability weights are based on health state valuations on a scale from 0 (no health loss) to 1 (complete health loss, equivalent to being dead), estimated from a set of global health surveys (Cassidy 2004 Salmond 2012). Disability weights were specific for stage (i.e., year post occurrence) and level of severity A short-term (Year 1) disability weight of 0.235 was assigned to all cases A longer-term (Year 2+) disability weight for mild and moderate / severe residual disability of 0.106 and 0.425 respectively were applied A disability weight of zero was attributed to those with no neurological deficit after the first year post TBI(Ministry of Health, 2012)(see Table 5).

*Table 5: Health states and disability weights adopted from the New Zealand Burden of Disease Ministry of Health (2012))*

| **Constituent Health State** | **Health State Disability Weight** |
|---|---|
| Short term | 0.235 |
| Long-term effects ( i.e. neurological deficit, psychological effects) for mild TBI | 0.106 |
| Long-term effects (i.e. neurological deficit, psychological effects) for moderate to severe TBI | 0.425 |

## Results

### Descriptive epidemiology of TBI, 2010 incidence

Table 6 summarises the estimated national incidence of first-ever in lifetime TBI in NZ in 2010. Incidence rates of first ever TBI by five year age bands are shown in figure4. Higher incidence rates of first-ever TBI are observed among younger age groups and among males. Translating rates into counts, the model estimates that almost 11,300 first-ever TBIs occurred in NZ in 2010, 57% of them in males. Almost 43% of first-ever TBIs occurred in people aged between 0 to 14 years. The crude incidence rate of first-ever TBI was 281 cases per 100,000 person years (males 330 cases per 100,000, females 233 cases per 100,000). Mild TBI cases are estimated to be 268 per 100,000 per year (age standardised rate of 297 cases) (see Table 7). The estimated mean age at diagnosis of first TBI was 23.0 years, (males 22.9 years, females 23.9 years).

*Table 6: Modelled age and sex-specific incidence of first TBI, 2010*

| Age group (years) | Rates per 100,000 [point estimate, 95% Uncertainty Interval] | | | | | | Counts (Number of new cases)[point estimate, 95% Uncertainty Interval] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | | Female | | Persons | | Male | | Female | | Persons | |
| 0-4 | 685 | | 602 | | 644 | | 962 | | 811 | | 1773 | |
| | 534 | 744 | 557 | 651 | 546 | 698 | 750 | 1044 | 750 | 877 | 1500 | 1921 |
| 5-9 | 591 | | 494 | | 543 | | 866 | | 691 | | 1557 | |
| | 314 | 673 | 458 | 529 | 386 | 601 | 460 | 986 | 641 | 740 | 1101 | 1726 |
| 10-14 | 563 | | 436 | | 501 | | 885 | | 649 | | 1534 | |
| | 387 | 633 | 404 | 468 | 396 | 551 | 608 | 994 | 601 | 697 | 1209 | 1691 |
| 15-19 | 556 | | 380 | | 469 | | 847 | | 562 | | 1409 | |
| | 470 | 636 | 357 | 406 | 414 | 521 | 716 | 970 | 528 | 600 | 1244 | 1570 |
| 20-24 | 466 | | 264 | | 365 | | 630 | | 359 | | 989 | |
| | 415 | 526 | 249 | 283 | 332 | 405 | 561 | 711 | 338 | 385 | 899 | 1096 |
| 25-29 | 342 | | 187 | | 262 | | 401 | | 235 | | 636 | |
| | 313 | 372 | 180 | 196 | 247 | 284 | 367 | 436 | 226 | 245 | 593 | 681 |
| 30-34 | 232 | | 149 | | 189 | | 304 | | 218 | | 522 | |
| | 221 | 243 | 143 | 155 | 182 | 199 | 290 | 318 | 209 | 225 | 499 | 543 |
| 35-39 | 173 | | 122 | | 146 | | 247 | | 194 | | 441 | |
| | 167 | 178 | 119 | 126 | 143 | 152 | 239 | 255 | 188 | 199 | 427 | 454 |
| 40-44 | 164 | | 102 | | 132 | | 248 | | 166 | | 414 | |
| | 159 | 170 | 99 | 104 | 129 | 137 | 240 | 256 | 162 | 169 | 402 | 425 |
| 45-49 | 192 | | 97 | | 143 | | 275 | | 146 | | 421 | |
| | 186 | 199 | 94 | 99 | 140 | 149 | 266 | 284 | 142 | 149 | 408 | 433 |
| 50-54 | 202 | | 104 | | 152 | | 250 | | 133 | | 383 | |
| | 193 | 210 | 101 | 106 | 147 | 158 | 239 | 262 | 130 | 136 | 369 | 398 |
| 55-59 | 164 | | 132 | | 148 | | 189 | | 156 | | 345 | |
| | 159 | 169 | 128 | 136 | 144 | 153 | 184 | 195 | 151 | 161 | 335 | 356 |
| 60-64 | 164 | | 199 | | 182 | | 145 | | 181 | | 326 | |
| | 158 | 169 | 189 | 207 | 174 | 188 | 140 | 149 | 173 | 189 | 313 | 338 |
| 65-69 | 112 | | 165 | | 139 | | 81 | | 126 | | 207 | |
| | 108 | 116 | 159 | 171 | 134 | 144 | 78 | 83 | 121 | 131 | 199 | 214 |
| 70-74 | 68 | | 93 | | 81 | | 38 | | 57 | | 95 | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 66 | 69 | 90 | 97 | 78 | 83 | 37 | 39 | 55 | 59 | 92 | 98 |
| **75-79** | 83 | | 63 | | 73 | | 38 | | 35 | | 73 | |
| | 81 | 85 | 62 | 64 | 72 | 75 | 37 | 39 | 34 | 35 | 71 | 74 |
| **80-84** | 134 | | 88 | | 111 | | 39 | | 38 | | 77 | |
| | 128 | 139 | 85 | 89 | 107 | 114 | 37 | 40 | 37 | 39 | 74 | 79 |
| **85+** | 244 | | 145 | | 195 | | 43 | | 56 | | 99 | |
| | 232 | 256 | 140 | 149 | 186 | 203 | 41 | 45 | 55 | 58 | 96 | 103 |

*Figure 4: Modelled age and sex-specific incidence of first TBI in 2010*

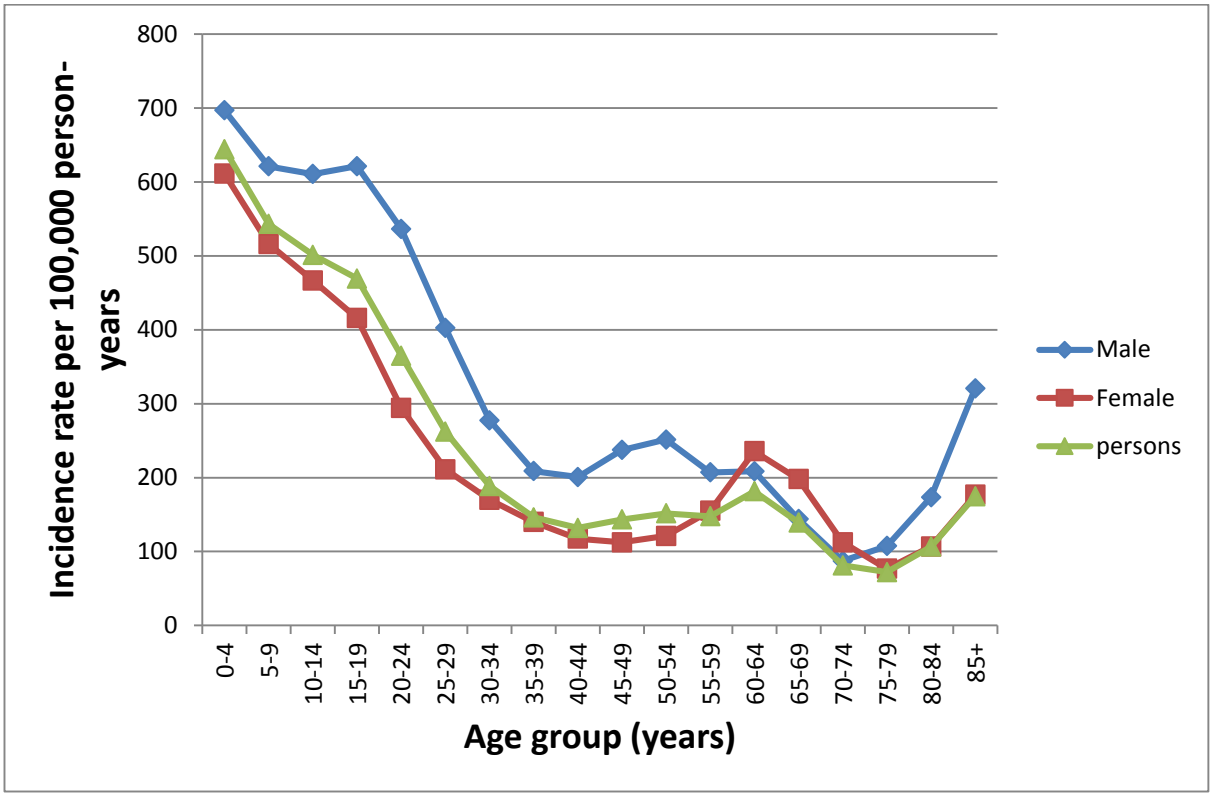


*Table 7: Modelled age and sex-specific incidence of first TBI, by severity of injury (mild, moderate severe), 2010*

| Age group (years) | Mild TBI | | | | | | Moderate Severe TBI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rates per 100,000 | | | Counts (Number of cases) | | | Rates per 100,000 | | | Counts (Number of cases) | | |
| | Male | Female | Persons | Male | Female | Persons | Male | Female | Persons | Male | Female | Persons |
| **0-4** | 646 | 586 | 616 | 906 | 790 | 1696 | 40 | 16 | 28 | 56 | 21 | 77 |
| **5-9** | 557 | 481 | 520 | 816 | 673 | 1489 | 34 | 13 | 24 | 50 | 18 | 68 |
| **10-14** | 531 | 424 | 479 | 834 | 632 | 1466 | 33 | 11 | 22 | 51 | 17 | 68 |
| **15-19** | 523 | 370 | 448 | 798 | 547 | 1345 | 32 | 10 | 21 | 49 | 15 | 64 |
| **20-24** | 439 | 257 | 348 | 593 | 350 | 943 | 27 | 7 | 17 | 37 | 9 | 46 |
| **25-29** | 322 | 183 | 250 | 378 | 229 | 607 | 20 | 5 | 12 | 23 | 6 | 29 |
| **30-34** | 219 | 146 | 180 | 286 | 212 | 499 | 13 | 4 | 8 | 18 | 6 | 23 |
| **35-39** | 163 | 119 | 140 | 233 | 189 | 422 | 10 | 3 | 6 | 14 | 5 | 19 |
| **40-44** | 155 | 99 | 126 | 234 | 162 | 395 | 10 | 3 | 6 | 14 | 4 | 19 |
| **45-49** | 181 | 95 | 137 | 259 | 142 | 401 | 11 | 3 | 7 | 16 | 4 | 20 |
| **50-54** | 189 | 101 | 144 | 235 | 130 | 365 | 12 | 3 | 7 | 15 | 4 | 18 |
| **55-59** | 155 | 128 | 141 | 178 | 152 | 330 | 10 | 3 | 6 | 11 | 4 | 15 |
| **60-64** | 155 | 193 | 174 | 137 | 176 | 313 | 10 | 5 | 7 | 8 | 5 | 13 |
| **65-69** | 106 | 161 | 134 | 76 | 123 | 199 | 7 | 4 | 5 | 5 | 3 | 8 |
| **70-74** | 64 | 91 | 78 | 36 | 56 | 91 | 4 | 2 | 3 | 2 | 2 | 4 |
| **75-79** | 77 | 62 | 69 | 36 | 34 | 70 | 5 | 2 | 3 | 2 | 1 | 3 |
| **80-84** | 126 | 86 | 102 | 37 | 37 | 74 | 8 | 2 | 5 | 2 | 1 | 3 |
| **85+** | 229 | 140 | 168 | 41 | 55 | 95 | 14 | 4 | 7 | 2 | 1 | 4 |

## Prevalence

Modelled prevalence rates of TBI (this includes total number of cases including first and recurrent TBI) are plotted by five-year age groups in figure 5 and summarised in Table 8. The results indicate that in 2010 approximately 527,400 New Zealanders (13% of the NZ population) had experienced at least one TBI event at some time in their lives. Crude prevalence estimates were 14.8% for males and 11.4 % for females. The prevalence of TBI was 23% higher in males than in females, adjusting for differences in age distributions. The highest prevalence occurred in the 40-49 years age group in both males and females. The age distribution of TBI survivors is skewed to the right with two-thirds (68%) of prevalent cases aged 35 years and older. Of these numbers of cases, an estimated 12,847 (or 2.4%) would have residual disability one year after having a brain injury (see table 9).

*Table 8: Modelled age and sex-specific prevalence of people who have had one or more TBI in 2010*

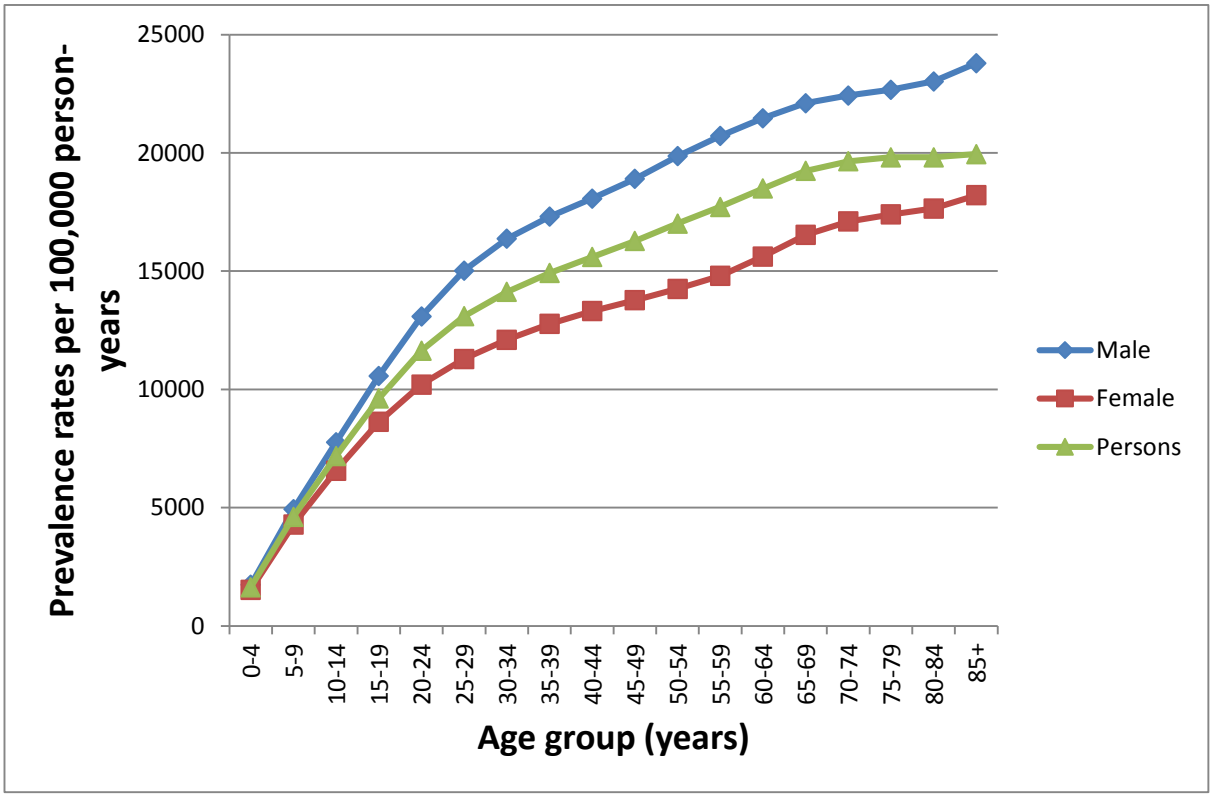
| Age group (years) | Rates per 100,000 point estimate, 95% UI | | | | | | Counts (Number of cases) point estimate, 95% UI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Male | | Female | | Persons | | Male | | Female | | Persons | |
| 0-4 | 1739 | | 1533 | | 1638 | | 2441 | | 2064 | | 4505 | |
| | 1580 | 1836 | 1419 | 1661 | 1500 | 1749 | 2217 | 2578 | 1911 | 2237 | 4128 | 4815 |
| 5-9 | 4933 | | 4286 | | 4617 | | 7229 | | 5998 | | 13227 | |
| | 4671 | 5199 | 3954 | 4572 | 4313 | 4886 | 6845 | 7618 | 5534 | 6399 | 12379 | 14017 |
| 10-14 | 7765 | | 6564 | | 7181 | | 12199 | | 9774 | | 21973 | |
| | 7348 | 8190 | 6133 | 6976 | 6741 | 7583 | 11545 | 12868 | 9132 | 10387 | 20677 | 23255 |
| 15-19 | 10570 | | 8626 | | 9614 | | 16114 | | 12746 | | 28860 | |
| | 9972 | 11185 | 8221 | 9100 | 9097 | 10143 | 15201 | 17050 | 12148 | 13446 | 27349 | 30496 |
| 20-24 | 13085 | | 10204 | | 11640 | | 17675 | | 13867 | | 31542 | |
| | 12311 | 13924 | 9755 | 10670 | 11033 | 12297 | 16630 | 18809 | 13256 | 14500 | 29886 | 33309 |
| 25-29 | 15022 | | 11286 | | 13092 | | 17608 | | 14133 | | 31741 | |
| | 14068 | 15942 | 10819 | 11799 | 12444 | 13871 | 16490 | 18686 | 13549 | 14775 | 30039 | 33461 |
| 30-34 | 16371 | | 12103 | | 14123 | | 21427 | | 17631 | | 39058 | |
| | 14390 | 17297 | 11635 | 12645 | 13013 | 14971 | 18834 | 22639 | 16949 | 18421 | 35783 | 41060 |
| 35-39 | 17302 | | 12771 | | 14920 | | 24742 | | 20249 | | 44991 | |
| | 12224 | 18209 | 12310 | 13315 | 12267 | 15762 | 17480 | 26040 | 19518 | 21110 | 36998 | 47150 |
| 40-44 | 18068 | | 13310 | | 15599 | | 27265 | | 21669 | | 48934 | |
| | 13020 | 18951 | 12856 | 13854 | 12938 | 16403 | 19648 | 28598 | 20929 | 22554 | 40577 | 51152 |
| 45-49 | 18900 | | 13774 | | 16273 | | 27036 | | 20712 | | 47748 | |
| | 13870 | 19776 | 13321 | 14318 | 13596 | 17047 | 19841 | 28290 | 20030 | 21529 | 39871 | 49819 |
| 50-54 | 19863 | | 14250 | | 17011 | | 24691 | | 18300 | | 42991 | |
| | 14851 | 20749 | 13792 | 14792 | 14322 | 17771 | 18461 | 25793 | 17712 | 18996 | 36173 | 44789 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **55-59** | 20714 | | 14799 | | 17717 | | 23868 | | 17514 | | 41382 | |
| | 15717 | 21605 | 14341 | 15344 | 15029 | 18475 | 18109 | 24894 | 16972 | 18159 | 35081 | 43053 |
| **60-64** | 21465 | | 15615 | | 18492 | | 18961 | | 14253 | | 33214 | |
| | 16477 | 22365 | 15167 | 16170 | 15822 | 19268 | 14555 | 19756 | 13844 | 14759 | 28399 | 34515 |
| **65-69** | 22102 | | 16533 | | 19237 | | 15938 | | 12637 | | 28575 | |
| | 17121 | 23022 | 16102 | 17027 | 16612 | 20025 | 12346 | 16601 | 12307 | 13014 | 24653 | 29615 |
| **70-74** | 22429 | | 17099 | | 19647 | | 12533 | | 10441 | | 22974 | |
| | 17448 | 23360 | 16656 | 17552 | 17052 | 20456 | 9750 | 13053 | 10170 | 10717 | 19920 | 23770 |
| **75-79** | 22670 | | 17398 | | 19813 | | 10510 | | 9544 | | 20054 | |
| | 17630 | 23609 | 16953 | 17923 | 17292 | 20766 | 8173 | 10945 | 9300 | 9832 | 17473 | 20777 |
| **80-84** | 23024 | | 17649 | | 19815 | | 6705 | | 7609 | | 14314 | |
| | 18058 | 23956 | 17209 | 18147 | 17634 | 21052 | 5259 | 6977 | 7419 | 7824 | 12678 | 14801 |
| **85+** | 23792 | | 18208 | | 19949 | | 4204 | | 7101 | | 11305 | |
| | 19132 | 24694 | 17766 | 18691 | 18449 | 21693 | 3381 | 4363 | 6929 | 7289 | 10310 | 11652 |

*Table 9: Modelled age and sex-specific prevalence of people who have had one or more TBI in 2010 with residual disability*

| Age group (years) | With residual disability | | | | | |
|---|---|---|---|---|---|---|
| | Rates per 100,000 | | | Counts (Number of cases) | | |
| | Male | Female | Persons | Male | Female | Persons |
| 0-4 | 29 | 20 | 25 | 40 | 27 | 68 |
| 5-9 | 119 | 83 | 101 | 174 | 116 | 290 |
| 10-14 | 197 | 134 | 166 | 309 | 200 | 509 |
| 15-19 | 273 | 181 | 228 | 417 | 267 | 684 |
| 20-24 | 345 | 218 | 281 | 465 | 296 | 762 |
| 25-29 | 401 | 243 | 319 | 470 | 305 | 775 |
| 30-34 | 441 | 262 | 347 | 577 | 382 | 959 |
| 35-39 | 468 | 277 | 368 | 669 | 440 | 1109 |
| 40-44 | 489 | 290 | 385 | 738 | 472 | 1209 |
| 45-49 | 511 | 300 | 403 | 731 | 451 | 1182 |
| 50-54 | 537 | 310 | 422 | 667 | 398 | 1066 |
| 55-59 | 561 | 322 | 440 | 647 | 381 | 1027 |
| 60-64 | 582 | 338 | 458 | 514 | 309 | 822 |
| 65-69 | 600 | 359 | 476 | 433 | 274 | 707 |
| 70-74 | 611 | 373 | 486 | 341 | 228 | 569 |
| 75-79 | 617 | 380 | 489 | 286 | 209 | 494 |
| 80-84 | 625 | 385 | 482 | 182 | 166 | 348 |
| 85+ | 643 | 396 | 473 | 114 | 154 | 268 |

*Figure 5: Modelled age and sex-specific prevalence of people who have had one or more TBI in 2010*



## Duration of survival

Table 10 presents the estimated duration of survival after first-ever TBI (i.e. the time from onset of first TBI to death from any cause). Males were slightly younger at onset than females, and also had a higher mortality. On average, females survive nearly five years longer after first TBI than males (58.9 years vs 54.3 years).

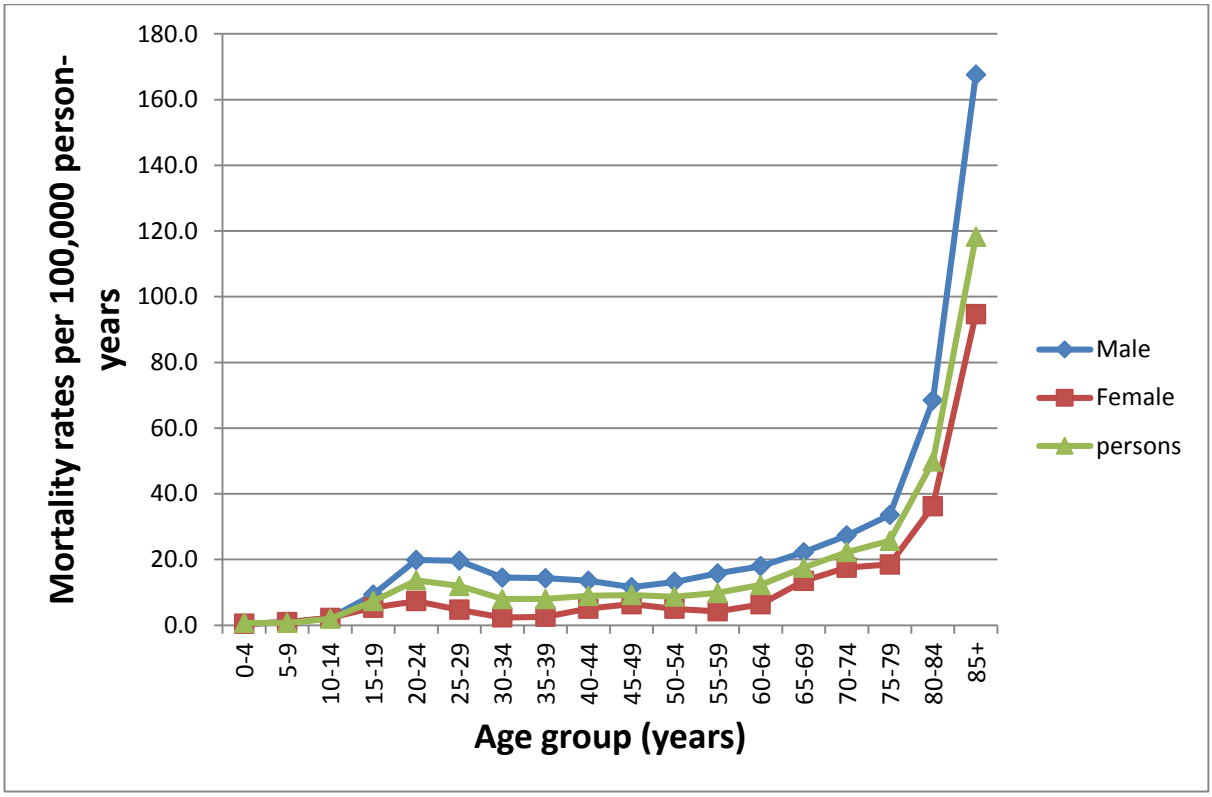
*Table 10: Modelled survival times (years) of TBI survivors, 2010*

| **Duration of survival after first TBI (years) Point estimate, 95% UI** | | | | |
|---|---|---|---|---|
| **Age at first TBI (years)** | **Male** | | **Female** | |
| **0-4** | 73.8 | | 79.7 | |
| | 73.6 | 74 | 79.6 | 79.8 |
| **5-9** | 69.2 | | 75 | |
| | 27.7 | 69.3 | 75 | 75.1 |
| **10-14** | 64.2 | | 70.1 | |
| | 48.2 | 64.4 | 70 | 70.2 |
| **15-19** | 59.5 | | 65.4 | |
| | 55.9 | 59.7 | 65.4 | 65.5 |
| **20-24** | 55.2 | | 60.8 | |
| | 53.5 | 55.3 | 60.7 | 60.8 |
| **25-29** | 50.8 | | 56 | |
| | 49.7 | 50.9 | 56 | 56 |
| **30-34** | 46.3 | | 51.2 | |
| | 45.5 | 46.4 | 51.1 | 51.2 |
| **35-39** | 41.6 | | 46.3 | |
| | 41 | 41.7 | 46.3 | 46.4 |
| **40-44** | 36.9 | | 41.6 | |
| | 36.4 | 37 | 41.6 | 41.6 |
| **45-49** | 32.3 | | 36.9 | |
| | 32 | 32.4 | 36.9 | 36.9 |
| **50-54** | 28 | | 32.3 | |
| | 27.7 | 28.1 | 32.3 | 32.4 |
| **55-59** | 23.7 | | 27.7 | |
| | 23.5 | 23.8 | 27.7 | 27.8 |
| **60-64** | 19.7 | | 23.6 | |
| | 19.5 | 19.7 | 23.6 | 23.6 |
| **65-69** | 16.1 | | 19.8 | |
| | 16 | 16.2 | 19.8 | 19.9 |
| **70-74** | 12.6 | | 16.2 | |
| | 12.4 | 12.6 | 16.2 | 16.3 |
| **75-79** | 9.3 | | 12.7 | |
| | 9.2 | 9.3 | 12.7 | 12.8 |
| **80-84** | 6.9 | | 9.8 | |
| | 6.8 | 6.9 | 9.8 | 9.9 |
| **85+** | 4.3 | | 7 | |
| | 4.2 | 4.3 | 7 | 7 |

### TBI-related mortality

Modelled TBI-related mortality rates are plotted in figure 6. TBI-related deaths among males were 1.98 times higher than females, with an annual death rate of 15 deaths per 100,000 for males compared to eight deaths per 100,000 for females. Translating rates into counts, 448 deaths in 2010 were estimated to be attributable to TBI, of which 293 (66%) were male. Modelled TBI-related deaths numbered 16% fewer than those registered as being caused by TBI in routine mortality statistics (448 modelled deaths vs 519 registered).

*Figure 6: Modelled TBI-related mortality rates (per 100,000) 2010*




### Projection of TBI epidemiology in 2020

Projected TBI incidence and prevalence of TBI survivors are presented in Table 11. The number of incidences is expected to increase to 13,591 (2% per year increase) and the number of prevalent cases is expected to increase to 641,104. The incidence and prevalence counts generated by DISMOD II assume similar rates of TBI incidence and prevalence to those estimated for 2010. Information on the number of incidences and prevalence in the future provides information to health planners and funders on the likely demand for health services.

*Table 11: Projected number of first-ever TBI 2010-2020*

| Age group (years) | Incidence (counts) | | | Prevalence (counts) | | |
|---|---|---|---|---|---|---|
| | **Male** | **Female** | **Persons** | **Male** | **Female** | **Persons** |
| **0-4** | 1356 | 1135 | 2491 | 3445 | 2891 | 6336 |
| **5-9** | 1151 | 919 | 2070 | 9737 | 8058 | 17795 |
| **10-14** | 1054 | 784 | 1838 | 15000 | 12121 | 27121 |
| **15-19** | 893 | 598 | 1491 | 17790 | 14064 | 31854 |
| **20-24** | 740 | 411 | 1151 | 22034 | 16601 | 38635 |
| **25-29** | 548 | 300 | 848 | 25649 | 19026 | 44675 |
| **30-34** | 348 | 236 | 584 | 26416 | 20234 | 46650 |
| **35-39** | 233 | 181 | 414 | 25328 | 20122 | 45450 |
| **40-44** | 197 | 138 | 335 | 23523 | 19284 | 42807 |
| **45-49** | 242 | 143 | 385 | 26048 | 21630 | 47678 |
| **50-54** | 251 | 151 | 402 | 27238 | 22086 | 49324 |
| **55-59** | 207 | 191 | 398 | 28780 | 23068 | 51848 |
| **60-64** | 184 | 253 | 437 | 26678 | 21496 | 48174 |
| **65-69** | 106 | 177 | 283 | 23221 | 19183 | 42404 |
| **70-74** | 56 | 87 | 143 | 20467 | 17390 | 37857 |
| **75-79** | 47 | 42 | 89 | 14288 | 12625 | 26913 |
| **80-84** | 49 | 41 | 90 | 9339 | 8975 | 18314 |
| **85+** | 72 | 70 | 142 | 7720 | 9549 | 17269 |
| **Total** | **7734** | **5857** | **13591** | **352701** | **288403** | **641104** |

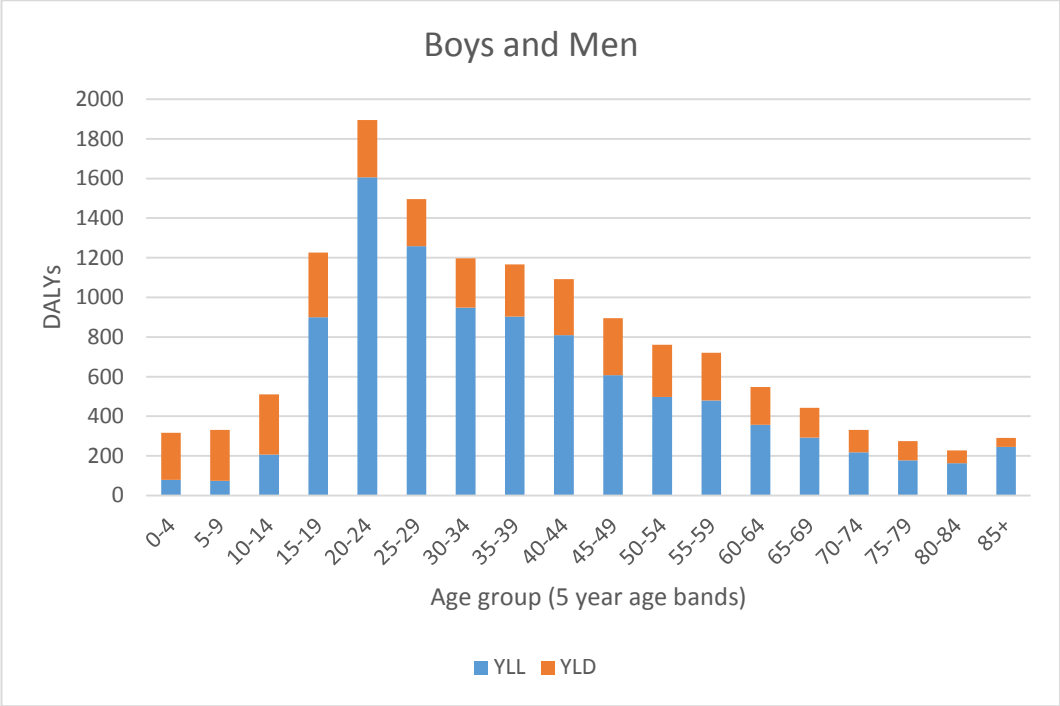
### Total DALYs due to TBI in NZ

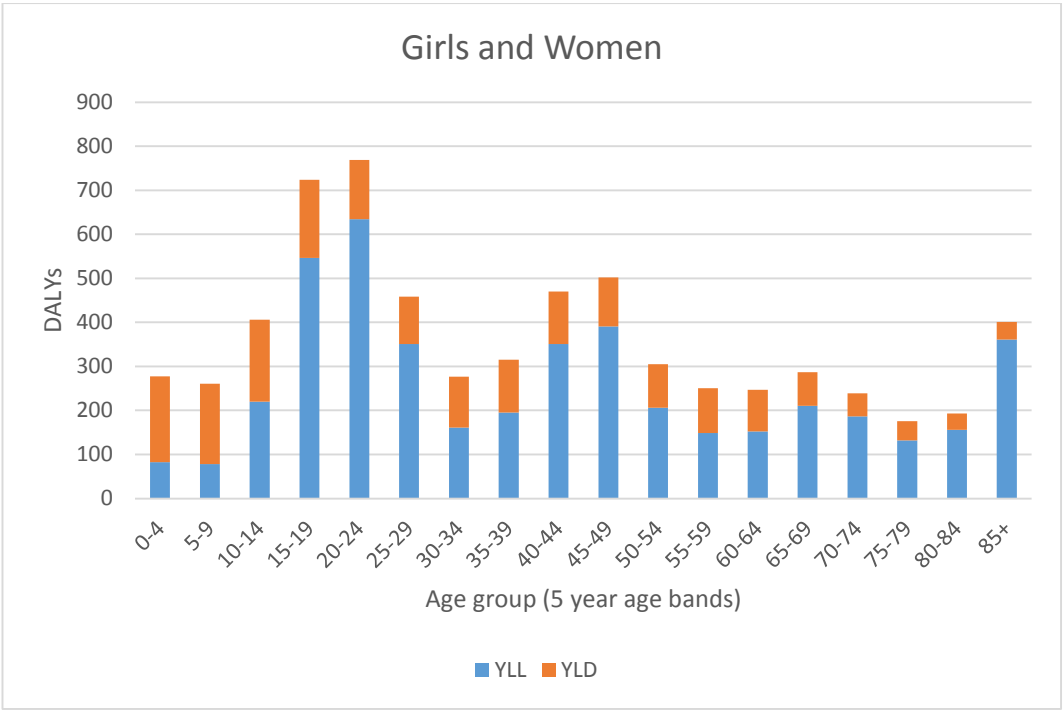
As shown in Table 12, TBI accounted for approximately 20,300 DALYs. This is 27% of all injury-related health loss and 2.4.% of DALYs from all causes in 2010 (Ministry of Health, 2012). The TBI DALYs were made up of 14,386 years of life lost (YLLs) (71%) and only 5891 years lived with disability (YLDs 29%). Thus the majority of health loss from TBI reflects fatal outcomes. Of the nonfatal health loss from TBI, 56% (approximately 3300 YLDs) resulted from mild cases and 44% (approximately 2,600 YLDs) from moderate to severe cases. DALY rates were approximately twice as high in males than females (adjusting for differences in their age distributions). DALY rates were higher in younger than older age groups, peaking in the 20-24 age group (Figure 7). After adjusting for age and sex distributions, population burden for TBI is expected to increase to 29,485 DALYs in 2020 (Table 14).

*Table 12: Disability-adjusted life years due to TBI, 2010*

| | YLL | YLD (mild) | YLD (moderate severe) | % YLD due to short term consequence | % YLD due to long term consequence | DALYs | DALYs per 100,000 population |
|---|---|---|---|---|---|---|---|
| **Current 2010** | | | | | | | |
| Boys and Men | 9,823 | 1,745 | 2,153 | 39% | 61% | 13,721 | 698 |
| Girls and Women | 4,564 | 1,532 | 461 | 57% | 43% | 6,556 | 318 |
| Total | 14,386 | 3,277 | 2,614 | 45% | 55% | 20,277 | 503 |

*Figure 7: TBI DALYs by sex and total population, 2010*




Girls and Women
DALYs
900
800
700
600
500
400
300
200
100
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85+
Age group (5 year age bands)
YLL
YLD

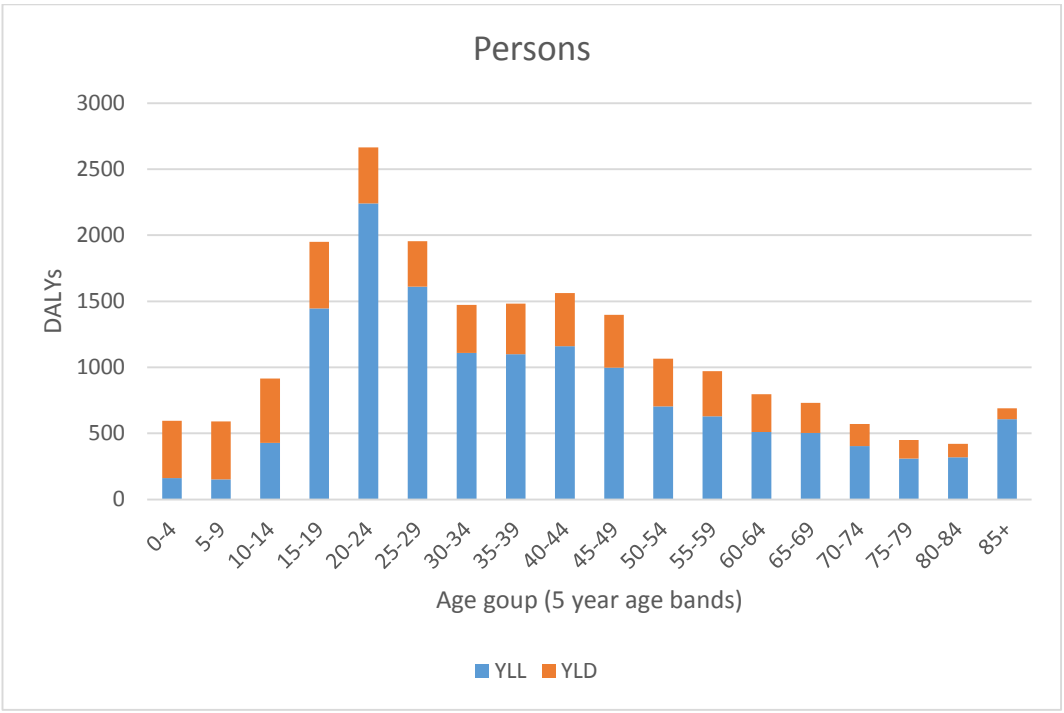

Persons
DALYs
3000
2500
2000
1500
1000
500
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85+
Age goup (5 year age bands)
YLL
YLD

*Table 13: Disability-adjusted life years due to TBI, 2010*

| | YLL | | YLD Mild | | YLD Moderate/Severe | | DALY | | |
|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Female** | **Male** | **Female** | **Male** | **Female** | **Male** | **Female** | **Male** | **Total** |
| **0-4** | 82 | 78 | 188 | 215 | 7 | 24 | 278 | 317 | 594 |
| **5-9** | 78 | 74 | 168 | 199 | 14 | 58 | 260 | 331 | 591 |
| **10-14** | 220 | 208 | 165 | 208 | 21 | 94 | 406 | 510 | 916 |
| **15-19** | 546 | 899 | 151 | 204 | 26 | 122 | 724 | 1225 | 1949 |
| **20-24** | 634 | 1605 | 107 | 158 | 27 | 132 | 769 | 1896 | 2664 |
| **25-29** | 351 | 1259 | 80 | 107 | 27 | 130 | 458 | 1496 | 1954 |
| **30-34** | 161 | 949 | 82 | 90 | 34 | 157 | 277 | 1196 | 1473 |
| **35-39** | 195 | 904 | 82 | 81 | 39 | 181 | 315 | 1166 | 1481 |
| **40-44** | 351 | 809 | 78 | 84 | 41 | 199 | 470 | 1092 | 1563 |
| **45-49** | 391 | 607 | 72 | 90 | 39 | 198 | 502 | 895 | 1397 |
| **50-54** | 206 | 498 | 64 | 82 | 35 | 181 | 305 | 760 | 1066 |
| **55-59** | 149 | 479 | 68 | 68 | 33 | 174 | 250 | 721 | 972 |
| **60-64** | 152 | 357 | 68 | 53 | 27 | 138 | 247 | 548 | 795 |
| **65-69** | 210 | 292 | 52 | 35 | 24 | 116 | 287 | 443 | 730 |
| **70-74** | 187 | 218 | 32 | 22 | 20 | 91 | 239 | 331 | 570 |
| **75-79** | 132 | 178 | 26 | 20 | 18 | 76 | 176 | 274 | 450 |
| **80-84** | 156 | 164 | 23 | 16 | 14 | 49 | 193 | 228 | 422 |
| **85+** | 361 | 245 | 26 | 14 | 13 | 31 | 401 | 290 | 691 |

*Table 14: Disability-adjusted life years due to TBI projected to 2020*

| | YLL | | YLD Mild | | YLD Moderate/Severe | | DALY | | |
|---|---|---|---|---|---|---|---|---|---|
| **Age** | **Female** | **Male** | **Female** | **Male** | **Female** | **Male** | **Female** | **Male** | **Total** |
| **0-4** | 82 | 78 | 263 | 302 | 10 | 34 | 356 | 414 | 770 |
| **5-9** | 156 | 148 | 224 | 264 | 19 | 78 | 399 | 490 | 889 |
| **10-14** | 293 | 277 | 200 | 248 | 26 | 116 | 519 | 641 | 1160 |
| **15-19** | 615 | 1092 | 162 | 216 | 29 | 135 | 805 | 1443 | 2248 |
| **20-24** | 824 | 2141 | 124 | 187 | 33 | 165 | 981 | 2492 | 3473 |
| **25-29** | 468 | 1970 | 103 | 149 | 37 | 190 | 608 | 2308 | 2916 |
| **30-34** | 214 | 1249 | 91 | 105 | 39 | 194 | 344 | 1548 | 1892 |
| **35-39** | 195 | 1039 | 78 | 79 | 38 | 185 | 312 | 1303 | 1615 |
| **40-44** | 351 | 768 | 67 | 69 | 37 | 172 | 455 | 1009 | 1464 |
| **45-49** | 430 | 643 | 73 | 82 | 41 | 190 | 544 | 915 | 1459 |
| **50-54** | 275 | 622 | 75 | 85 | 42 | 199 | 392 | 906 | 1299 |
| **55-59** | 209 | 639 | 86 | 77 | 44 | 210 | 339 | 926 | 1265 |
| **60-64** | 228 | 558 | 97 | 69 | 41 | 195 | 367 | 822 | 1189 |
| **65-69** | 358 | 475 | 76 | 49 | 37 | 169 | 470 | 692 | 1162 |
| **70-74** | 323 | 406 | 52 | 35 | 33 | 149 | 408 | 590 | 997 |
| **75-79** | 198 | 267 | 33 | 26 | 24 | 104 | 255 | 397 | 651 |
| **80-84** | 195 | 253 | 26 | 21 | 17 | 68 | 238 | 342 | 581 |
| **85+** | 4323 | 0 | 34 | 24 | 18 | 56 | 4374 | 81 | 4455 |

## Discussion

The aim of this study was to estimate first ever in lifetime TBI incidence, prevalence of TBI survivors in the population, TBI attributable deaths and TBI-attributable health loss (denominated in DALYs) for NZ in 2010. Combining information from the BIONIC study with NZ national health data, the modelled results suggest that there were approximately 11,300 first-ever TBI events in 2010 with a total prevalence of approximately 527,000. Males experienced higher rates of TBI than females. A high proportion of TBIs occurred among children (aged <16 years) and young adults (aged <34 years), accounting for about 75% of all first-ever TBI cases.

Health loss attributable to TBI in NZ was estimated to be approximately 20,300 DALYs in 2010. This is over one quarter (27%) of all health loss attributable to intentional and unintentional injuries in that year, and almost 2.4% of all health loss from all causes (i.e., all diseases and injuries) (Ministry of Health and Accident Compensation Corporation, 2013). Importantly, we found that most of the health loss attributable to TBI (71%) resulted from fatal injuries. However, nonfatal outcomes (i.e., disability) still accounted for a substantial share of the total TBI burden. While both moderate/severe and mild TBI contributed to this nonfatal burden, mild TBI made the greater contribution (56% of total TBI YLDs).

Our findings are consistent with previously reported studies. Tagliaferri and colleagues (Tagliaferri, Compagnone, Korsic, Sevadei, & Kraus, 2006) reviewed 23 studies conducted in Europe and reported an aggregate hospitalised TBI incidence rate of 235 per 100,000 person-years. However, these estimates reflect episode rates of TBI (incident and recurrent) sourced from hospitalisation data. In the BIONIC study approximately 30% of incident TBI cases were never seen in hospital. Similarly Corrigan et al. (2010) reviewed TBI incidence and prevalence studies conducted in the US and abroad. The authors concluded that approximately 235,000 Americans are hospitalised for non-fatal TBI each year, but were unable to estimate the incidence of non-hospitalised events (Corrigan et al., 2010). In contrast, a prospective birth cohort study found the incidence of TBI to be much higher (McKinlay et al., 2008). The authors reported an incidence rate of 1,750 per 100,000 per year. The result was based on a population capture methodology which included non-hospitalised TBI (McKinlay et al., 2008). However McKinlay et al.'s (2008) findings were limited to a 0-25 year age group. It is of note that high quality epidemiological design and case ascertainment is lacking in most previous studies. TBI DALYs have previously been reported for New Zealand in the New Zealand Burden of Disease Study (Ministry of Health, 2012) these estimates are consistent with those reported here, despite differences in time period, methodology and data sources.

Strengths of this study include the use of data from a population-based TBI incidence study (Barker-Collo & Feigin, 2009; Feigin et al., 2013; Theadom et al., 2012). Unlike previous studies (Cassidy et al., 2004; Ribbers, 2007; Tate et al., 1998), the estimates reported here are based on investigating TBI in both hospital and community settings across all ages and severities of injury.

The main limitation of our study is the use of routinely collected mortality data to estimate TBI mortality. However, the multi-state life table model corrects for inaccuracy in routine cause of death coding. Thus we estimated 448 deaths from TBI in NZ in 2010, whereas 519 deaths were coded to this cause in the official mortality statistics. This correction is itself a useful output of our study and helps to inform policy makers of the true impact of TBI on our society; reasons why TBI appears to be over-

reported as the underlying cause of death require further investigation to understand how underlying causes of death are coded, especially where multiple trauma is involved. Secondly, the data used on levels of disability (from the BIONIC Study) is subject to self-report bias, however it is the best available data.

Finally, the model as currently constructed does not disaggregate by ethnicity or by socio-economic status due to insufficient data. This clearly reduces the policy relevance and value of our findings. Despite these limitations the model still provides an internally consistent description of TBI epidemiology (including incidence, prevalence and survival) and current burden (including both YLL and YLD).

In conclusion, the current study quantifies the substantial population health impact of TBI in NZ. Further studies are needed to extend the findings to ethnic and socioeconomic subpopulations, and study trends in TBI epidemiology and impacts over time, including recurrent TBI. Such data is essential for planning and evaluating public health interventions and clinical TBI services.

## Summary

The current study used DISMOD II and multi-state life table modelling to estimate the incidence and prevalence of TBI for NZ. The results suggest that the number of TBI sufferers in NZ is substantial and is expected to increase further by 2020. Further similar studies are needed to confirm the findings in other populations; to establish reliable estimates for monitoring TBI as more population-based longitudinal data becomes available. Taking further steps towards improving models will allow predicting the burden of TBI to be extended to a fuller and effective description. Good information on disability outcomes are lacking and current research make the best possible estimates as to the true disability burden.

# CHAPTER FOUR: The direct and indirect cost of traumatic brain injury in New Zealand: A cost-of-illness study

The main findings of the results from this research have been published; the key findings of this paper are reported in this chapter. It was presented as an oral communication at the 3rd International Congress on Neurology and Epidemiology in 2013. The details of the publication are:

1. **Te Ao B**, Brown P, Tobias M, Ameratunga S, Barker-Collo S, Theadom A, McPherson K, Starkey N Dowell A, Jones K, Feigin V, on behalf of the BIONIC Study Group. (2014). The cost of traumatic brain injury in New Zealand: Evidence from a population based study. Neurology; 83; 18:1645-1652. (see *appendix seven*)

## Introduction

Previous authors have concluded that hospitalisation costs accounts for a large portion of the overall direct medical costs associated with TBI. The direct and indirect cost increases with TBI severity (Access Economics, 2009; Brener, Harman, Kelleher, & Yeates, 2004; Davis et al., 2007; Grabow, Offord, & Rieder, 1984; Tilford et al., 2005), with estimates including CAN$32,132 (per person) for patients hospitalised with a brain injury in Canada (Chen et al., 2012). The investigators also provided evidence of an overall annual medical cost for all patients hospitalised with TBI of approximately CAN$120·7 million. Other international estimates of average hospitalisation charges for TBI include US$21,160, US$25,271 for mild and moderate TBI and US$57,637 for severe TBI (Farhad et al., 2013) in the US, and £15,462 per person per hospitalised patient in the UK (Morris, Ridley, Lecky, Munro, & Christensen, 2008).

A limitation of previous studies is that these have been focused primarily on individuals who were hospitalised for their TBI (McGregor & Pentland, 1997). These patients tend to have the most severe injuries and as a result, the costs of non-hospitalised TBI were not considered. Given that mild TBI (as measured by Glasgow Coma Scale ≥ 13) constitutes 95% of all cases, this omission might tend to overstate the average cost per individual but understate the total societal cost of TBI. A further limitation of previous studies is the lack of focus on the other, non-hospitalisation costs TBI places. This is in part because accurate population level data about resource use and the health impact of TBI is scarce. The aim of this chapter is to utilise brain injury data from the population-based BIONIC study in combination with electronic hospital records, official death records, and self-reported health service usage to estimate the societal cost of TBI in one year and the lifetime direct and indirect costs of TBI for NZ in 2010 projected to 2020.

## Chapter objectives

1. From a societal perspective, what are the one-year and lifetime direct and indirect costs of all TBI by severity in NZ in 2010?
2. What are the projected societal costs of all TBI in NZ in 2020?
3. What are the predictors of high immediate (hospitalisation) and long-term (one-year community health service utilisation) costs for persons with TBI?

4. What are the first-year direct costs of all TBI by age, gender and ethnicity, area of residence and cause of injury in NZ in 2010?

## Methods

The primary outcome was the cost of health care services and loss of productivity associated with having a TBI.

### Estimating TBI incidence and prevalence in New Zealand

NZ has a public health system that is available to all, accounting for over 95% of all expenditure on inpatient and outpatient care. In addition, home support services post-TBI (including home help and personal care) are funded by the public health system (including an accident compensation scheme). These publicly funded expenditures can be linked to the TBI survivor via a unique identifier (the National Health Index, (NHI)) that accompanies each reimbursement to health providers. The NHI is also used to record other medical events and treatments and death following TBI. Identifying the burden of TBI requires consideration of factors such as the age and sex structure of the general population, and the treatment and health care services used by the general public. Incidence or first-ever events from the BIONIC study were combined with NZ national population estimates to provide the number of first-ever cases of TBI for NZ in 2010.

The BIONIC study used multiple overlapping sources of information to capture all new TBI cases (fatal and non-fatal, hospitalised and non-hospitalised) across all age groups and the TBI severity spectrum (mild, moderate, severe) in urban and rural residents of Hamilton and Waikato districts (population approximately 170,000) from 1 March 2010 to 28 February 2011. During the course of the study a total TBI incidence of 790 cases (95% CI 749-832) per 100,000 person-years was identified; incidence per 100,000 person-years of mild TBI was 749 cases (95% CI 709–790) and of moderate to severe TBI was 41 cases (95% CI 31–51). All TBI cases consenting to participate in the study (n=725; 53%) were followed-up over 12 months following injury. Further details of the methodology, diagnostic criteria and main incidence results of the study have been reported elsewhere (Feigin et al., 2013; Theadom et al., 2012). Where possible all surviving participants were interviewed at baseline, one, six and twelve months post injury. TBI severity was defined using standard definitions (Ponsford et al., 2004; Shores et al., 1986; Teasdale & Jennett, 1974). Mild TBI was defined as Glasgow Coma Scale (GCS) 13-15 and/or post-traumatic amnesia (PTA) (Ponsford et al., 2004; Servadei, Teasale, & Merry, 2001) <24 hours; moderate TBI as GCS 9-12 and/or PTA one-six days; and severe TBI as GCS 8 or less and/or PTA seven or more days. If GCS and PTA severities differed, the more severe category was assigned. If no information on PTA was available, severity was based on the GCS score alone. All confirmed cases of TBI where a GCS score was not recorded were classified as mild.

The information collected at baseline included demographics, medical history and place of residence prior to TBI. Information at one month documented initial acute treatment. At six and twelve months participants' use of outpatient, rehabilitation and home care services, and health status were recorded. For those recruited to BIONIC, information on emergency department presentations and hospital admissions was obtained from the National Minimum Dataset (NMDS), NZ Ministry of Health (data received on 29/10/2012). The NMDS includes all presentations and admissions to public or private

hospitals in NZ and are linked to the individual via their NHI number (Ministry of Health, 2010a). Only information for services funded in whole or part by district health boards and the Accident Compensation Corporation (ACC), a no-fault personal accident insurance cover (health funders in NZ), was available. Unit cost and prices for outpatient services used were obtained from ACC.

Prevalence was modelled (Dismod II, 2013) from data on incidence, remission and mortality using multi-state life table methods (Barendregt et al., 2003; Barendregt & Ott, 2005). Compared to the total NZ population census (base 2006) information, the Hamilton and Waikato populations have demographic and social characteristics that are reflective of NZ with the exception of having a slightly lower representation of Pacific peoples. TBI incidence and prevalence were estimated for NZ in the reference year and then projected to 2020, assuming similar trends in TBI prevalence to that estimated for 2010.

### Data management

A quality check on completed health resource use data forms was undertaken by the candidate (N=725; 53% of completed cases), post-data lock. Every tenth case report form (BIONIC questionnaire) was audited by comparing the data forms with the original database for keying errors. As with many studies it is hoped that the level of missing data is kept to a minimum; in some cases it will not be possible to avoid. The main analysis was conducted on non-missing data (i.e. complete case analysis).

Data preparation involved the following steps:

- Identification of relevant clinical measures and health service use variables for estimating the cost of TBI from the BIONIC database.
- Resource use data collected at baseline, one, six and twelve months were extracted into a separate file. Costs were calculated using unit costs from Waikato District Health Board's costing system. Costs per unit service were interpolated between follow-up points using a moving average.
- Extraction of data for index hospitalisation and hospital readmission from the NMDS (Ministry of Health, 2010a), removal of duplicates and selection only of the inpatient information relating primarily to having a TBI.
- Matching participant occupation information identified from the BIONIC database to average income by occupation (ANZCO) from Statistics New Zealand (Statistics New Zealand, 2010a, 2013)
- Merging of all data onto a single line by participant ID.

### Health care resource usage questionnaire

The questionnaire was designed to capture and measure health care use, out of pocket costs related to TBI as well as home aids and equipment over the 12 month follow up period. The questionnaire covers relevant aspects of health and productivity, including TBI related absence from work. Questions were developed based on existing design and recommendations from large incidence studies undertaken over three decades within the wider Auckland region for stroke (Anderson et al., 2005; Bonita et al., 1993; Feigin et al., 2003; Krishnamurthi et al., 2014) with inputs from a multidisciplinary and multi-instutional team including health economists, health services researchers, psychologists rehabilitation consultants

and neurologists. Resource use and TBI related absence from work were assessed at one, six and twelve months follow up points. Each consented participant were asked to recall their frequency of visits to health care professionals (i.e., general practioners, medical specialists, allied health professionals) and any community services (i.e., home help) within the last month of being assessed. The participants were also asked to identify who paid for each service they visited (i.e., out of pocket, health insurance, DHB or ACC). Resources were valued according to funding source. Participants were asked to state the quantity of hours work performed compared to regular work hours in order to asses productivity loss.

### Cost-of-Illness model

An incidence-based, COI model (bottom-up approach) was developed to estimate the economic cost of TBI in NZ. Average costs per case for the first year following TBI and the lifetime direct and indirect costs were calculated.

### Costs

The types and unit costs of each health service are shown in *appendix eight***.** The cost analysis included direct health care costs (e.g. hospitalisations and outpatient rehabilitation services), indirect costs (e.g. productivity loss for persons with TBI) and out-of-pocket expenses (e.g. aids and home modification). Costs are presented in New Zealand dollars, 2010 value.

*Hospital inpatient and outpatient costs* – There were two steps involved with identifying the cost of hospitalisation. First we identified those admissions primarily due to a TBI, second the average cost of hospitalisations relating to TBI (costs relating to other conditions were not included) was estimated by multiplying the percentage of individuals hospitalised for TBI times the average cost per person hospitalised. TBI hospitalisations were confirmed by ICD-10 codes (i.e. S02.1, S02.7, S02.9, S06.0-S06.9 and S07.1). For the purpose of data extraction from the National Minimum Dataset and ACC's claims data, the Classification of Disease 10th revision codes (ICD 10) is used. Specific ICD 10 codes are listed in Table 15.

*Table 15: Specific International Classification of Disease codes relating to brain injuries*

| Description | ICD-10 |
|---|---|
| Open wound of the head | S01.0-S01.9 |
| Fracture of the skull and facial bones | S02.0, **S02.1**, S02.3, **S02.7**, S02.8, **S02.9** |
| Injury to optic nerve and pathways | S04.0 |
| Intracranial injury | **S06.0-S06.9** |
| Crushing injury of head | S07.0, **S07.1**, S07.8, S07.9 |
| Other unspecified injuries of head | S09.7-S09.9 |
| Open wounds involving head with neck | T01.0 |
| Fractures involving head with neck | T02.0 |
| Crushing injuries involving head with neck | T04.0 |
| Injuries of brain and cranial nerves with injuries of nerves and spinal cord at neck level | T06.0 |
| Sequelae of injuries of head | T90.1, T90.2, T90.4, T90.5, T90.8, T90.9 |

*Note: Codes in **bold** are most relevant in the context of strictly brain injuries

The cost was taken from assessed hospital charges. Hospitalisation costs were determined using weighted discharge value known as the Weighted Inlier Equivalent Separations (WIES) for all National Minimum Dataset events by the Ministry of Health (Ministry of Health, 2010a). The national price for financial year 2010/2011 per WIES was NZ$4,410.38 (Ministry of Health, 2010b). The public-hospital-based inpatient (including medical and surgical) units of NZ$4,410.38 will be multiplied by inpatient service case weight to obtain the cost of inpatient services. As the hospital services are provided by the publicly owned district health boards (DHBs) (not patient charges) the costs are internal weighted estimates (based on Disease-Related Groups and length of stay) of the cost of each type of care. WIES cost weight includes medical costs, ward stay, medication, laboratory tests, diagnostic imaging, and nursing and other ward staff.

*Community and home support* – Although most formal care for home support services is funded by the state, most providers contract with the government to provide the bulk of services. As a result, no accurate information exists regarding the individual charges for TBI-related community and home support. To estimate the cost of these services, a resource-based costing approach was used where a common price was applied to each resource (e.g. cost per hour per therapist).

Number of visits to therapists (i.e. visiting nurses, physiotherapists, medical specialists, occupational therapists, speech therapists, general practitioners, counsellors, psychologists and social workers) over the month prior to each of the BIONIC assessments (i.e. one, six and twelve months post TBI) were assessed via patient and significant other questionnaires. The cost of therapy visits were estimated by multiplying visit numbers by the resource unit cost. Similarly, the hours of home support (home help

and personal care) were estimated using BIONIC follow-up questionnaire data with the cost estimated by multiplying the number of reported hours provided by the current cost of care for the service (in NZ$, 2010). Thirdly, the cost of basic maintenance and home modification support resulting from TBI was estimated by combining the information provided from the patient, family or caregiver survey responses with current market prices.

Direct costs included hospitalisation and emergency department visits, regardless of whether or not they resulted in an admission, and the number of therapy visits provided to individuals living at home included home help and personal care services. All categories were summed together to estimate average cost per case. National incidence costs were estimated by multiplying the average cost per case by the national TBI incidence (based on the incidence of TBI calculated from the BIONIC study). The proportion of prevalent (including those who were still symptomatic at 12 months post TBI) TBI cases having a disability at 12 months follow up were estimated and combined with total NZ incidence cases to estimate national prevalence costs. TBI cases with no disability (at 12 months follow up) were assumed to have no on-going costs.

### Lifetime direct costs associated with TBI

At each follow up BIONIC participants were questioned about direct medical resources used relating to their TBI. At 12 months post TBI, the proportion of participants identified as having a moderate to severe disability (as measured by the Glasgow Outcome Score (GOS) (Jennett & Bond, 1975)) was sourced from the BIONIC dataset and used to determine the probability of needing on-going health resources (i.e. post 12 months). GOS describes the degree of recovery and prediction of long-term disability (Jennett & Bond, 1975). If an individual with either mild or moderate severe TBI had residual disability (moderate or severe) at 12 months, this was assumed to persist for a lifetime. A weighted average cost for adults and children identified as having a moderate to severe TBI was then calculated (i.e. average direct cost per case x probability of having a moderate/severe disability). The discounted lifetime health care costs (see statistical analysis section) occurring in each year were then summed together with the first year costs.

### Productivity loss

First, production losses within 12 months of injury were estimated only for a friction period after the loss of paid work (Koopmanschap & Martin Van Ineveld, 1992; Koopmanschap & Rutten, 1993). A friction-cost approach assumes individuals who die or leave the workforce due to disability (for instance from TBI) will be replaced after a specific time period, resulting in short-term productivity loss (Koopmanschap & Martin Van Ineveld, 1992). Following similar methods in (Cadilhac et al., 2011) three months was used as the friction period. Secondly, in an attempt to estimate long-term productivity loss, at 12 months follow up the proportion of participants reporting a decrease in their income was identified. The value of time lost from employment or productive activity (indirect costs) up to the age of 65 years was estimated both for adults in the paid workforce and for adults in unpaid productive activity before injury. Costs of productivity were estimated using reported loss of income from BIONIC case record forms combined with Statistics NZ data on average weekly earnings linked to occupation for those who were in the paid workforce (Statistics New Zealand, 2010a). Long-term loss of production

cost methods are presented in *appendix nine*. Due to lack of accurate information, cost of informal care (including care for childhood TBI) or compensation was not included in the analysis.

### Statistical analysis

SPSS statistics version 20 (IBM SPSS Statistics) and Microsoft Excel 2010 (Microsoft Corporation 2010) were used to analyse data for this study. The results are presented from the perspective of the society in terms of direct and indirect costs for incident and prevalent TBI cases (per person and total for NZ) for a given year and overall (lifetime cost). Descriptive analyses, including means and 95% confidence intervals [CI] using bootstrapping methods, were used to determine the economic profile of TBI in NZ (by levels of severity). We calculated average per person costs for TBI overall and by TBI severity (mild and moderate to severe). Ethnicity was self-identified and was extracted from the BIONIC dataset. Prioritised ethnic origin in accordance with the New Zealand 2006 census was used to obtain a single ethnicity. Participants were groups as European, Maori, Pacific, Asian or Other. We combined the moderate and severe categories because of the small number of cases in these groups. Significance of differences between the costs of mild TBI and moderate/severe TBI were tested using t-tests and Wilcoxon rank sum tests. The level of significance was set at $P<0.05$ (2-sided).

### Sensitivity analysis

Multivariate probabilistic uncertainty analyses including a 5000 replications Monte Carlo simulation were undertaken using @Risk software version 6 (Palisade Corporation 2013) to estimate a mean and 95% uncertainty interval for the outcome parameters. Calculation of sensitivity analysis used gamma distributions for costs estimates. A discount rate of 3.5% was used for lifetime cost projections as recommended by the NZ Treasury (New Zealand Treasury, 2005; Wren & Barrell, 2010) and PHARMAC (an organisation that manages all hospital medicines and vaccines funded by NZ Government) (PHARMAC, 2007). Further, one-way sensitivity analysis was conducted to test net present value for lifetime cost projections by varying the discount rate between 0% and 6% for projected costs.

## Results

### Demographic information

A summary of the participants' characteristics is shown in Table 16. Of the 725 TBI participants, the average age at time of injury is 25.9 years (25.7 years for mild and 32.2 years for moderate severe), mostly male (60.6%) and residing in the urban centre (74.6%). The majority of the participants are of European descent (70.3%) compared to other ethnic groups while 47% are classified with an area deprivation of decile 8 or higher. While most TBI were identified through hospital sources 29.6% were identified in the community.

*Table 16: Overview of incidence and prevalence of TBI in the BIONIC study*

| | Mild TBI n=691 | | Moderate/severe TBI n=34 | | Total n=725 | |
|---|---|---|---|---|---|---|
| | n | (%) | n | (%) | n | (%) |
| **Mean age in years (SD)** | 25.7 | 20.3 | 32.2 | 23.2 | 25.9 | 20.5 |
| **Median age in years (IQR)** | 20 | 10-39 | 26.5 | 17-55 | 20 | 11-39 |
| **Male** | 412 | 59.6% | 27 | 79.4% | 439 | 60.6% |
| **Urban residency** | 519 | 75.1% | 22 | 64.7% | 541 | 74.6% |
| **ACC claim** | 615 | 89.0% | 31 | 91.2% | 646 | 89.1% |
| **NZDep ≥ 8** | 324 | 46.9% | 17 | 50.0% | 341 | 47.0% |
| **Ethnic origin** | | | | | | |
| European | 418 | 60.5% | 20 | 58.8% | 438 | 60.4% |
| Maori | 230 | 33.3% | 11 | 32.4% | 241 | 33.2% |
| Pacific | 23 | 3.3% | 2 | 5.9% | 25 | 3.4% |
| Asian | 18 | 2.6% | 1 | 2.9% | 19 | 2.6% |
| Other | 2 | 0.3% | | | 2 | 0.3% |
| **Site of case detection** | | | | | | |
| Hospital* | 479 | 69.3% | 31 | 91.2% | 510 | 70.3% |
| Family doctor | 125 | 18.1% | | | 125 | 17.2% |
| Other | 87 | 12.6% | 3 | 8.8% | 90 | 12.4% |
| **History of TBI** | 284 | 41.1% | 13 | 38.2% | 297 | 41.0% |
| **Cause of TBI** | | | | | | |
| Transport accident | 126 | 18.2% | 12 | 35.3% | 138 | 19.0% |
| Fall | 282 | 40.8% | 11 | 32.4% | 293 | 40.4% |
| Exposure to mechanical force | 144 | 20.8% | 2 | 5.9% | 146 | 20.1% |
| Assault | 119 | 17.2% | 7 | 20.6% | 126 | 17.4% |
| Other | 7 | 1.0% | 2 | 5.9% | 9 | 1.2% |
| Unknown (not specified) | 13 | 1.9% | | | 13 | 1.8% |

* through emergency department, does not indicate hospital admission

In 2010, 11,301 first-ever TBI cases are estimated to have occurred in NZ, 57% of which are among males. The majority (75%) are aged less than 35 years. Taken together the total number of TBI patients in NZ (including prevalent cases) is estimated to be 527,388. In the year 2020, the number of first-ever cases is estimated to increase to 13,591 and the number of prevalent cases (period prevalence) is also expected to increase to 641,104 cases (see Table 17) (refer to chapter three). The increase in incidence and prevalence are due to increases in population.

*Table 17: Incidence and prevalence of traumatic brain injury in New Zealand in 2010 projected to 2020 (modelled estimates from the BIONIC study)*

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| | Current Burden (2010) | | Projected Burden (2020) | |
|---|---|---|---|---|
| | **Incidence** | **Prevalence** | **Incidence** | **Prevalence** |
| **Male** | 6,488 | 291,146 | 7,734 | 352,701 |
| **Female** | 4,813 | 236,242 | 5,857 | 288,403 |
| **Total** | 11,301 | 527,388 | 13,591 | 641,104 |

## What are the first-year and lifetime direct and indirect costs of all TBI by severity in NZ in 2010?

### Average first-year per person cost of TBI in New Zealand

A detailed breakdown of 12-month follow-up resources used and average per-person costs are presented in Table 18. Of the 725 cases, about 64% were not initially hospitalised for their TBI. Of those who were hospitalised, survivors spent on average 2·6 days (min 0 days, max 61 days) in hospital. After discharge most of the patients used general practitioner services (36% [263]), allied health services (18% [133]) and specialised medical care (14% [105]) at follow up. Total direct health care costs over 12 months per-patient amount to NZ$5,637 (min NZ$38, max NZ$167,052). On average 17% [124] reported having a loss in income due to their injury. Costs attributable to production losses were estimated at NZ$2,980 (min NZ$243, max NZ$19,745), resulting in an average total first year cost of NZ$6,144 per person (95% CI NZ$5,104-NZ$7,413). This amount is reflective of the high proportion of mild TBI (95%) identified in the study cohort and high proportion of cases not needing acute hospitalisation.

*Table 18: Proportion and cost per case for the categories of resource use during the first year – Cost of all traumatic brain injury in New Zealand (modelled estimates from the BIONIC study*

| | Users | Resources per patient (N. of days or N. visits) | Cost per category (NZD) | |
|---|---|---|---|---|
| | % | Mean | Mean | 95% CI[a] |
| **Total (N)** | **725** | | | |
| ***Health care*** | | | | |
| Emergency Department | 42% | | $270 | |
| Initial hospitalisation | 36% | 2.6 | $4,374 | $3,157-$5,800 |
| Hospital readmission | 4% | 6.5 | $7,009 | $3,591-$11,461 |
| Outpatient care | 6% | 6.1 | $2,669 | $1,441-$5,923 |
| Specialised medical care | 14% | 9.6 | $3,476 | $2,579-$4,423 |
| Allied health care | 18% | 21.4 | $6,289 | $5,081-$7,690 |
| General practice | 36% | 9 | $1,421 | $1,244-$1,610 |
| Nursing | 4% | 19.1 | $3,366 | $1,625-$5,907 |
| Radiology | 1% | 3.8 | $3,544 | $795-$7,328 |
| Community services | 3% | | $31,735 | $15,952-$51,866 |
| Out-of-pocket expenses | 4% | | $1,033 | $352-$1,919 |
| Other expenses | 100% | | $215 | $211-$218 |
| **Total direct medical costs per person** | 100% | | **$5,637** | **$4,605-$6,959** |
| ***Non-health care (indirect)*** | | | | |
| Loss in productivity | 17% | | $2,980 | $2,470-$3,553 |
| **Total 1-year costs per person** | 100% | | **$6,144** | **$5,128-$7,446** |
| On-going direct medical costs[b] | 5% | | $25,929 | $9,351-$49,770 |
| Long-term productivity[b] | 3% | | $46,130 | $25,215-$71,185 |
| **Total lifetime cost per person[b]** | 100% | | **$8,824** | **$7,118-$11,709** |

[a]Bootstrap results are based on 1000 bootstrap samples
[b] 3.5% discounting

### Average first-year cost by TBI severity

Table 19 summarises the resources used and average per person cost in survivors who had a mild or a moderate/severe TBI. Six hundred and ninety one cases (95% [691 of 725]) are found to be mild (GCS ≥ 13) and 34 cases are moderate/severe (GCS ≤ 12). A consistent pattern of resource usage is found in the mild cohort. The composition of costs varied over the 12-month follow-up period, with general practice (37% [253 of 691]) and allied health services (17% [119 of 691]) most commonly used. In contrast, a higher percentage of those with moderate/severe TBI (88% [30 of 34]) required initial hospitalisation

(min $869; max $109,317) with an average length of stay 13.3 days. Of those who were hospitalised, 12% [4 of 34] were readmitted. Cost of hospital readmission is significantly greater than for those whose injuries were mild (Wilcoxon rank sum Z=-2·191, P=0.028). After discharge allied health services (41% [14 of 34]), general practitioner (32% [11 of 34]) and specialised medical care (29% [10 of 34]) are the most commonly utilised services, with 12% [4 of 34] having some community home care support. One year cost per case for mild (95% of all cases) and moderate/severe TBI are NZ$5,058 (95% CI NZ$4,142-NZ$5,867) and NZ$31,854 (95% CI NZ$16,114-NZ$47,377), respectively. Due to the higher cost of hospitalisation, the one year cost of moderate/severe TBI is significantly higher than that for mild TBI (Wilcoxon rank sum Z=-5·914, p≤0.0001). The total cost of treating all mild TBI cases over a one year period is three times that of all moderate/severe TBI cases.

*Table 19: Cost of traumatic brain injury in New Zealand by severity (modelled estimates from the BIONIC study)*

| | Mild TBI (GCS ≥13) | | | Moderate/Severe TBI (GCS ≤ 12) | | |
|---|---|---|---|---|---|---|
| | **% of all mild** | **Mean** | **95% CI[a]** | **% of all severe** | **Mean** | **95% CI[a]** |
| **Total (N)** | **691** | | | **34** | | |
| ***Health care*** | | | | | | |
| Emergency Department | 41% | $270 | | 44% | $270 | |
| Initial hospitalisation | 34% | $2,813 | $2,160-$3,567 | 88% | $16,500 | $7,418-$27,033 |
| Hospital readmission | 3% | $5,623 | $2,198-$10,661 | 12% | $14,285 | $8,023-$18,089 |
| Outpatient care | 6% | $1,590 | $786-$2,360 | 15% | $11,300 | $696-$31,672 |
| Specialised medical care | 14% | $3,358 | $2,382-$4,821 | 29% | $4,604 | $1,689-$9,105 |
| Allied health care | 17% | $5,869 | $4,751-$7,358 | 41% | $9,854 | $4,188-$16,661 |
| General practice | 37% | $1,430 | $1,255-$1,677 | 32% | $1,214 | $696-$1,912 |
| Nursing | 4% | $2,306 | $1,235-$3,717 | 12% | $9,988 | $1,051-$26,212 |
| Radiology | 1% | $1,866 | $540-$3,218 | 3% | $10,256 | * |
| Community services | 3% | $29,642 | $13,608-$53,209 | 12% | $42,197 | $2,785-$106,023 |
| Out of pocket expenses | 4% | $1,137 | $345-$2,144 | 15% | $489 | $310-$675 |
| Other expense | 100% | $214 | $210-$218 | 100% | $226 | $225-$228 |
| **Total Direct medical costs per person** | **100%** | **$4,588** | **$3,753-$5,466** | **100%** | **$30,681** | **$16,994-$47,683** |
| ***Non health care (indirect)*** | | | | | | |
| loss in productivity | 16% | $2,940 | $2,371-$3,574 | 35% | $3,352 | $1,767-$5389 |
| **Total 1-year costs per person** | **100%** | **$5,058** | **$4,176-$5,991** | **100%** | **$31,854** | **$17,816- $46,942** |
| On-going direct medical costs[b] | 4% | $9,634 | $5,629-$15,568 | 27% | $80,246 | $14,847-$190,691 |
| Long-term productivity loss[b]- | 3% | $48,802 | $27,630-$75,086 | 6% | $18,080 | -$146,083-$182,242** |
| **Total lifetime cost per person[b]** | 100% | **$6,908** | **$5,597-$8,286** | 100% | **$54,605** | **$24,359-$97,371** |

[a] Bootstrap results are based on 1000 bootstrap samples

[b] 3.5% discounting

*Sample size in this group was too small to estimate 95 CI

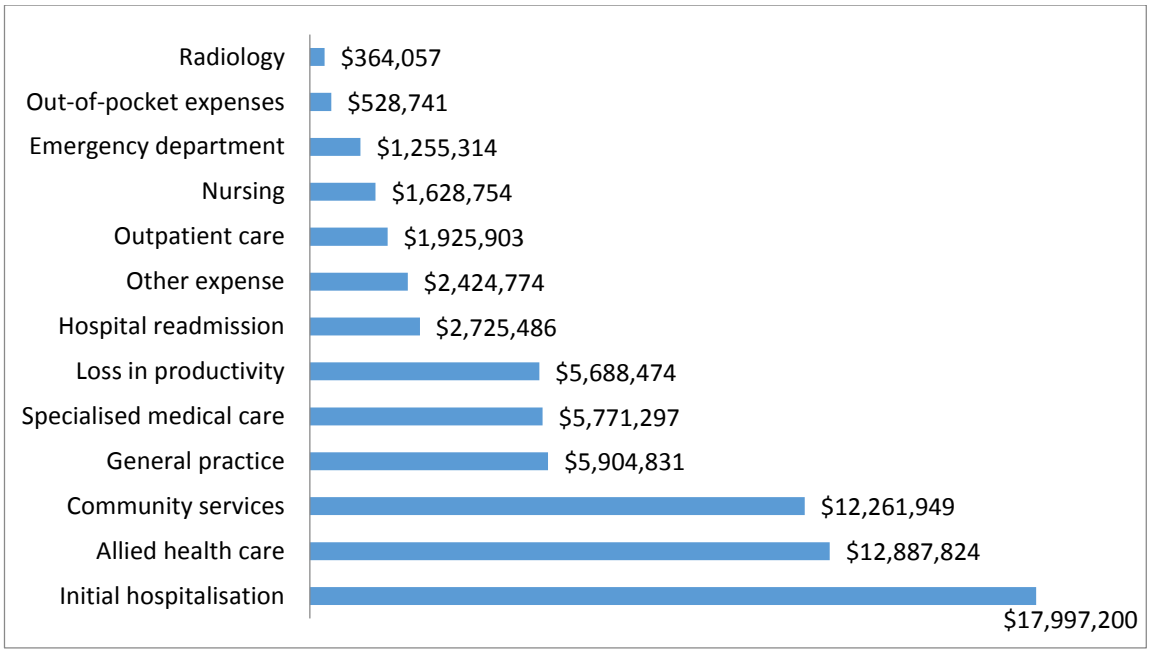
**Some or all bootstrap sample results are missing, so no bootstrap estimation has been performed for this item

## What are the projected societal costs of all TBI in NZ in 2020?

### Total first-year incidence and prevalence costs in 2010 projected to 2020

Details for the main cost drivers during the first year for all TBI are provided in figure 8. The results suggest, that in the first year hospitalisation (29%) accounts for the largest costs in all patients (NZ$20·7 million). Followed by (21%) outpatient rehabilitation (NZ$14.8 million), (17%) community services (NZ$12.3 million) and the value of indirect costs (loss of productivity), which are estimated to be NZ$5.7 million.

*Figure 8: Annual cost according to cost category for traumatic brain injury NZ$*




When applied to all TBI survivors in NZ (Table 20) the total first-year costs of all new cases of TBI that occurred in NZ during 2010 are estimated to be NZ$71 million (95% CI NZ$53.2 million-NZ$88.3 million). Using a prevalence-based approach, the total cost for all TBI equates to NZ$151 million (95% CI NZ$112.9 million-NZ$186.5 million). While assuming similar trends in TBI incidence to those estimated for the reference year, the prevalence cost of TBI is expected to increase by 21% to over NZ$182.7 million (95% CI NZ$136.6 million-NZ$225.5 million) in 2020. Source of healthcare funder distribution in the first year for TBI is illustrated in figure 9. The majority of health care resources are funded by ACC (43%) followed by personal out-of-pocket payments (31%), and 23% are funded by the DHB. It is interesting to note, that a fairly large proportion of healthcare services is financially covered by the individual, most likely due to co-payments for service.

*Figure 9: Healthcare funder distribution in the first year*

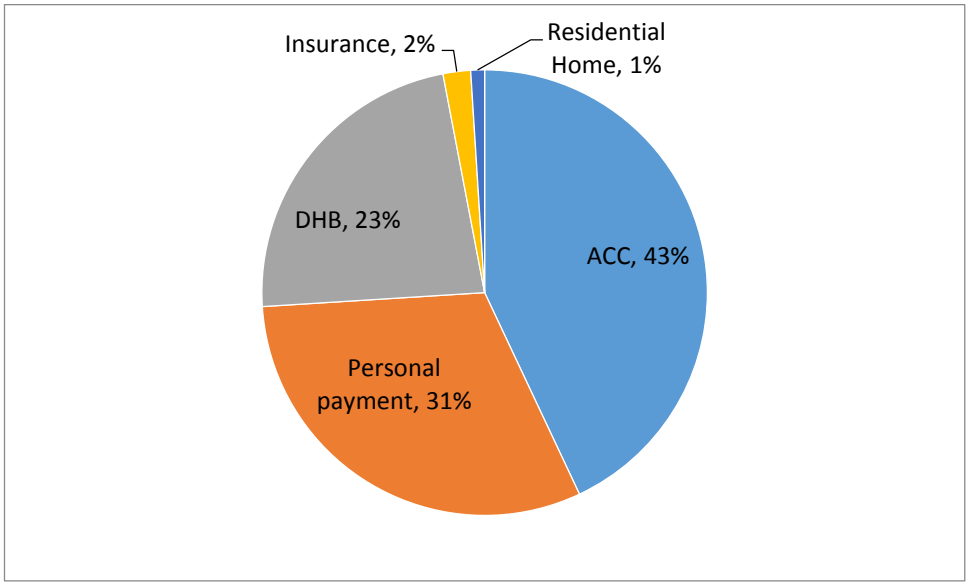



*Table 20: Current and future burden of traumatic brain injury*

| Cost estimates for New Zealand | Current Burden 2010 | Projected Burden 2020 |
|---|---|---|
| **Incidence (First-ever TBI)** | | |
| One-year direct healthcare cost | $65,676,129 | $78,189,847 |
| One-year indirect cost | $5,688,474 | $6,819,650 |
| One-year total cost | $71,364,604 | $85,009,497 |
| Lifetime cost | $103,342,853 | $122,831,743 |
| | | |
| **Prevalence** | | |
| One-year direct healthcare cost | $138,948,741 | $168,045,754 |
| One-year indirect cost | $12,118,102 | $14,655,733 |
| One-year total cost | $151,066,843 | $182,701,487 |
| Lifetime cost | $218,284,240 | $263,994,762 |

Estimated lifetime costs per person

Estimated on-going direct health care and long-term loss of productivity costs of first TBI having occurred in 2010 are outlined in Tables 18 and 19. A total average lifetime cost per case is estimated to be NZ$8824 (95% CI NZ$6,861-NZ$11,374). Estimated lifetime costs for mild and moderate/severe TBI is NZ$6,908 (95% CI NZ$5,538-NZ$8,274) and NZ$54,605 (95% CI NZ$16,123-NZ$91,979) respectively. The results suggest that the average lifetime cost of a mild TBI is significantly lower (i.e. less than 15%) than that of the cost of moderate/severe cases. However, given the distribution of TBI by severity levels (95%

mild TBI, 5% moderate/severe TBI), the overall average lifetime cost of all mild TBI patients in NZ in 2010 (10,771 x NZ$6,908) is nearly three times greater than the overall average lifetime cost of all moderate/severe TBI patients (530 x NZ$54,605). The total lifetime cost of all incident and prevalent TBI cases in NZ is NZ$218 million (95% CI NZ$145·2 million - NZ$290·1 million) in 2010 (see Table 19).

### Sensitivity and uncertainty analyses

Following the sensitivity and uncertainty analyses, the total lifetime cost of TBI in NZ (of first TBI occurring in 2010) may range between NZ$86 million and NZ$119.9 million (Table 21). The average lifetime cost per person is NZ$8,018 (95% uncertainty interval NZ$7,914, NZ$8,173), ranging from NZ$7,312 (95% uncertainty interval NZ$7,195, NZ$7,490) for mild and moderate severe cases equating to NZ$59,276 (95% uncertainty interval NZ$58,087, NZ$60,832). When projected lifetime costs are not discounted, estimated future costs are up to 19% greater. The present value of future average costs per person with a 6% discount rate is NZ$6,283 for mild TBI and NZ$44,825 for moderate/severe (Table 22). Overall the probabilistic sensitivity analysis suggests that the results are robust to different sources of uncertainty.

*Table 21: Results of uncertainty analyses on cost estimates (New Zealand $2010).*

| | Modelled Point Estimates* | | 95% Uncertainty Interval* | |
|---|---|---|---|---|
| | **Mean** | **Median** | **Lower bound** | **Higher bound** |
| **All TBI** | | | | |
| **No. of TBI** | 11301 | 11300 | 9442 | 13158 |
| First-year direct costs | $64,973,164 | $64,971,438 | $54,285,642 | $75,651,752 |
| First-year indirect costs† | $6,869,778 | $6,718,963 | $5,401,787 | $8,819,652 |
| Total first-year costs | $71,842,942 | $70,730,873 | $59,097,806 | $82,357,877 |
| Lifetime direct costs‡ | $64,974,133 | $64,973,047 | $54,276,258 | $75,657,372 |
| Lifetime indirect costs‡ | $25,633,758 | $25,286,971 | $20,450,068 | $31,877,900 |
| Total lifetime costs‡ | $90,607,891 | $103,030,594 | $86,068,611 | $119,974,589 |
| Total first year/incident TBI (cost per case) | $6,367 | $6,344 | $6,321 | $6,420 |
| Total lifetime costs/incident TBI (cost per case) | $8,018 | $7,988 | $7,914 | $8,173 |
| | | | | |
| **Mild TBI** | | | | |
| **No. of TBI** | 10796 | 10794 | 9020 | 12570 |
| First-year direct costs | $48,888,119 | $48,887,078 | $40,843,921 | $56,925,157 |
| First-year indirect costs† | $6,094,479 | $5,989,172 | $4,762,210 | $7,794,217 |
| Total first year costs | $54,982,598 | $54,031,188 | $45,141,884 | $62,915,324 |
| Lifetime direct costs‡ | $53,881,887 | $53,852,098 | $44,909,447 | $62,866,748 |
| Lifetime indirect costs‡ | $25,062,178 | $24,788,522 | $19,985,264 | $31,281,358 |
| Total lifetime costs‡ | $78,944,065 | $74,556,971 | $62,288,540 | $86,812,757 |
| Total first-year/incident TBI (cost per case) | $5,093 | $5,084 | $5,056 | $5,149 |
| Total lifetime costs/incident TBI (cost per case) | $7,312 | $7,286 | $7,195 | $7,490 |

| | | | | |
|---|---|---|---|---|
| **Moderate-Severe TBI** | | | | |
| **No. of TBI** | 505 | 504 | 422 | 588 |
| First-year direct costs | $15,434,197 | $15,433,963 | $12,895,058 | $17,971,507 |
| First-year indirect costs† | $710,865 | $697,453 | $555,582 | $911,596 |
| Total first-year costs | $16,145,062 | $16,031,318 | $13,394,136 | $18,667,132 |
| Lifetime direct costs‡ | $28,566,025 | $28,413,134 | $23,414,723 | $34,088,895 |
| Lifetime indirect costs‡ | $1,368,264 | $1,355,590 | $1,097,985 | $1,680,123 |
| Total lifetime costs‡ | $29,934,289 | $27,294,997 | $22,803,993 | $31,782,435 |
| Total first year/incident TBI (cost per case) | $31,970 | $32,007 | $31,874 | $32,114 |
| Total lifetime costs/incident TBI (cost per case) | $59,276 | $59,065 | $58,087 | $60,832 |
| | | | | |
| * 5000 simulations; † friction cost approach; ‡3.5% discount rate used | | | | |

*Table 22: Sensitivity analysis varying discount rates for projected costs*

| Scenario | Cost/case in first years, NZ$ | Cost/case over lifetime, NZ$ |
|---|---|---|
| **All TBI** | | |
| Base case (3.5%) | $6,144 | $8,824 |
| 0% discount rate | $6,144 | $9,881 |
| 6% discount rate | $6,144 | $,7831 |
| **Mild TBI** | | |
| Base case (3.5%) | $5,058 | $6,908 |
| 0% discount rate | $5,058 | $7,585 |
| 6% discount rate | $5,058 | $6,283 |
| **Moderate Severe TBI** | | |
| Base case (3.5%) | $31,854 | $54,605 |
| 0% discount rate | $31,854 | $64,721 |
| 6% discount rate | $31,854 | $44,825 |

## What are the predictors of high immediate (hospitalisation) and long-term (one-year community health service utilisation) direct costs for persons with TBI?

### Methods

Multiple linear regression analyses were performed to determine predictors of costs incurred by TBI patients during the first-year follow up, for direct healthcare costs. The following predictors were used: socio-demographic conditions (age: young age (<34 years) vs older age), gender, ethnicity and living condition (living alone vs living with family), residency (urban or rural), socio-economic status (i.e. income and NZDEP), comorbidities, functional outcomes according to Glasgow Coma Scale (at baseline) and disability (GOS). All possible predictors with significance ($p<0.05$) of the coefficients generated by stepwise procedure were reported. Due to non-normal distribution of cost data all costs were logarithmically transformed to run the regression models.

*Table 23: Predictors of high direct costs*

| Independent variable | B | SE | Sig. |
|---|---|---|---|
| Disability | 0.913 | 0.169 | 0.00 |
| Young age | -0.713 | 0.145 | 0.00 |
| Severity of injury | 1.629 | 0.279 | 0.00 |
| comorbidity | 0.28 | 0.129 | 0.03 |
| (Constant) | 7.388 | 0.154 | 0.00 |
| | | | |
| $R^2$ | 0.18 | | |
| n | 725 | | |

**Dependent variable: log of direct costs**

Table 23 shows the results from the regression analysis. When the log of direct costs was predicted it is found that disability (beta=0.913, p<0.01), young age (beta=-0.713, p<0.01), TBI severity (beta=1.629, p< 0.01) and comorbidity (beta=0.28. p<0.05) are significantly associated with direct medical costs. The overall model fit is R2=0.18.

## What are the first year direct costs of all TBI by age, gender, ethnicity, area of residence and cause of injury in NZ in 2010?

The results do not record any statistically significant difference in the direct cost for TBI by sex, area of residence (rural vs urban) and ethnicity. Table 24 shows direct cost per person for TBI by sex, age and severity of injury. Our results suggest that age-specific cost begins to increase at the age of 35 years and continues to increase with age. Although there are no significant differences by sex, males report having slightly higher costs than females (total direct cost for males NZ$6,201 vs total direct costs for females NZ$5,056). There are high peaks in age-specific costs among the over 65 years age groups, which could reflect older peoples experience with trauma and better access and co-ordination to services provided by the DHB. Similar trends are observed for per-person direct cost by residency (see Table 25). The results suggest that rural populations require more health care resource for their injury while urban populations spend a lot less on direct costs. Figure 10 illustrates direct costs of TBI by ethnicity (Maori vs Non-Maori). While there is a NZ$1,216 (NZ$5,864-NZ$4,648) difference in cost between Maori females and Non-Maori females, direct costs by ethnicity are similar indicating no evidence of differential access to health care services. Direct costs by cause of injury are shown in Table 26. Traffic accidents (NZ$9,553) are associated with the highest per person costs followed by falls (NZ$6,320). Per-person costs related to traffic injuries peak in the 15-34 year age group and are highest among rural populations (NZ$17,077).

*Table 24: Direct medical cost of TBI by age, sex and severity of injury*

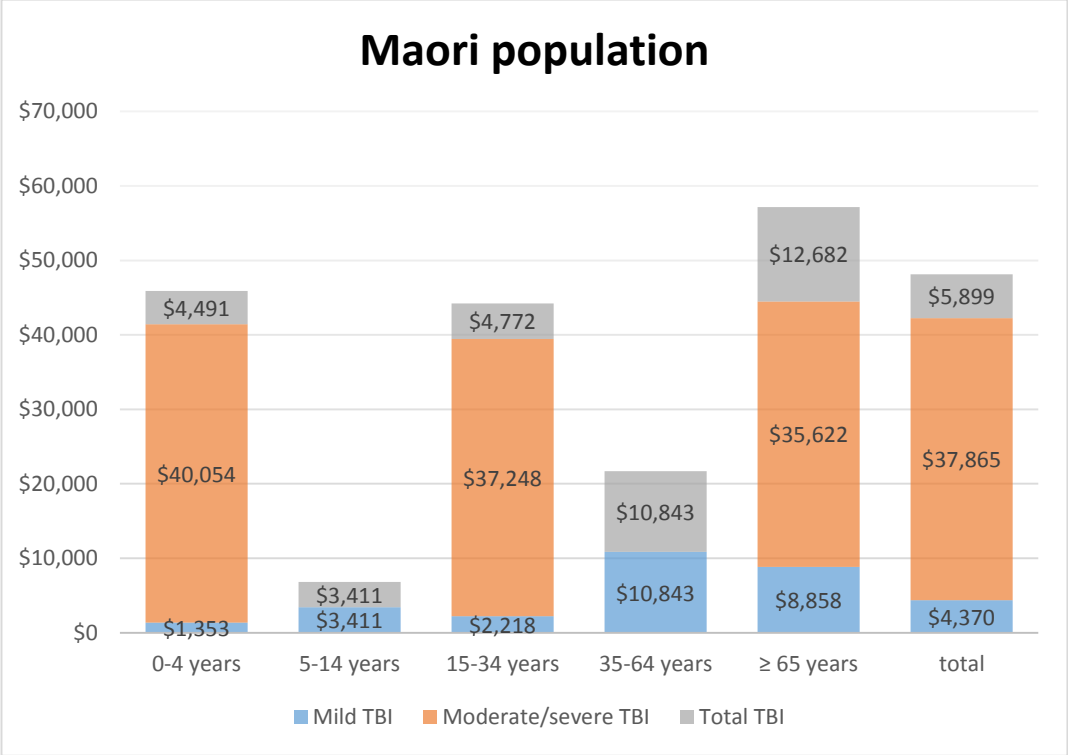
| | Mild TBI | | | Moderate/severe TBI | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** |
| **Males** | | | | | | | | | |
| 0-4 years | 62 | $1,473 | $1,031-$1,916 | 2 | $2,265 | -$12,621-$17,151 | 64 | $1,498 | $1,065-$1,931 |
| 5-14 years | 83 | $2,986 | $1,031-$4,942 | 1 | $84,029 | | 84 | $3,951 | $1,228-$6,674 |
| 15-34 years | 163 | $2,798 | $1,998-$3,597 | 16 | $27,015 | $4,222-$49,808 | 179 | $4,962 | $2,742-$7,182 |
| 35-64 years | 87 | $6,601 | $4,471-$8,732 | 5 | $23,733 | -$2,498-$49,964 | 92 | $7,533 | $5,1778-$9,887 |
| ≥ 65 years | 17 | $29,314 | $7,555-$51,073 | 3 | $71,615 | -$135,759-$278,988 | 20 | $35,659 | $12,343-$58,975 |
| total | 412 | $4,534 | $3,359-$5, 708 | 27 | $31,641 | $13,765-$49,516 | 439 | $6,201 | $4,572-$7,830 |
| **Females** | | | | | | | | | |
| 0-4 years | 38 | $1,770 | $952-$2,589 | 3 | $39,735 | -$123,541-$203,012 | 41 | $4,548 | $1,115-$10,212 |
| 5-14 years | 52 | $1,637 | $1,091-$2,184 | 1 | $1,363 | | 53 | $1,632 | $1,096-$2,168 |
| 15-34 years | 101 | $3,713 | $2,337-$5,089 | 1 | $224 | | 102 | $3,679 | $2,315-$5,043 |
| 35-64 years | 71 | $8,091 | $4,011-$12,171 | 1 | $6,598 | | 72 | $8,070 | $4,049-$12,092 |
| ≥ 65 years | 17 | $9,373 | $4,674-$a4,072 | 1 | $57,437 | | 18 | $12,043 | $4,889-$19,197 |
| total | 279 | $4,521 | $3,306-$5,735 | 7 | $26,404 | -$14,681-$67,489 | 286 | $5,056 | $3,600-$6,512 |
| **Total** | | | | | | | | | |
| 0-4 years | 100 | $1,586 | $1,179-$1,993 | 5 | $24,747 | -$38,346-$87,839 | 105 | $2,689 | $501-$4,878 |
| 5-14 years | 135 | $2,467 | $1,252-$3,682 | 2 | $42,696 | -$482,488-$567,881 | 137 | $3,054 | $1,374-$4,733 |
| 15-34 years | 264 | $3,148 | $2,429-$3,866 | 17 | $25,439 | $3,883-$46,994 | 281 | $4,496 | $3,003-$5,990 |
| 35-64 years | 158 | $7,271 | $5,118-$9,424 | 6 | $20,877 | -$267-$42,022 | 164 | $7,769 | $5,589-$9,948 |
| ≥ 65 years | 34 | $19,344 | $8,248-$30,439 | 4 | $68,070 | -$40,973-$177,114 | 38 | $24,473 | $11,690-$37,255 |
| total | 691 | $4,528 | $3,676-$5,381 | 34 | $30,563 | $15,067-$46,058 | 725 | $5,749 | $4,609-$6,889 |

*Table 25: Direct cost of TBI by residency and injury severity*

| | Mild TBI | | | Moderate/severe TBI | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** |
| **Hamilton (urban)** | | | | | | | | | |
| Males | | | | | | | | | |
| 0-4 years | 49 | $1,526 | $993-$2,058 | 1 | $1,093 | | 50 | $1,517 | $996-$2,039 |
| 5-14 years | 60 | $2,841 | $325-$5,358 | 1 | $84,029 | | 61 | $4,172 | $538-$7, 807 |
| 15-34 years | 127 | $2,630 | $1,826-$3,434 | 8 | $8,607 | $1,898-$15,317 | 135 | $2,984 | $2,132-$3,837 |
| 35-64 years | 58 | $6,404 | $3,673-$9,134 | 4 | $23,411 | -$15,383-$62,205 | 62 | $7,501 | $4,414-$10,588 |
| ≥ 65 years | 13 | $35,384 | $7,093-$63,675 | 3 | $71,615 | -$135,759-$278,988 | 16 | $42,178 | $13,502-$70,853 |
| total | 307 | $4,595 | $3,096-$6,094 | 17 | $27,204 | $5,382-$49,027 | 324 | $5,781 | $3,941-$7,621 |
| Females | | | | | | | | | |
| 0-4 years | 28 | $2,009 | $923-$3,095 | 1 | $1,868 | | 29 | $2,001 | $958-$3,051 |
| 5-14 years | 37 | $1,747 | $1,023-$2,471 | 1 | $1,363 | | 38 | $1,737 | $1,032-$2,441 |
| 15-34 years | 81 | $3,370 | $2,177-$4,563 | 1 | $224 | | 82 | $3,332 | $2,151-$4,512 |
| 35-64 years | 51 | $7,629 | $3,562-$11,697 | 1 | $6,598 | | 52 | $7,610 | $3,623-$11,597 |
| ≥ 65 years | 15 | $9,776 | $4,424-$15,128 | 1 | $57,437 | | 16 | $12,755 | $4,689-$20,821 |
| total | 212 | $4,385 | $3,208-$5,562 | 5 | $13,498 | -$17,149-$44,146 | 217 | $4,595 | $3,347-$5,843 |
| Total | | | | | | | | | |
| 0-4 years | 77 | $1,702 | $1,194-$2,210 | 2 | $1,481 | -$3,440-$6,401 | 79 | $1,696 | $1,201-$2,191 |
| 5-14 years | 97 | $2,424 | $858-$3,990 | 2 | $42,696 | -$482,488-$567,881 | 99 | $3,237 | $995-$5,480 |
| 15-34 years | 208 | $2,918 | $2,247-$3,590 | 9 | $7,676 | $1,519-$13,833 | 217 | $3,115 | $2,428-$3,803 |
| 35-64 years | 109 | $6,977 | $4,620-$9,334 | 5 | $20,048 | -$7,781-$47,877 | 114 | $7,550 | $5,115-$9,986 |
| ≥ 65 years | 28 | $21,666 | $8,280-$35,052 | 4 | $68,070 | -$40,973-$177,114 | 32 | $27,466 | $12,446-$42,486 |
| total | 519 | $4,509 | $3,503-$5,515 | 22 | $24,089 | $6,785-$41,393 | 541 | $5,305 | $4,097-$6,514 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Waikato (rural)** | | | | | | | | | |
| Males | | | | | | | | | |
| 0-4 years | 13 | $1,275 | $497-$2,053 | 1 | $3,437 | | 14 | $1,429 | $641-$2,217 |
| 5-14 years | 23 | $3,364 | $488-$6,240 | | | | 23 | $3,364 | $488-$6,240 |
| 15-34 years | 36 | $3,389 | $1,050-$5,729 | 8 | $45,421 | -$990-$91,833 | 44 | $11,032 | $2,381-$19,682 |
| 35-64 years | 29 | $6,997 | $3,448-$10,546 | 1 | $25,023 | | 30 | $7,598 | $3,960-$11,235 |
| ≥ 65 years | 4 | $9,586 | -$6,813-$25,986 | | | | 4 | $9,586 | -$6,813-$25,986 |
| total | 105 | $4,354 | $2,895-$5,814 | 10 | $39,183 | $2,736-$75,630 | 115 | $7,383 | $3,908-$10,859 |
| Females | | | | | | | | | |
| 0-4 years | 10 | $1,103 | $303-$1,902 | 2 | $58,669 | -$665,105-$782,443 | 12 | $10,697 | -$10,309-$31,703 |
| 5-14 years | 15 | $1,367 | $623-$2,110 | | | | 15 | $1,367 | $623-$2,110 |
| 15-34 years | 20 | $5,103 | -$248-$10,453 | | | | 20 | $5,103 | -$248-$10,453 |
| 35-64 years | 20 | $9,268 | -$1,628-$20,164 | | | | 20 | $9,268 | -$1,628-$20,164 |
| ≥ 65 years | 2 | $6,350 | -$18,940-$31,639 | | | | 2 | $6,350 | -$18,940-$31,639 |
| total | 67 | $4,950 | $843-$4,972 | 2 | $58,669 | -$665,105-$782,443 | 69 | $6,507 | $1,843-$11,171 |
| Total | | | | | | | | | |
| 0-4 years | 23 | $1,200 | $684-$1,716 | 3 | $40,258 | -$121,908-$202,424 | 26 | $5,707 | -$3,362-$14,776 |
| 5-14 years | 38 | $2,576 | $837-$4,314 | | | | 38 | $2,576 | $837-$4,314 |
| 15-34 years | 56 | $4,001 | $1,663-$6,340 | 8 | $45,421 | -$990-$91,833 | 64 | $9,179 | $3,062-$15,296 |
| 35-64 years | 49 | $7,924 | $3,234-$12,614 | 1 | $25,023 | | 50 | $8,266 | $3,622-$12,910 |
| ≥ 65 years | 6 | $8,507 | -$153-$17,168 | | | | 6 | $8,507 | -$153-$17,168 |
| total | 172 | $4,586 | $2,980-$6,193 | 12 | $42,431 | $8,982-$75,879 | 184 | $7,055 | $4,292-$9,817 |

*Figure 10: Direct cost per person by ethnic origin (Maori vs non-Maori), and injury severity*



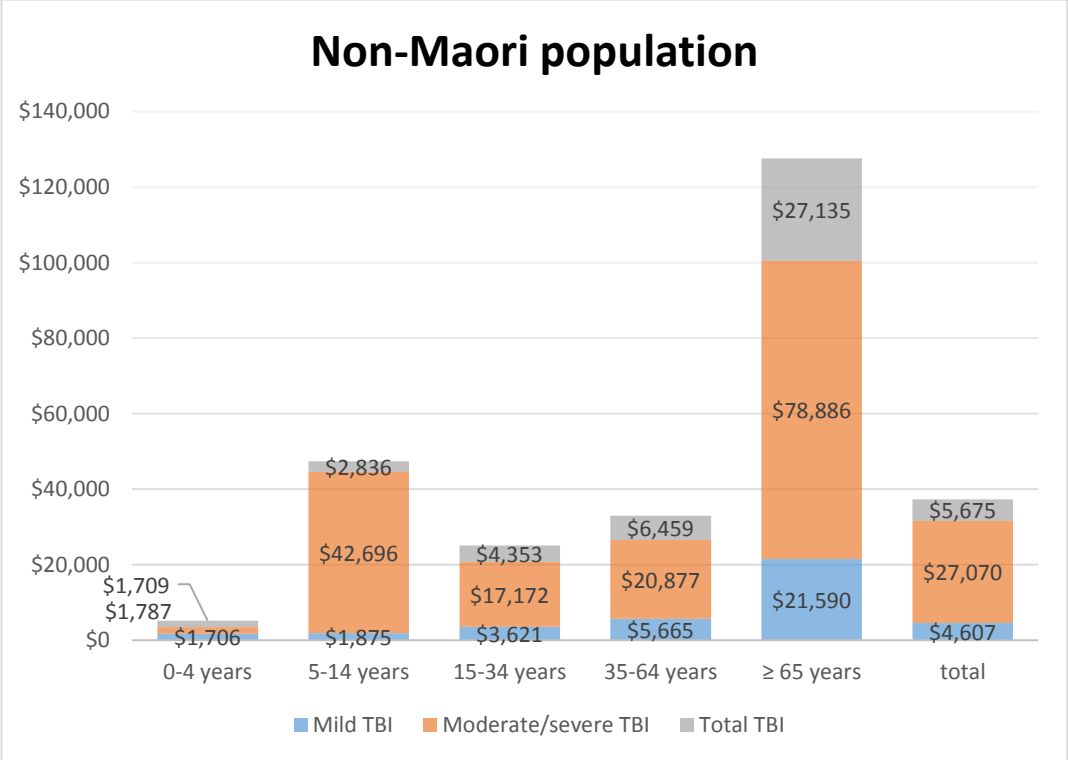



*Table 26: Direct cost of TBI by cause, age, sex and residency (urban vs rural)*

| | Transport accident | | | Fall | | | Exposure to mechanical force | | | Assault | | | Other/unknown | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** | **n** | **mean** | **95% CI** |
| Males | | | | | | | | | | | | | | | |
| 0-4 years | 4 | $1,539 | -$827-$3,905 | 45 | $1,635 | $1,044-$2,225 | 12 | $898 | $487-$1,309 | 2 | $2,445 | $1,941-$2,948 | 1 | $494 | |
| 5-14 years | 16 | $7,325 | -$3,691-$18,342 | 33 | $4,175 | -$661-$9,009 | 27 | $1,638 | $738-$2,538 | 4 | $632 | $293-$970 | 4 | $7,542 | -$3,597-$18,681 |
| 15-34 years | 42 | $13,870 | $4,839-$22,899 | 32 | $2,923 | $1,592-$4,254 | 36 | $1,893 | $730-$3,055 | 63 | $2,168 | $1,338-$2,997 | 6 | $1,241 | $136-$2,345 |
| 35-64 years | 31 | $7,780 | $3,092-$12,468 | 26 | $5,815 | $2,602-$9,027 | 13 | $6,793 | $1,106-$12,479 | 18 | $9,123 | $2,229-$16,016 | 4 | $12,024 | -$12,981-$37,029 |
| ≥ 65 years | 2 | $35,823 | -$148,758-$220,404 | 16 | $39,254 | $10,134-$68,374 | 1 | $1,311 | | | | | 1 | $12,169 | |
| total | 95 | $10,723 | $6,089-$15,357 | 152 | $7,132 | $3,640-$10,624 | 89 | $2,391 | $1,407-$3,374 | 87 | $3,543 | $1,974-$5,110 | 16 | $6,148 | $1,279-$11,016 |
| Females | | | | | | | | | | | | | | | |
| 0-4 years | 2 | $62,881 | -$607,377-$733,139 | 35 | $1,646 | $916-$2,374 | 4 | $782 | -$383-$1,946 | | | | | | |
| 5-14 years | 6 | $2,432 | $237-$4,627 | 27 | $1,600 | $703-$2,495 | 14 | $1,669 | $800-$2,537 | 4 | $668 | -$574-$1,911 | 2 | $1,331 | -$12,149-$14,811 |
| 15-34 years | 20 | $3,704 | $1,766-$5,642 | 28 | $2,933 | $712-$5,152 | 24 | $4,834 | $425-$9,242 | 27 | $3,603 | $1,056-$6,149 | 3 | $1,924 | -$5,795-$9,644 |
| 35-64 years | 14 | $5,495 | $493-$10,497 | 37 | $10,739 | $3,294-$18,183 | 12 | $4,466 | -$376-$9,309 | 8 | $6,009 | -$2,240-$14,259 | 1 | $5,122 | |
| ≥ 65 years | 1 | $8,267 | | 14 | $13,390 | $4,095-$22,684 | 3 | $7,017 | -$3,264-$17,299 | | | | | | |
| total | 43 | $6,968 | $1,448-$12,487 | 141 | $5,445 | $3,198-$7691 | 57 | $3,810 | $1,750-$5,869 | 39 | $3,796 | $1,539-$6,051 | 6 | $2,259 | -$388-$4,906 |
| Total | | | | | | | | | | | | | | | |
| 0-4 years | 6 | $21,986 | -$26,308-$70,280 | 80 | $1,639 | $1,189-$2,089 | 16 | $869 | $525-$1,213 | 2 | $2,445 | $1,941-$2,948] | 1 | $494 | |
| 5-14 years | 22 | $5,991 | -$1,832-$13,813 | 60 | $3,016 | $372-$5,660 | 41 | $1,649 | $1,009-$2,287 | 8 | $650 | $206-$1,093 | 6 | $5,472 | -$1,177-$12,120 |
| 15-34 years | 62 | $10,590 | $4,407-$16,772 | 60 | $2,927 | $1,711-$4,144 | 60 | $3,069 | $1,213-$4,925 | 90 | $2,598 | $1,659-$3,537 | 9 | $1,469 | $88-$2,848 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35-64 years | 45 | $7,069 | $3,583-$10,556 | 63 | $8,707 | $4,195-$13,218 | 25 | $5,676 | $2,165-$9,185 | 26 | $8,165 | $3,054-$13,275 | 5 | $10,643 | -$6,684-$27,971 |
| ≥ 65 years | 3 | $26,638 | -$26,880-$80,155 | 30 | $27,184 | $11,196-$43,171 | 4 | $5,591 | -$1,447-$12,628 | | | | 1 | $12,169 | |
| total | 138 | $9,553 | $5,956-$13,150 | 293 | $6,320 | $4,220-$8,419 | 146 | $2,945 | $1,950-$3,939 | 126 | $3,621 | $2,349-$4,892 | 22 | $5,088 | $1,532-$8,642 |
| **Hamilton (urban)** | | | | | | | | | | | | | | | |
| 0-4 years | 4 | $3,212 | -$4,231-$10,656 | 60 | $1,731 | $1,156-$2,307 | 12 | $989 | $552-$1,426 | 2 | $2,445 | $1,941-$2,948 | 1 | $494 | |
| 5-14 years | 16 | $7,748 | -$3,218-$18,715 | 47 | $2,971 | -$218-$6,161 | 26 | $1,557 | $849-$2,264 | 7 | $673 | $146-$1,198 | 3 | $3,900 | -$11,816-$19,616 |
| 15-34 years | 43 | $5,272 | $3,118-$7,426 | 48 | $2,726 | $1,515-$3,936 | 45 | $2,530 | $1,186-$3,873 | 73 | $2,625 | $1,502-$3,748 | 8 | $1,624 | $74-$3,174 |
| 35-64 years | 34 | $6,646 | $2,234-$11,059 | 38 | $8,598 | $3,488-$13,707 | 17 | $5,194 | $861-$9,528 | 23 | $8,845 | $3,089-$14,599 | 2 | $8,157 | -$30,408-$46,721 |
| ≥ 65 years | 3 | $26,638 | -$26,880-$80,156 | 25 | $30,913 | $11,934-$49,891 | 3 | $4,674 | -$7,571-$16,919 | | | | 1 | $12,169 | |
| total | 100 | $6,694 | $4,169-$9,219 | 218 | $6,761 | $4,136-$9,386 | 103 | $2,607 | $1,672-$3,541 | 105 | $3,854 | $2,344-$5,363 | 15 | $3,578 | $1,107-$6,048 |
| **Waikato (rural)** | | | | | | | | | | | | | | | |
| 0-4 years | 2 | $59,534 | -$653,249-$772,317 | 20 | $1,363 | $787-$1,938 | 4 | $511 | -$44-$1,065 | | | | | | |
| 5-14 years | 6 | $1,303 | $556-$2,050 | 13 | $3,178 | -$1,606-$7,962 | 15 | $1,808 | $429-$3,185 | 1 | $494 | | 3 | $7,043 | -$11,027-$25,113 |
| 15-34 years | 19 | $22,626 | $2,907-$42,344 | 12 | $3,733 | -$471-$7,936 | 15 | $4,688 | -$2,114-$11,491 | 17 | $2,483 | $1,078-$3,888 | 1 | $224 | |
| 35-64 years | 11 | $8,377 | $3,069-$13,683 | 25 | $8,872 | $52-$17,692 | 8 | $6,699 | -$953-$14,351 | 3 | $2,954 | -$3,481-$9,389 | 3 | $12,302 | -$35,480-$60,083 |
| ≥ 65 years | | | | 5 | $8,541 | -$2,915-$19,996 | 1 | $8,340 | | | | | | | |
| total | 38 | $17,077 | $5,799-$28,355 | 75 | $5,038 | $1,950-$8,125 | 43 | $3,754 | $1,157-$6,349 | 21 | $2,456 | $1,262-$3,649 | 7 | $8,323 | -$3,398-$20,043 |

## Discussion

This study utilised data from a population-based TBI incidence study to report first-year and lifetime costs of TBI by severity levels across all age groups of the urban and rural population. Our cost estimates are based on patterns of resources used during the first year after having a TBI and provides important information for future health care planning. New Zealand is among other high income countries that are faced with balancing expenditure versus benefit in tight fiscal environments. The results provide evidence that the cost of treating TBI varies greatly, with the most severe TBI sufferers attracting maximal costs. Our main findings estimate total first-year incidence costs for TBI in NZ during 2010 to be NZ$71 million (US$47.7 million) with total prevalence cost of NZ$151 million (US$101.3 million). This equates to an average cost per person of NZ$6,144 (US$4,123) with average costs per person for mild (95% of all cases) and moderate/severe TBI NZ$5058 (US$3,395) and NZ$31,854 (US$21,379) respectively. Although the cost per case of mild TBI is significantly lower than the cost of moderate/severe injuries, the unexpectedly large number of mild TBI (95% of all TBI cases) means that the total cost of treating these cases is three times that of moderate/severe. Lifetime costs per person for all first TBI occurring in 2010 are estimated to be NZ$8,824 (US$5922) for all severities pooled, NZ$6,908 (US$4,636) for mild and NZ$54,605 (US$36,648) for moderate/severe. The overall lifetime cost of all incident and prevalent TBI cases in NZ was NZ$218 million (US$146.3 million) in 2010 and is projected to increase to NZ$263.9 million (US$177.1 million) in 2020, if the current trend in TBI incidence continues.

The per-person (first year) cost estimates reported in this study are much lower than those reported in previous TBI cost studies (Access Economics, 2009; Chen et al., 2012; Davis et al., 2007; McGarry et al., 2002; Morris et al., 2008; Schootman et al., 2003). The explanation may be that previous studies focused primarily upon patients who were hospitalised for their TBI. These patients tend to have more severe injuries and, as a result, the highest direct and indirect health care costs. While we acknowledge that it is difficult to assess accurate hospital costs between countries, it is unclear the extent to which the conclusions relate to other hospital settings, due to different costing systems. By contrast, the present results are based on the first large prospective population-based study investigating TBI incidence and outcomes in both hospital and community settings (non-hospitalised TBI patients) across the spectrum of severity in all age groups in a geographic region with urban and rural populations (Feigin et al., 2013; Theadom et al., 2012). A significant proportion of TBI patients (64%) were not hospitalised at the acute stage of TBI (the majority sustaining mild TBI) and a significant proportion (30%) were identified through non-hospital sources. Based on the estimated number of people who experience new mild (51.8-56.4 million) and moderate/severe (2.2-3.6 million) TBI per year in the world (Feigin et al., 2013), extrapolation of our estimates to the world population suggest that the global economic burden for TBI may range between NZ$331.7 billion (US$222.6 billion) and NZ$368.6 billion (US$247.4 billion).

Information regarding the cost and pattern of health services usage is useful for identifying areas in which interventions might improve outcomes. This analysis does not account for factors that might determine access to TBI care, such as prospects for recovery, nor does it attempt to link outcomes (such

as life expectancy) with access to specialised TBI care. Such an endeavour would require controlling for health status and TBI severity and modelling the pathways that individuals follow after care.

Caregiver time and expense is clearly a significant cost to those living at home, but estimating the cost requires a different methodology than used in the current study. Basing lifetime cost estimates on short-term data may overstate calculated estimates; therefore, estimating lifetime cost of TBI requires identifying the outcomes and health service usage over a longer period (i.e. five years or more) and modelling the likely use of other health services after TBI. In addition, we are not able to estimate costs associated with possible long-term consequences of TBI, especially repeated, such as cognitive decline, dementia etc. Taken together, these limitations of the data suggest that the estimated health service use and cost of services presented in this study should not be taken as the total cost of TBI in NZ.

In summary the economic burden for TBI in NZ is high, but significant cost savings and improvements in outcomes may be achieved by targeting high cost individuals, and by reducing the incidence of lower cost mild injuries. Further studies are required to confirm the findings in other populations and to explore the impact of TBI on families and caregivers, and ways to prevent both moderate/severe and mild TBI. The findings from this study represent the first economic study estimating the cost of TBI on a population level. Every effort has been made to include only those costs that are attributable to the condition. Given the considerable costs associated with TBI, further investigation of the cost effectiveness of a variety of prevention strategies and rehabilitation services aimed at improving TBI, should be a priority.

# CHAPTER FIVE: Trends in mild TBI in New Zealand and the public health response

## Introduction

Approximately half a million New Zealanders will experience a traumatic brain injury (TBI) each year and this is expected to increase by 21% in 2020 (see chapter three). Of all identified cases, about 95% were estimated to be mild TBI. The high prevalence of brain injuries warrants governments and health systems to invest in evidence-based polices and interventions for both mild and moderate/severe TBI. Although the first-year per-capita cost of mild TBI in NZ is comparatively minimal when compared to moderate and severe (NZ$5,058 per mild TBI vs NZ$31,854 per moderate/severe TBI), overall it is rather significant due to the increased incidence (see chapter four). Of those who suffer from mild TBI, many do not seek medical attention (34%) (Feigin et al., 2013) and are not referred to accident emergency departments or admitted into hospital for observation (64%). In particular, the mild TBI cohort is of great interest as previous research has demonstrated that even mild TBI can lead to significant and persistent long-term difficulty (New Zealand Guidelines Group, 2006; Wrightson & Gronwall, 1998) such as post-concussion (Sotir, 2001; Yang et al., 2007), and intracranial haematoma (Stein et al., 2006; Stein et al., 2008). A better understanding of mild TBI and people with TBI not seeking medical attention may bring about population health efforts to improve prevention strategies. If predictive factors of severity of injury hospitalisation and on-going care can be identified, they can be useful for informing public health interventions aimed at reducing the incidence and related costs.

## Chapter objectives

Obtaining accurate population level data and health service use information among those who do not seek medical attention is challenging. A methodological limitation of previous studies has been a heavy reliance on clinical diagnostic codes (ICD codes) used in hospital medical records. As a result the characteristics of patients included in these studies are those who seek medical care, as opposed to those who do not.

This chapter combines data from a prospective population-based incidence study of brain injuries in Hamilton and Waikato region, NZ (population approximately 170,000), that identified TBI in the community, including people not presenting to hospitals for treatment or who died immediately following their TBI. The purpose of this chapter is to identify what public health officials should do to prevent TBI in NZ.

The chapter objectives are:

1. To examine the characteristics of people with mild TBI who seek medical attention compared with those who do not.
2. To identify predictors of hospitalisation among mild TBI.
3. To identify predictors among mild TBI of needing on-going care.
4. To identify the effectiveness of prevention strategies for mild TBI.
5. To estimate potential cost savings from effective prevention strategies in the literature.

## A review of current TBI prevention strategies

The following section will present an overview of the recommendations for preventing TBI both nationally and internationally. Published and grey literature on TBI prevention strategies were analysed to describe current policies and guideline recommendations.

### New Zealand Accident Compensation Co-operation (ACC)

Consultation between ACC with clients, their families and caregivers was undertaken in the early development stages of the current strategy to gain insight and understanding of the patient experience (New Zealand Guidelines Group, 2005, 2006). Similarly close communication with service providers was also carried out to better understand the part "providers" play in the rehabilitation phase. The present strategy is focused on adults with moderate to severe injuries. This approach provides direction for treatment and rehabilitation and to ensure the right systems and services are in place. The strategy has four key objectives:

1. Achieving optimal client outcomes:
    a. person-centred approach to rehabilitation
    b. rehabilitation that is meaningful for the client and their family
    c. Optimal outcomes.
2. Providing quality services from initial care to on-going rehabilitation services and community support (i.e. compensation for lost wages etc.):
    a. high quality of care
    b. right services at the right time in the right place
    c. Continual drive for improvements.
3. Ensuring providers are engaged and focused on achieving the right client outcomes across the continuum of care:
    a. skilled external capability
    b. engaged external capability
    c. Measureable results from service provided.
4. To maintain ACC's role and involvement in the provision and funding of TBI treatment and rehabilitation services:
    a. understanding of TBI
    b. strong internal capability
    c. Collaboration with other agencies.

One positive output from ACC's strategy was the introduction of a residential rehabilitation project (Accident Compensation Coorporation, 2014). A critique of the current strategy is that it does not include adults and children with mild TBI. Despite recent research indicating a large proportion of TBIs are in fact mild, it is equally important that polices reflect evidence from research. TBI is commonly known as the "silent epidemic" due to the growing number of mild TBI occurrences which often occur without notice for the individual and society as a whole (Feigin et al., 2013).

### Australia

No specific prevention strategy for TBI was found in Australia; however, most efforts are currently focused towards the general unintentional injuries (e.g. falls) with a strong focus on falls among the elderly (The Australian Commision on Safety and Quality in Health Care, 2009) and road traffic injuries (Newstead, Cameron, & Leggett, 2001).

### Europe

Whereas in the United Kingdom (UK), both the National Health Services (NHS) (Millward, Morgan, & Kelly, 2003), and the National Institute for Health and Care Excellence (NICE) support the use of protective head gear to reduce head injuries. There is evidence of a prevention strategy aimed at minor head injuries and severe head injuries. The overarching strategy emphasised the following key areas:

- safety helmets
- safety in the home
    - including home modifications to reduce the chances of falls or slips
- childproofing the home environment
- safety at work
- Sport safety.

### United States

TBI is at the forefront of injury prevention in the United States (US). Increased interest in TBI is driven namely through sports such as American football and returning soldiers with severe head injuries or disability. Similar to efforts found in Europe, the Centres for Disease Control and Prevention (CDC) developed the "Heads up: educational initiative" which helps protect people of all ages from concussions and other serious brain injuries in the US (see http://www.cdc.gov/concussion). The initiative is aimed at parents, clinicians, high school coaches, youth sport coaches and school staff, and is available in print or mobile app. The tool starts with describing the conditions of concussion and brain injuries, to signs and symptoms, responding to concussion, danger signs and severe brain injury. The prevention concludes with safety information around the use of helmets, and car restraints.

Lastly, the CDC recommends seven ways to reduce TBI.

1. Use a child safety seat or booster seat or seat belt (Turner, McClure, Nixon, & Spinks, 2005).
2. Wear a seat belt every time while driving or riding in a motor vehicle (Rivara, Thompson, & Cummings, 1999).
3. Never drive under the influence of alcohol or drugs (Elder et al., 2002).
4. Wear a helmet and make sure children wear helmets when:
    a. riding a bike or motorcycle
    b. Playing contact sport, such as hockey, boxing or football.
5. Make living areas safer for seniors (Campbell, Robertson, Garner, Norton, & Buchner, 1999) by:
    a. installing hand rails on stairways
    b. Using non-slip mats in bathrooms.
6. Make living areas safer for children by:

a. installing window guards
b. Using safety gates.

7. Make sure children's playground surfaces are made of shock absorbing material (Mack, Sacks, & Thompson, 2000).

## Methods

### BIONIC study data source

In brief the BIONIC study is a large TBI-incidence and outcomes study undertaken in Hamilton Waikato district (population 170,000) NZ and encompassed the use of multiple overlapping sources to ascertain all new and recurrent cases of TBI among residents in Hamilton Waikato region, over a 12-month calendar period (2010 to 2011). In the study area, Europeans constituted 55% of the study population, Maori 20% (the indigenous population of NZ), Pasifika (Pacific Island people living in NZ) 2%, and people of other ethnic groups 15%. The details of the study have been described elsewhere (Feigin et al., 2013; Theadom et al., 2012). Case definition and TBI surveillance procedures are reported in chapter three. Each diagnosis of potential TBI patients was identified by health care providers (e.g. health centres, family doctors, and physiotherapists), hospital emergency departments, and ambulance services and was verified by the BIONIC study operations group at weekly meetings. For cases flagged as needing classification of inclusion criteria further review were followed up by the study diagnostic adjudication group. All surviving patients were interviewed at baseline, one, six and twelve months post TBI. Baseline information included demographics, medical history and place of residence prior to TBI. Information at one month documented initial acute treatment while at six and twelve months included use of outpatient, rehabilitation and home care services, and health status.

### Variables measured

The following baseline and follow-up outcome variables from adult and child forms will be summarised. Glasgow Outcomes Score (GOS) describes the degree of recovery and prediction of long-term disability to return to work and activities of daily living (Jennett & Bond, 1975). The scale has the following categories:

1. Dead
2. Vegetative state – unresponsive and unable to interact with environment
3. Severe disability – able to follow commands, but unable to live independently
4. Moderate disability – able to live independently, but unable to return to work or school
5. Good recovery – able to return to work or school.

#### *New Zealand Deprivation*

The New Zealand Deprivation 2006 score (NZDep2006) combines nine variables from the NZ census 2006 to provide a deprivation score for each geographic area in NZ (Salmond, Crampton, & Atkinson, 2007). Deprivation scores range from 1 to 10, where 10 represents the most deprived areas. Deprivation scores were assigned by automatically geocoding individual participants' known street addresses to meshblock. NZDep2006 scores apply to geographical areas not individual people. The nine variables used to derive an NZDep2006 score are (see Table 27):

*Table 27: Description of the nine dimensions of deprivation*

| Dimension of deprivation | Variable description |
|---|---|
| Income | People aged 18-64 receiving a means-tested benefit |
| Income | People living in households with incomes below an income threshold |
| Owned home | People not living in own home |
| Support | People aged <65 living in a single parent family |
| Employment | People aged 18-64 unemployed |
| Qualifications | People aged 18-64 without any qualifications |
| Living space | People living in households below a bedroom occupancy threshold |
| Communication | People with no access to a telephone |
| Transport | People with no access to a car |

*Individual income*

In order to estimate individual annual income, occupational information for all adults who were in paid employment sourced at baseline was linked to average annual earnings (Statistics New Zealand, 2010a) using the Australian New Zealand Standard Classification of Occupation (Trewin & Pink, 2006). Median annual earnings in 2010 of NZ$39,998 were assigned to adults who were in paid employment but did not record occupation information at baseline (Statistics New Zealand, 2010a). Applicable, parent or significant other occupation information was used as proxy for those younger than 15 years.

### Outcomes

The outcomes measures included findings of CT scan that lead to either complications or neurosurgical intervention. Abnormal CT findings are determined by CT findings attributable to brain trauma, which includes lesions, skull fracture, and intracranial bleeding. Secondary outcomes were identifying those that needed hospital admission for their mild TBI.

### Review of current injury prevention programmes

A review of the literature was conducted to identify systematic reviews or intervention studies evaluating prevention strategies for TBI. Studies that compared the effect of the interventions of two or more alternative strategies were sought. Articles were selected by searching MEDLINE and Google from 1990 to the present. The list of keyword search terms used to conduct the search included, but was not limited to, the following: prevention (consisting of accident prevention and fall prevention), traffic accidents, motor vehicle and pedestrian. Selected articles were English language. A summary of the literature on interventions and effectiveness of reducing injuries relating to TBIs were presented.

### Costs analysis and estimation of potential cost savings

The analysis is taken from a NZ health funder perspective. The cost per case of TBI can inform decisions regarding cost-effective interventions to reduce TBI by providing information on the costs that can be averted through prevention activities. Unit costs are presented in *appendix seven* in NZ dollars 2010 value. The costs included the following:

- The cost of administrating a brain computerised tomography scan was NZ$133.37 (see *appendix seven*).
- The cost of hospitalisation for mild TBI of NZ$2,813 (based on an average of 1.76 days) and health service usage were sourced from the BIONIC study (Te Ao et al., 2014).

Direct costs (e.g., hospitalisation and out-patient) as well as out-of-pocket expenses (e.g. aids and home modification) were summed and averaged to estimate per person costs and multiplied by the national incidence to give a cost total for the country. Potential cost savings from prevention strategies were estimated by calculating costs saved from numbers of injuries averted. Total first year direct medical costs associated with TBI have been previously estimated (see chapter four). From a health policy standpoint it quantifies the amount of money that could be saved if effective interventions are introduced. The unknown parameters of interest in the current study are the efficacy rates of reducing the incidence of TBI. The purpose of the analysis is to identify interventions known to reduce injury and to estimate potential cost savings.

### Statistical analysis

Descriptive analyses included calculation of means, median and standard deviations for continuous data and counts and percentages for categorical data. Differences in characteristics and causes of brain injury were assessed by chi square or t-test. Significance level was set at $p<0.05$ (2 sided). Logistic regression analyses were used to identify factors associated with severity of injury. Regression analysis used a forward step wise calculation approach. Factors examined as possible predictors include: baseline demographics such as age at injury (<34 years vs 35 years and over), gender, ethnicity (Maori vs non Maori), residency (urban vs rural), intention of injury (accidental vs self-harm), moderate to severe disability and mechanism of injury. Using the same independent variables, two further logistic regression analyses were undertaken, first to examine predictors of in-hospital admission among mild TBI survivors (using "hospitalisation" as the dependant variable), and second to examine predictors of needing on-going care (post-acute phase).

## Results

### Characteristics of those seeking medical attention

Over 85% of consenting TBI survivors sought immediate medical attention from either emergency departments (EDs) (including 24 hour accident and medical clinics) or from their family doctor. Brain CT scan was performed on admission for 14% of TBI survivors; however, for four patients the brain was explored on admission by MRI. The results of brain CT scan were as follows: 33% of those scanned had external lacerations, 43% had bruising, 1% was identified as having a subdural haematoma, 0.4% epidural haematoma, 1.7% subarachnoid haemorrhage and 2.5% had another identified structural lesion. Around 39.4% (244/618) of patients who attended the ED with a brain injury were admitted into hospital; in comparison with those that did not attend ED of which approximately 18.7% (20/107) were admitted. On admission, six (0.8%) patients needed neurosurgery. The most observed surgical interventions were: craniotomy, evacuation of a subdural haematoma and elevation of depressed skull fracture; while 41 (5.7%) patients needed either orthopaedic or other surgery.

As seen in Table 28, moderate to severe TBI are more likely to seek medical attention (100%) and to be admitted into hospital (88%) for further observation. The most alarming descriptive is the low performance of brain CT scanning among TBI patients (14%), despite the efforts to increase screening through current NZ clinical guidelines. However for moderate to severe TBI, the uptake of neuroimaging was high (12% for mild, 71% for moderate/severe). A large proportion of TBI (64%) is managed in the community (i.e. not in a hospital setting), which is inclusive of approximately 458 mild TBI survivors.

*Table 28: Percentage TBIs seeking immediate medical attention*

| | | All TBI (n=725) | | Mild TBI (n=691) | | Moderate Severe TBI (n=34) | |
|---|---|---|---|---|---|---|---|
| | | n | % | n | % | n | % |
| **Seek medical attention** | **Yes** | 618 | 85% | 584 | 85% | 34 | 100% |
| | **No** | 107 | 15% | 107 | 15% | 0 | 0% |
| **CT Scanning** | **Yes** | 104 | 14% | 80 | 12% | 24 | 71% |
| | **No** | 621 | 86% | 611 | 88% | 10 | 29% |
| **Hospital admission** | **Yes** | 263 | 36% | 233 | 34% | 30 | 88% |
| | **No** | 462 | 64% | 458 | 66% | 4 | 12% |

### Predictors of severity of injury and in-hospital observation

Logistic regression analysis was undertaken to examine for any systematic differences to predict severity of injury. As can be seen in Table 29, urban residency, and TBI caused by either road traffic accident or exposure to mechanical force was significantly related to increased injury severity at baseline post TBI. As shown in Table 30, another logistic regression analysis identified significant differences between the characteristics of mild TBI patients admitted into hospital compared with those who did not. In-hospital admission for clinical observation appears to be based primarily on those who were older than 35 years living in geographic areas of least deprivation, which may reflect socio-economic factors.

*Table 29: Predictors of TBI severity*

| Independent variable | B | S.E. | Wald | Sig. | Exp(B) |
|---|---|---|---|---|---|
| **Urban** | -0.525 | 0.256 | 4.216 | 0.040 | 0.591 |
| **Traffic accident /MVA** | 0.654 | 0.26 | 6.333 | 0.012 | 1.923 |
| **Exposure to mechanical force** | -1.645 | 0.602 | 7.459 | 0.006 | 0.193 |
| **Constant** | -2.55 | 0.233 | 119.34 | 0.000 | 0.078 |
| | | | | | |
| **Model $x^2$** | 28.229 | p.<0.000 | | | |
| **Pseudo-$R^2$** | 0.061 | | | | |
| **n** | 1369 | | | | |

*Table 30: Predictors of hospitalisation among mild TBI*

| Independent variable | B | S.E | Wald | Sig | Exp(B) |
|---|---|---|---|---|---|
| **Young age** | -0.552 | 0.183 | 9.064 | 0.003 | 0.576 |
| **NZDep 8-10** | 0.637 | 0.237 | 7.247 | 0.007 | 1.891 |
| **Disability** | 0.521 | 0.238 | 4.807 | 0.028 | 1.684 |
| | | | | | |
| **Model $x^2$** | 26.694 | p.<0.000 | | | |
| **Pseudo-$R^2$** | 0.053 | | | | |
| **n** | 691 | | | | |

Characteristics of mild TBI, by those who were admitted to in-hospital care and those who were not

The mild cohort included 691 participants (including both adults and children) who consented to follow up. Demographic and injury-related information for the BIONIC sample at baseline is provided in Table 30. Roughly, 458 people (66%) were not admitted into hospital for observation; the average age at the time of mild TBI was 23 years (ranging from 0 to 91, with a median age of 19). In contrast for those who were admitted for observation, the sample were slightly older with an average age of 30.5 years (median age of 24; $p<0.05$). The majority of mild TBI survivors were of European descent (60%), due in part to the absolute numbers which represent a larger population of NZ European compared with Maori or Pacific peoples in Hamilton/Waikato. Approximately 60% of each sample was male, while the majority of TBI survivors were earning less than NZ$20,000 per annum and were living in the city of Hamilton (76% vs 74%).

Amongst the non-hospitalised sample, about 10% were rated as having a moderate/severe disability according to the Glasgow Outcome Score compared to 19.3% for those admitted. At the end of the 12-month follow up, a 58% (19.3-8%) reduction in disability score between those receiving in-hospital observations compared to a 70% (10.3-3%) reduction in disability for those who did not. Among those who were hospitalised, brain injuries were caused by falls (41%), transport accident (28%), exposure to mechanical force (12%), assault (16%) or unknown/other (3%). The two samples (hospitalised versus non-hospitalised) differed significantly at baseline by age, area deprivation (10 indicating most deprived), disability and cause of injury.

*Table 31: Characteristics of hospitalised versus non-hospitalised mild TBI at baseline*

| | Non Hospitalised mild TBI (n=458) | | Hospitalised mild TBI (n=233) | | Significance of difference | |
|---|---|---|---|---|---|---|
| | n | (%) | n | (%) | Chi Square | p-value |
| **Mean age in years (SD)** | 23.2 | 17.9 | 30.5 | 23.68 | **11.955** | **0.001** |
| **Median age in years (IQR)** | 19 | 9-33 | 24 | 13-45 | | |
| **Aged 34 years and younger** | 352 | 76.9% | 147 | 63.1% | **14.564** | **0.000** |
| **Male** | 274 | 59.8% | 138 | 59.2% | 0.230 | 0.880 |
| **Urban residency** | 347 | 75.8% | 172 | 73.8% | 0.312 | 0.577 |
| **NZDep 8-10** | 45 | 9.8% | 41 | 17.6% | **8.547** | **0.003** |
| **Low Income (less $20,000)** | 324 | 70.7% | 153 | 65.7% | 1.859 | 0.173 |
| **Live alone** | 26 | 5.7% | 21 | 9.0% | 2.707 | 0.100 |
| **Own home** | 83 | 18.1% | 43 | 18.5% | 0.110 | 0.915 |
| **Moderate or Severe Disability (GOS 4 & 5)** | 47 | 10.3% | 45 | 19.3% | **10.947** | **0.001** |
| **More than one comorbidity** | 192 | 41.9% | 115 | 49.4% | 3.453 | 0.063 |
| **Maori (vs Non-Maori)** | 152 | 33.2% | 78 | 33.5% | 0.006 | 0.939 |
| **Cause of TBI** | | | | | **16.739** | **0.000** |
| Transport accident | 61 | 13.3% | 65 | 27.9% | | |
| Fall | 187 | 40.8% | 95 | 40.8% | | |
| Exposure to mechanical force | 115 | 25.1% | 29 | 12.4% | | |
| Assault | 83 | 18.1% | 36 | 15.5% | | |
| Other | 1 | 0.2% | 6 | 2.6% | | |
| Unknown (not specified) | 11 | 2.4% | 2 | 0.9% | | |

### Health service usage

Resource consumption post injury at 12 months follow up is shown in Table 32. Of those mild TBI who were observed in hospital, there is clear evidence that they were more likely to receive health services post discharge. Irrespective of whether TBI sufferers were hospitalised or not, the most common health care received was general practice (39% vs 35%), followed by allied health care (24% vs 14%), then specialised medical care (19% vs 11%).

*Table 32: Resources used over 12 months post mild TBI*

| | mild TBI (GCS ≥13) Not hospitalised | mild TBI (GCS ≥13) hospitalised |
|---|---|---|
| | % | % |
| Total (N) | **458** | **233** |
| **Healthcare** | | |
| Emergency department | 34% | 55% |
| Initial hospitalisation | 0% | 100% |
| Hospital readmission | 2% | 6% |
| Allied health care | 14% | 24% |
| Specialised medical care | 11% | 19% |
| General practice | 35% | 39% |

| | | |
|---|---|---|
| Outpatient care | 3% | 11% |
| Nursing | 2% | 6% |
| Radiology | 1% | 0% |
| Community services | 2% | 7% |
| Out-of-pocket expenses | 2% | 6% |
| | | |

### Predictors of receiving health care post TBI

In order to understand the characteristics of people with mild TBI who are likely to receive on-going care after the acute stage, further multiple linear regression analyses were undertaken to examine possible predictors of needing on-going care. As can be seen in Table 33, young age, low income and males were significantly related to increased healthcare usage post-TBI.

*Table 33: Predictors of after care*

| **Independent variable** | **B** | **SE** | **Sig** |
|---|---|---|---|
| Young age | -0.477 | 0.179 | 0.008 |
| Low income | 0.401 | 0.182 | 0.028 |
| Male | -0.368 | 0.183 | 0.046 |
| Constant | 18.09 | 0.192 | 0.000 |
| R | 0.07 | | |
| n | 725 | | |

### Direct costs associated with mild TBI

Translating health care resources into costs, a summary of first-year direct medical costs for mild TBI are shown in Table 34. At baseline the average direct cost per mild TBI is NZ$4,528 (ranging from NZ$2,895 per non-hospitalised to NZ$7,739 per hospitalised). When comparing two strategies, CT scanning for early management with in-hospital observation, the expected cost of resources for each alternative is also presented in the table below. It is estimated that administering CT scanning to diagnose all people with expected TBI is a cost saving of NZ$1,242 per person per year (NZ$4,528-NZ$3,286), translating to a potential cost saving for the country of up to NZ$46.5 million. Conversely, if all TBI patients are hospitalised that would amount to an additional NZ$3,211 per person (NZ$7,739-NZ$4,528), transforming to a total additional cost of NZ$34.5 million for the country.

*Table 34: Summary of direct medical costs associated with having a TBI*

| | Medical cost per person | Total medical costs for NZ |
|---|---|---|
| Expected cost of mild (if 100 % received CT scan) | $3,286 | $2,270,589 |
| Current cost of mild-baseline (12% received CT scan, 34% hospitalised) | $4,528 | $48,775,181 |
| Expected cost of mild (if 100% hospitalised) | $7,739 | $83,353,799 |

### A review of prevention strategies

The summary of the estimated effectiveness of potential intervention is shown in Table 35. A total of eight reviews were found (Elder et al., 2002; Fagan & Catalano, 2013; Gillespie et al., 2012; Khouzam, Al-

Mawed, Farah, & Mizeracki, 2014; Liu et al., 2008; Rivara et al., 1999; Thompson, Rivara, & Thompson, 1999; Turner et al., 2005). Of these reviews two targeted children aged 14 years or younger (Fagan & Catalano, 2013; Turner et al., 2005) while one targeted older populations (Gillespie et al., 2012). Interventions for traffic injuries were most common with a reduction in injury ranging from 25% (Khouzam et al., 2014) to 69% (Liu et al., 2008). Interventions for assault and exposure to mechanical force were hard to find; however, a review of a school-based violence prevention programme among middle-school-aged children found a 32% reduction in self-reported assaults (Fagan & Catalano, 2013). Fall prevention programmes mostly centred around slip-proofing home environments, but a number of hospital and community-based exercise programmes to prevent falls were often restricted to the elderly (Gillespie et al., 2012); very little prevention programmes were found for all ages.

*Table 35: Summary of effectiveness of injury prevention*

| **Study** | **Intervention** | **Target group** | **Effectiveness (based on literature)** |
|---|---|---|---|
| **Intervention for traffic injuries** | | | |
| Turner, McClure, Nixon, Spinks, 2005 | Promote car seat restraints | Children aged 0-14 years | 33% reduction in motor vehicle injury |
| Elder, Shults, Sleet et al., 2002 | Sobriety checkpoints (including mass media campaign and breath testing) | General population | 24% median decrease in non-fatal injury crash |
| Thompson DC, Rivara F, Thompson R, 1999 | Helmets for bicycles | General population | Injuries to the head and facial area are reduced to 65% |
| Liu BC, Ivers R, Norton R, Boufous S, Blows S, Lo SK, 2008 | Helmets for motorcycles | General population | 69% reduction in injuries |
| Rivara, Thompson, Cummings, 1999 | Mandatory seat belt use | General population | 45% reduction in motor vehicle-related death or injury |
| Khouzam, Al-Mawed, Farah and Mizeracki, 2014 | Airbags in cars | General population | 25% reduction in mortality and injury |
| **Intervention for violence prevention** | | | |
| Fagan and Catalano, 2013 | School-based violence prevention programme | Children aged 0-10 years | 32% reduction of self-reported assaults |
| **Intervention for fall prevention** | | | |
| Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE, 2012 | Community-based prevention | Older population (aged 65 years and older) | 31% reduction in falls |

### Potential cost savings of prevention programmes

The potential cost savings of introduced preventions are shown in Table 36. If a car seat restraint programme was implemented and yields 33% effectiveness in reducing injury (resulting in 136 injuries averted), the intervention would be a cost saving (at NZ$816,012). It is obviously demonstrated that as

the effectiveness of the intervention increases it will subsequently increase the number of injuries that can be averted (i.e. potential cost savings). Falls or unintentional injuries were the leading mechanism of TBI; however, most fall prevention programmes concentrated on the older population. Although, NZ$6 million was the estimated likely return for fall prevention among the elderly, maximum cost savings are likely to accrue due to the higher incidence of fall-related injuries. The second most common cause of TBI was road traffic injuries. If a prevention programme for wearing bike helmets could reach an effectiveness of 69%, then the cost savings due to the campaign would be up to a maximum of NZ$15 million. Taken together if all interventions were in place, the overall potential cost savings to the country could be up to NZ$16.3 million. However, this is only an approximation as the analysis does not acknowledge that the implementation of prevention strategies will have associated costs. Further studies are needed to investigate potential cost savings together with implementation costs.

*Table 36: Potential cost savings if preventions are introduced (costs measured in NZ 2010 dollars)*

| Intervention for TBI | Average direct cost per person by mechanism of injury | Total direct costs for NZ | Number of TBI cases, by mechanism of injury (Total 11,301) | Percentage of reduction of injury from baseline(from the literature) | Expected number of TBI cases averted | Potential cost saving (based on effectiveness from the literature) |
|---|---|---|---|---|---|---|
| **Intervention for traffic injuries (n=2287)** | | | | | | |
| Promote car seat restraints (aged 0-14 years) | $5,991* | $2,472,764 | 413 | 33% | 136 | $816,012 |
| Sobriety checkpoints (including mass media campaign and breath testing) | $9,553 | $21,844,041 | 2287 | 24% | 549 | $5,242,570 |
| Helmets for bicycles | | | 2287 | 65% | 1486 | $14,198,626 |
| Helmets for motorcycles | | | 2287 | 69% | 1578 | $15,072,388 |
| Mandatory seat belt use | | | 2287 | 45% | 1029 | $9,829,818 |
| Airbags in cars | | | 2287 | 25% | 572 | $5,461,010 |
| **Intervention for violence prevention (n=1882)** | | | | | | |
| School-based violence prevention programme (aged 0-10 years) | $2,770* | $365,859 | 132 | 32% | 42 | $117,075 |
| **Intervention for falls (n=4260)** | | | | | | |
| Community-based prevention (aged 65 years or older) | $27,184* | $19,971,781 | 735 | 31% | 228 | $6,191,252 |

*Average costs were adjusted for age

## Discussion

Overall, the findings suggest that mild TBI is a common presenting condition in emergency departments and community settings. Identifying the characteristics of mild TBI are not well understood; a better understanding of these characteristics is important to inform public health efforts aimed at reducing the incidence of mild injuries. The findings suggest that the increased incidence of mild TBI indicates not only a need for public health action, but also that a targeted approach to prevention may be needed.

A high proportion of children and young adults are at highest risk of mild TBI, especially those who are managed in the community. On the other hand those who are managed in-hospital tend to be older adults (mean age 30.5 years). Mild TBI is more common in men than in women with most common causes identified as falls followed by motor vehicle accidents. Previous authors have suggested that many people experience long-term consequences following a mild TBI (McMahon et al., 2014). Therefore it is important to include characteristics of people with mild TBI who seek medical attention as well as those that do not.

Emergency medical staff face the difficult challenges of selecting patients for urgent CT, or in-hospital observation and those that can go home. The results suggest that screening for early diagnosis among mild TBI remains low. For instance, only 12% received CT compared to 71% for moderate/severe TBI. The low CT screening among mild TBI may be due to their not meeting clinical criteria to undergo screening as recommended by current clinical guidelines. The study also reported that overall there seems to be good awareness among those with mild TBI to seek immediate medical attention for their injuries (85% of mild TBI); however, of these cases 66% were not admitted into hospital. This could be reflective of a number of mild injuries being successfully managed in the community, thus minimising the burden on hospital services.

This study identifies predictors of hospitalisation among mild TBI which can help public health officials identify high risk patients. Common predictors found tend to be older age (35 years+) and living in geographic areas of least deprivation. While urban residency, and TBI caused by either road traffic accident or exposure to mechanical force are significantly related to increased injury severity at baseline. This interpretation is consistent with previous studies (Delen, Sharda, & Bessonov, 2006; Kamel, Kamel, Foda, Khashab, & Aziz, 1999) that risks of severe injury are dependent on the mechanism of injury. Improved early management (Ribbers, 2007; Sherer, Madison, & Hannay, 2000; Tate et al., 1998) can significantly reduce the predicted incidence on an ageing population. Additionally, more attention towards prevention and improving early management among mild TBI is warranted.

It is unclear whether a strategy for increasing hospital observation is more beneficial or yields greater effectiveness when compared to an alternative of increasing CT to triage for mild TBI admission (or vice versa). Previous authors have stated that a large proportion of patients with mild TBI had no additional benefit from in-hospital care (Geijerstam, Britton, & Marke, 2004) and thus could be managed by CT scan and early discharge from the emergency department, assuming CT is easily available within the clinical context (Geijerstam, Oredsson, & Britton, 2006). There has been growing evidence suggesting screening and CT is more important than admission and both are absolutely necessary for the proper evaluation of TBI (Geijerstam

& Britton, 2005; Stein et al., 2006; Stein et al., 2008). No current international examples were found of where clinical practice or guidelines recommended either hospitalisation of all mild TBI or CT for all. At present in NZ there seems to be a mix of both strategies with a trend towards higher use of CT due to increased availability and lower costs. Even though potential cost savings could be made if NZ introduces a strategy to screen all mild TBI, an additional study is needed to examine the cost effectiveness (cost and health benefits) of implementing screening options within current trends. Further studies will need to consider both clinical benefit and patient safety.

Patterns of resource usage, indicate that although small amounts of resources are consumed 12 months post TBI the variables of young age, low income and males are significantly related to increased health care usage post-TBI. This information is important for health services planning, including helping public health officials anticipate health care services needed to detect and treat TBI by identifying the characteristics of mild TBI.

When interpreting the results a note of caution to consider involves the comparability of patients receiving care in hospitals. While there were some differences between those admitted to hospital and those who were not admitted, it is possible that those treated in-hospital were of poorer health than those who were treated in the community. As the current study is an observational comparison, the possibility exists that the differences in outcomes are dependent upon some unmeasured characteristic. The above caution needs to be considered when generalising these results to other settings.

In summary, this chapter has described the characteristics of mild TBI in NZ and has major implications for current practice and future research. The results suggest greater improved prevention strategies particularly among mild TBI should be a priority. Furthermore there is a need to examine and increase current efforts towards CT scanning among mild TBI. This study highlights the need for both targeted TBI prevention programmes to reduce the risk of TBI as well as universal strategies.

# CHAPTER SIX: Discussion and conclusions

## Introduction

The purpose of this thesis was to explore the economic burden of TBI in NZ, using data collected from a prospective population-based study linked with self-reported health services usage and electronic medical records. This is an area that has received relatively little attention in health services research. This final chapter starts with a brief overview on the burden of TBI in NZ, investigating the first-ever incidence and prevalence of TBI for all ages as described in chapter three. This is followed by a discussion of the findings from the cost-of-illness study reported in chapter four that examines the direct and indirect costs associated with TBI reported as per-person costs, then extrapolated to the whole prevalence sample (from chapter three) to project an estimated total cost for NZ. Lastly, a description to better understand the mild TBI cohort and those TBI survivors that do not seek immediate acute care for their injury was outlined in chapter five, with the goal of identifying areas where public health officials might intervene. A discussion of these findings in relation to previous research is considered together with a critical evaluation of the methods used in the current study. Finally, the implications for research, policy and prevention are explored.

## Summary of main findings

The present research is based on the completed Brain Injury Outcomes New Zealand in the Community (BIONIC) study, the main results of which have been published (Feigin et al., 2013). Findings from the first traumatic brain injury (TBI) population-based incidence and one-year outcomes study found that the incidence of TBI in the population is far greater than previously estimated. The authors also provided evidence that there were significantly more mild injuries (95% of all cases) than previously reported. These findings help illustrate the size of the problem and contribute important information and characteristics to inform health planners and researchers on prevention programmes. This thesis extends that work by estimating the burden of TBI in NZ as well as the direct and indirect cost of treating TBI in a year. Viewing these findings alongside the reported incidence estimated from the BIONIC study not only informs decisions on resource allocation in health services but also provides information on the amount of money that might be saved from interventions aimed at reducing TBI. As such, this information is very important for researchers interested in understanding the impact of TBI on the health system and for evidence-based health care planning.

As outlined in chapter three, in 2010, 11,301 first-ever TBI cases were estimated to have occurred in NZ, while prevalent cases were estimated to be 527,388 (Te Ao et al., 2015). The numbers of incident cases are expected to increase to 13,591 with a total period prevalence of 641,104 cases by the year 2020 if current trends continue. The estimated 20,300 DALYs attributable to TBI accounted for 27% of total injury related health loss and 2.4% of DALYs from all causes (Ministry of Health, 2012). Although current research suggests that our communities are characterised by ageing populations (Cornwall & Davey, 2004) and people are generally living longer, these results suggest that for those who experience a TBI not all enjoy longer life and good health (Ministry of Health, 2012). Previous estimates for TBI were based on hospital admission data, which possibly

may have missed some cases. The burden of TBI estimated in this thesis draws upon the first population-based TBI incidence data, which includes those that were hospitalised for their injury and those that were not.

Within that context, chapter four contained a number of ground breaking results relating to TBI. The COI results suggest that the cost of treating TBI varies greatly, with first-year and lifetime costs of mild TBI being significantly lower than that of moderate/severe TBI. In addition, the unexpectedly large number of mild TBI (defined by GCS) means that the total cost of treating these cases is three times that of moderate/severe TBI (Te Ao et al., 2014). With this in mind, any significant cost savings and improvements in outcomes may be achieved by targeting both high cost individuals as well as population-based programmes aimed at reducing the incidence of lower cost mild injuries. Given the considerable costs associated with TBI, there is an urgent need to develop effective interventions to prevent TBI and manage its consequences.

Chapter five presented a general public health framework to identify possible areas for intervention by exploring the characteristics of TBI. This study has found that people with mild and moderate/severe TBI in NZ are doing quite well with 85% reporting seeking medical attention for their injury. There is evidence to suggest that good public health awareness exists for injury prevention including seeking acute medical care (Accident Compensation Coorporation, 2014). A number of areas were identified to guide prevention strategies for those at risk of TBI including the need to increase uptake of neuroimaging and screening. Currently 12% of all mild cases had CT scans which is relatively low; as a result there is a need to increase access to screening (Stein et al., 2006; Stein et al., 2008; Stein, Fabbri, Servadei, & Glick, 2009). However, most cases identified in BIONIC were classified as mild injuries, so may not have meet the selection criteria for screening.

Interestingly, of mild TBI those who were hospitalised tended to be older than 35 years and living in geographic areas of least deprivation. Similar trends exist for those individuals with TBI needing long-term care. The results suggest an inequality in access to secondary and long-term care for children and young adults from low socio-economic backgrounds. The need for determining risk factors and the effectiveness of interventions is important to prevent injury. Public health officials need to design and implement interventions based on current evidence. Targeted interventions among mild TBI should account for these factors attributable to injury towards the individual (host), the mechanism of injury (agent) and the social and physical environment (Barnett et al., 2005; Runyan, 1998).

### How can the burden of TBI inform planning and monitoring?

Public health surveillance of TBI is very important particularly for informing the rates of occurrence and for determining risk factors to guide the development of prevention strategies. It helps to quantify the magnitude of TBI on society by combining incidence and prevalence statistics with other measures of morbidity, mortality and financial burden. TBIs are preventable; the burden of brain injury and its associated health loss (measured in DALYs (Murray et al., 2012; Salomon et al., 2012)) is largely avoidable. The results reported in this thesis highlight the scope of the potential health gains and cost savings through effective prevention, treatment and rehabilitation. On-going surveillance is required to measure the frequency of the brain injury by socio-

demographic group (e.g. age, sex, severity of injury). Its purpose will not only inform on the current burden of TBI on society but it can also be used to evaluate the effectiveness of prevention efforts to reduce injuries.

There are a number of options that might be considered, including educational campaigns to raise awareness of TBI in the community (Emanuelson et al., 2003; Hatziandreu et al., 1995; Jacques, 1994; Mack et al., 2000; Palmer et al., 2001; Turner et al., 2005), increased neuroimaging during the pre-hospital assessment (Dharap, Khandkar, Pandey, & Sharma, 2005; Figg, Burry, & Vander Kolk, 2003; Weiss, Galanaud, Carpentier, Naccache, & Puybasset, 2007), or high intensity integrated rehabilitation services for moderate severe TBI (Carnevale, Anselmi, Busichio, & Millis, 2002; Smith et al., 2006; Turner-Stokes, Disler, Nair, & Wade, 2005). When deciding whether to adopt an intervention, decision makers must also consider the cost and resources that will be required and the outcomes (health benefit) that can be expected. The current study did not investigate prevention measures or interventions of this kind. However, it is an important aspect to consider and opportunities exist for further studies to investigate the efficiency and cost effectiveness of TBI prevention.

### What is already known about the cost of TBI?

The economic burden (including additional cost and lifetime costs) of TBI in NZ has not been previously quantified. The current study attempted to quantify these cost burdens to society by examining trends in TBI incidence, direct and indirect costs to the patients, families and society for the reference year 2010 and estimating the economic burden of TBI in NZ, projected to 2020. COI studies (as conducted in this study), are useful for measuring the potential cost savings of averting a case of illness. If the cost burdens of TBI are quantified and compared with other disease conditions this can provide another evidence-based argument to reallocate resources.

The cost of health services for TBI is expected to increase considerably in the future as the number of people suffering a brain injury is expected to increase especially among young adults, and as the number of vehicle users increases (Murray, Butcher, & McHugh, 2007). In addition, better early detection and treatment of brain injuries is expected to increase the survival rate from TBI. In the present study, we also estimated that one-year prevalence costs in NZ are expected to increase by 21% to over NZ$182.7 million (US$122.6 million) by the year 2020 should the current trend in TBI incidence and outcomes continue. As a result, health systems can expect significantly higher expenditures on both acute care, immediately following TBI, and health services post TBI as more TBI sufferers and their families and informal caregivers learn to adjust to life after TBI.

Assessing the economic burden of TBI on society provides information on the scope of the problem and potential savings from interventions aimed at reducing the incidence or severity, or improving treatment for TBI (Rice, 2000). The prevalence-based TBI cost estimates are essential to advocate for more preventive resources, as well as for policy makers to inform the changing allocation of scarce public resources (Hodgson & Meiners, 1982).

Information on the cost and pattern of health service use has a number of advantages. First, it can be used for health services planning. Combined cost and health services information with projections of population trends and the number of TBI incidences in the future, provides funders with an understanding of the cost of care

likely to be incurred in the future. Although the data only considers the cost of health services for the first year after TBI, the results here suggest that most TBI survivors receive little input from community and health care services after having a TBI.

Second, the cost findings can be used to identify unmet needs and inequities in the accessing and delivery of health services after TBI. This requires identifying the appropriate level of care after TBI and requires consideration of a number of factors, including the severity of injury, availability of health services, developmental needs (in the case of children) and living situation upon returning to the home. The economic burden is disproportionately experienced by those in low socio-economic status and more marginalised communities. Of course these population groups also more often experience injuries (TBI included). Consequently, it is not uncommon to find that people who are injured and are also financially compromised fall even further into poverty (a well-recognised phenomenon described as the 'injury poverty trap'). However, the results do suggest that there are limited resources being made available to TBI survivors who return home in NZ. At the very least it suggests an unmet need that is not being recognised. The challenge here is that groups who have less access to health care and accident insurance beyond the acute injury phase will have spuriously lower reported costs of injury. So it is possible that Maori, Pacific and some other marginalised groups in NZ, will have disproportionately lower estimated costs of injury than might be expected had they experienced the same access to services.

There are a number of challenges involved with accessing accurate information on the health services resources associated with care after having a TBI. Accurate information on some funded health services, such as primary care, home and vehicle modification, and vocational rehabilitation is difficult to obtain. Although there are electronic records containing this information, there is no central, accessible data with complete health services usage. Some information on cost of health services from the ACC schedule of treatment was obtained; however, selected services were routinely given on medical or rehabilitation wards and the costs of these medications were reflected in the bed day cost at hospitals. Therefore, this approach does not allow an accurate identification of the difference in costs between individuals. Accurate information on on-going health services is held by ACC's claims database, but was not accessible for the current study. These limitations may have resulted in some underestimates of the costs; therefore, the results of the study should be interpreted with caution.

### Implications of the current estimates and projections of the study

Previous authors have concluded that the incidence of mild TBI is far greater than was previously estimated (Feigin et al., 2013). It is accepted that mild TBI constitutes up to 95% of all cases and a large number of mild cases are not treated in hospitals (66% [458/691]). Almost 70% of all TBI cases were attributable to children and young adults; men are known to have a 77% greater risk of TBI than women in NZ. Current data in NZ, suggests that TBIs were mostly due to falls (41%), mechanical forces (21%) and transport accidents (18%). Understanding the external causes of injury may bring about primary prevention ideas. Interestingly, falls are the leading cause of TBI. Yet there is less evidence available for fall prevention especially among children and young adults, whereas previous fall prevention has focused heavily on the elderly population. Fall prevention

awareness messages at home, school and the workplace should be a priority. Unlike other countries (Delen et al., 2006; Hoang et al., 2008) traffic accidents were the third leading cause of non-fatal TBI in NZ. The difference is likely to be due to a number of explanations. Firstly, road traffic accidents are renowned as being the leading cause of injury deaths, yet TBI-related mortality in NZ was relatively low. Secondly, there is good reason to accept that good prevention measures are in place for the evidence clearly states that traffic accident prevention is a cost-effective intervention. For instance, i) wearing helmets for both motorcycles and bicycles, ii) mandatory seat belts, iii) child restraint, and iv) airbag use in motor vehicles can prevent TBIs (Bunn et al., 2003; Elder et al., 2002; Soori, Nasermoadeli, Ainy, Hassani, & Mehmandar, 2011). However more prevention targeting pedestrian and bus passenger injury might be necessary, especially in the urban centres where walking and taking public transport is encouraged. Pedestrian injury prevention is often lacking in developing countries.

The current research has demonstrated the importance of TBI as a public health problem and identified mild TBI as a priority. A conclusion drawn from the cost-of-illness study indicates that the economic burden of TBI is very significant and that improved prevention and treatment strategies are warranted. Substantial cost savings may be achieved by preventing TBI and targeting high cost individuals; in particular public health officials should identify measures to reduce the incidence of mild TBI.

At present, current efforts in NZ to reduce brain injuries have been based on best available surveillance information. Common limitations on current literature are that it is primarily based on hospital and clinical databases. Although there are some discrepancies in case definition, most have relied on clinical diagnosis (i.e. ICD-10 codes). There is a possibility of missing mild cases that may have been treated in the emergency department but not admitted into hospital or misclassification into other injuries. This thesis highlights the importance of the need for on-going surveillance for TBI to provide useful information to inform decision makers on 1) resource allocation, 2) guiding development of prevention measures, and 3) the importance of the “value for money “of the health care provided.

## Strengths and weaknesses of the study

The method for the current study was designed to be extremely thorough and is one of very few studies to meet criteria for “ideal” TBI incidence study (Barker-Collo & Feigin, 2009; Theadom et al., 2012). Similar hot-pursuit data ascertainment methods used in this study have been used successful in Auckland for the incidence of stroke for three decades (Anderson et al., 2005; Bonita et al., 1993; Feigin et al., 2003; Krishnamurthi et al., 2014). Still no method is perfect; in addition given the access to nationwide hospitalisation data it is likely that any missed cases were mild rather than moderate to severe.

A limitation of the current study is the absence of a control sample (i.e. a cohort without TBI) to quantify the additional burden by comparing the outcomes of those with TBI to those without. (Although a matched sample may be possible by means of statistical techniques such as propensity score matching (Dehejia & Wahba, 2002), adjusting for age, gender, ethnicity and socio-economic status.) Unfortunately it was not feasible to obtain such a control sample given that the full BIONIC study included those who were aged under 16 years

and assessed on four follow-up occasions each (i.e. baseline, one, six and twelve months). A controlled sample could be achieved using national hospitalisation data; however, a large number of cases were mild (95% of all cases) and managed in the community (i.e. not hospitalised).

Details on the mechanisms of injury were previously published (Feigin et al., 2013); similarly the detail of sports-injury mechanisms is also now available in the press (Theadom et al., 2014). Complications associated with having a TBI such as diffuse axonal injury, haemorrhage or intracranial pressure were obtained using medical codes extracted from hospital medical records and were reviewed weekly by a diagnostic adjudication team (which included neurologists, neuropsychologists and other allied health professionals). The costs associated with the different types of mechanisms were included in the results (e.g. injuries due to road traffic accidents, sports related etc. and were presented together on a population level. The relationship between impairment and functional consequences on productivity or performance in the workplace is very interesting. However, it is beyond the scope of this thesis.

The overall mortality rate collected from the BIONIC study was very low (crude death rate 10 cases per 100,000 person-years), and the costs associated with mortality were included in the study (e.g., hospitalisations and end-of-life care). Because the data collection period ended at 12 months, no data were available on the long-term costs. However TBI survivors were asked at 12 months to indicate the extent to which they had recovered from their TBI. We then applied this percentage to their costs for the first year to approximate the long-term costs. Lifetime costs reported in this thesis should be viewed as only an approximate and the study highlights the need for a longitudinal study to identify the long-term costs and outcomes.

The COI results reported in the current study provide significant relevance to the cost of TBI in other high income countries. While it is accepted that there are international differences between health systems, NZ in particular is often a very good source of international benchmarking, because it has features that map on to many different systems in developed countries (Minister of Health, 2013). For instance, there are elements which align to the other publicly funded healthcare systems such as the National Health Service in the United Kingdom, the Dutch healthcare system in the Netherlands and also to a more North American and Australian paradigm.

The reported medical care cost for moderate/severe cases was likely to be under-powered to detect statistically significant differences within this group. The BIONIC sample consisted of 1,369 newly registered TBI cases; of these 725 cases (53%) consented to follow up with 5% (n=34) identified as having a moderate/severe injury. Although the results are consistent with previous literature concluding that medical costs increase with higher injury severity, further investigation among moderate to severe cases may be needed. While there were some limitations of the data on community and home support; the findings included some estimated costs based on responses in the baseline and subsequent surveys. While more extensive data collection would provide more accurate estimates; the estimates provided are likely to be indicative of the level of support people are actually receiving.

A more serious source of underestimation is the potential lack of access to community and home support. Previous work with other vulnerable populations in New Zealand (e.g. support for frail elderly or stroke sufferers) suggests that people in New Zealand frequently are not provided with adequate support services (Brown, 2009; Dyall, Feigin, Brown, & Roberts, 2008). Thus, the more significant source of underestimation of the 'true' cost of TBI may be the lack of access to services. Unfortunately, it was not possible to assess the level of unmet need in this study.

Furthermore the indirect costs estimated in this study may look low, particularly when one considers the significant impact that TBIs can have on people with severe injuries. The relatively low estimates arise because they are *average* estimates that include those who had only minor or no impairment at 12 months post injury. Lifetime costs were determined based on the responses from both mild and moderate/severe TBI sufferers at 12 months (i.e. whether there were persistent problems at 12 months). Most of those reporting on-going problems were people with moderate/severe TBI, but there were some mild sufferers with on-going problems.

In addition, extrapolating costs from one region (Hamilton and Waikato district) to the entire country is subject to error, particularly if differences in lifestyles, clinical practices and treatment options impact rates and health service usage. The methodology did not provide accurate estimates of total caregiver time and effort in supporting injured persons. Lifetime costs were based on short-term data; therefore, it should be viewed as an estimate. But it highlights the need for a longitudinal study of the long-term effects. These issues will be addressed in the BIONIC four-year outcomes study.

## Suggestions for future research

Based on current estimates, the cost of treating TBI varies greatly with the majority of sufferers having only minimal costs. However, high cost TBI sufferers can incur significant costs, and there are differences between treatments received as a function of severity of injury. The economic burden for TBI is high, but significant cost savings and improvements in outcomes may be achieved by targeting high cost individuals. Given the considerable costs associated with TBI, further investigation of the cost effectiveness of: i) prevention strategies, ii) early management and detection, and iii) a variety of rehabilitation services aimed at improving TBI, should be a priority. It is strongly recommended that it is important to describe the prevention strategies that are available, and this data is relevant in helping understand the cost savings that might result from a particular strategy. Outlining the cost effectiveness of strategies to prevent TBIs and improve outcomes from TBI sufferers is the subject of the next phase of research. It also highlights the need for decision makers to form criteria around not only the effectiveness of proposed preventions but also to further explore the acceptability, equity and economic feasibility of the intervention.

Substantial gaps in the literature remain with respect to investigating the long-term outcomes on quality of life, on-going healthcare service utilisation and informal carer costs associated with TBI. It is also interesting that internationally, fall prevention focuses on the elderly population, yet falls are identified as the leading cause of TBI in the current study. The same is true in NZ, with the majority of fall prevention initiatives

targeted to those aged 65 years or older. The New Zealand Fall Strategy (Minster of ACC, 2005) also acknowledges that a gap exists. Opportunity exists to further investigate the effectiveness of fall prevention interventions among children and including alcohol prevention activities is something worth considering for fall among young adults (Gentiello et al., 1999). This study has identified evidence-based messages that can be used to guide primary prevention strategies for TBI.

### Recommendations for further research

The current research has raised important implications for future research, practice and policy in NZ.

Key recommendations for further research are:

1. At present, less is known about the long-term consequences associated with TBI. A longitudinal study observing risk factors, comorbidity, healthcare usage, return to work and health status is needed.
    a) Examine the impact of TBI on quality of life and social and economic costs.
2. This thesis has demonstrated that a COI study can be carried out using population-based incidence and self-reported health usage data. Further COI studies should be carried out every ten years in conjunction with large population-based incidence studies. This will not only inform public health surveillance, but can also be used as an evaluation of improvement measures by comparing rates of injury, associated risk factors and costs between decades.
3. There is a need for standard health economic data, whether it is in the form of self-reported health care and service use or as a guideline to assist researchers conducting such analysis. This will ensure that future studies will be collecting similar information that is comparable.
4. Further cost-effectiveness studies are needed to assess the efficiency of the following.
    a) Current interventions aiming to prevent injuries should be a priority, as they are important for informing decision making.
    b) A range of early management and neuroimaging for all TBIs and to the investigation of further options of whether all mild TBI or selected mild TBI receive CT scanning.
    c) Integrated rehabilitation services aimed at improving the quality of life and health outcomes for people with moderate/severe TBI.
5. As the current COI study reported costs based on patterns of resources used, it is possible that some people with TBI that go untreated or have limited access to health care services or compensation beyond one year post TBI will have lower costs. Further COI studies need to identify the "***additional***" resources (i.e. community and home services) needed by TBI sufferers and their families/caregivers:
    a) For example, of those who went untreated or have limited access to resources post TBI, what proportion of these individuals needed additional resources in the first instance, but were unable to access them (i.e. identifying unmet need)?
    b) The current study did not account for informal caregiving costs borne by the families and friends of the individual. Further study is required to investigate the amount of informal care provided and to estimate the cost of that care.

6. Further evaluation of current interventions for TBI is needed to identify to what extent the intervention works in practice. This information will be used to guide the development of new prevention interventions including strategies to make sure people with TBI receive needed care.

Key recommendations for practice are:

7. There is a need for central accessible data with complete health service usage.
8. Due to the high TBI incidence among Maori populations in NZ, more culturally appropriate prevention messages are merited:
    a) to extend current interventions to include ethnic-specific language translation of general public health messages and aired on Maori radio and television networks; or
    b) to develop an injury prevention programme based on a kaupapa Maori framework, incorporating appropriate Tikanga-based programmes similar to the PHARMAC's 'one heart healthy lives' programme.

Key recommendations for health policy are:

9. Increase public health awareness and education efforts in the prevention of mild TBI particular from falls, at the home, school, workplace or through sport.

This thesis has provided important information for quantifying not only the burden of TBI to NZ society, but also contributes towards the development of public health policies for reducing the incidence of TBI and policy decisions on health care delivery. Further studies are required to confirm the findings. Few high quality COI evidence exists for TBI. This thesis adds value and has demonstrated that information on the cost and patterns of health service usage can assist decision makers and public health officials anticipate and budget for health care resources needed to detect and treat TBI. It further provides evidence towards assessing whether new interventions for testing or treating are cost effective and to identify disparities and inequalities in accessing and delivery of health services post TBI. Lastly, the cost per case of TBI can also inform potential cost savings from preventing TBI particularly for high cost individuals.

# Appendices

# Appendix one: Search methods

**Database: EBSCO Health database a collection of health databases**

**Sources included: Biomedical Reference Collection: Basic, CINAHL Plus with Full Text, Health Business Elite, Health Source - Consumer Edition, Health Source: Nursing/Academic Edition, MEDLINE, Psychology and Behavioural Sciences Collection, SPORTDiscus with Full Text, Dentistry & Oral Sciences Source**
**Search Strategy:**
**----------**

1. Economics/
2. "costs and cost analysis"/
3. Cost of illness/
4. Health care costs/
5. Direct service costs/
6. indirect costs/
7. Drug costs/
8. Employer health costs/
9. Hospital costs/
10. Health expenditures/
11. exp economics, hospital/
12. exp economics, medical/
13. Economics, nursing/
14. Economics, pharmaceutical/
15. exp "fees and charges"/
16. (low adj cost).mp.
17. (high adj cost).mp.
18. (health?care adj cost$).mp.
19. (fiscal or funding or financial or finance).tw.
20. (cost adj estimate$).mp.
21. (cost adj variable).mp.
22. (unit adj cost$).mp.
23. (economic$ or pharmacoeconomic$ or price$ or pricing).tw.
24. Population based study/
25. Community based study/
26. Cohort study/
27. Prospective study
28. Retrospective study
29. Head injury/
30. Head trauma/
31. Brain injury/
32. Traumatic brain/
33. Traumatic brain injury/
34. Brain concussion/
35. OR/1-23
36. OR/24-28
37. OR/29-34
38. 35 AND 36 AND 37

# Appendix two: Quality checklist for health economic studies

Checklist adapted from (Drummond et al., 2005).

1. **Was a clear definition of the illness given?**

   **This need not be in one statement but may be a combination of statements throughout the article*

2. **Were epidemiological sources carefully described?**

   **This need not be in one statement but may be a combination of statements throughout the article*

- Score a "yes" if the epidemiological sources were stated

3. **Were costs sufficiently disaggregated?**

- Score "yes" if:

   a. results were projected, short-term results were presented

4. **Were activity data appropriately assessed?**

- Score a "yes" if:

   a. subgroup analyses were specified in a protocol, statistical analysis plan, or study concept document of the health economic analysis and referenced in the manuscript

   b. if estimate came from one source pre-specified at the beginning of the study or if no subgroup analysis was performed

5. **Were all sources of all cost values analytically described?**

- Score a "yes" if sources of costs were clearly described, and statistical analysis was used to address sampling variation AND sensitivity analysis covered more than one assumption

6. **Were unit costs appropriately valued?**

- Score "yes" if (a) - (c) are satisfied:

   a. Important and relevant costs and consequences for each alternative were identified

   b. Costs and consequences were measured accurately in appropriate physical units

   c. Unit values for costs and consequences were credible and their source clearly described

7. **Were the methods adopted carefully explained?**

- Score "yes" if (a) - (d) are all satisfied:

a. Study methods for estimating both the numerator and denominator were displayed in a clear, transparent manner

b. Numerator was displayed in a clear, transparent manner; presented group-specific costs and incremental difference in costs

c. Denominator was displayed in a clear, transparent manner; presented group-specific effects and incremental difference in effects

d. If a valid and reliable scale/measure was used OR if such scales/measures were not used, justification was given for the measures/scales used

**8. Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

- Score "yes" if :

a. Justification for discount rate was provided for costs and benefits that occurred beyond a one-year period

**9. Were the major assumptions tested in a sensitivity analysis?**

- Score "yes" if:

a. Main assumptions, and limitations were stated

b. Main assumptions were justified

**10. Was the presentation of study results consistent with the methodology of the study?**

- Score "yes" if the conclusions/recommendations of the study were in agreement with the results reported; conclusions/recommendations should include aspects of (a-e).

a. Intelligently interpreted index/indices

- Conclusions about cost analysis cannot be made based on inappropriate statistical testing (i.e. non-parametric testing)

b. Were comparisons made with others who answered the same question or answered a question of efficiency in TBI?

c. Generalisability of results, other settings or patient/client groups

d. Issues of implementation discussed

e. Other important factors in choice/decision under consideration

# Appendix three: Excluded studies

| Authors | Title of article | Reason for exclusion |
|---|---|---|
| Kristman, Cote, Yang, Hogg-Johnson, Vidmar and Rezai, 2014 | Health care utilisation of workers' compensation claimants associated with mild traumatic brain injury: a historical population-based cohort study of workers injured in 1997-1998. | This was an epidemiological study. It did not include or report health service use costs |
| Meerding, Mulder and Van Beeck, 2006 | Incidence and cost of injuries in the Netherlands | Included all injuries, TBI was not the main focus of the study |
| Bener, Yassir, Rahman and Mitra, 2008 | Incidence and severity of head and neck injuries in victims of road traffic crashes: in an economically developed country | This study did not report health service use costs |
| Yang, Yilan, Shih, Chang, Huang and Chien, 2011 | Long-term medical utilisation following ventilator-associated pneumonia in acute stroke and traumatic brain injury patients: a case-control study | TBI was not the main focus |
| Hoang, Pham, Vo, Nguyen, Doran and Hill, 2008 | The costs of traumatic brain injury due to motorcycle accidents in Hanoi, Vietnam. | Did not include TBI from all causes - only TBI due to motorcycle accidents |
| Bradbury, Wodchis, Mikulis, Pano, Hitzig, McGillivary, Ahmad, Craven and Green, 2008 | Traumatic brain injury in patients with traumatic spinal cord injury: clinical and economic consequences. | Only included TBI with spinal cord injury - therefore higher expected costs could be associated with this sample |
| Singh, Vaishya, Gupta and Mehta, 2006 | Economics of head injuries | Did not report detailed health service costs aggregated by acute, rehabilitation, outpatient or community services |

# Appendix four: Included studies

**Ref: Mc Garry et al., (2002) Outcomes and Costs of Acute Treatment of Traumatic Brain Injury**

**Was a clear definition of the illness given?**

YES

Traumatic brain injury was briefly described. TBI was identified by reviewing discharge records from January 1 1997 through to June 30 1999 with recorded ICD-9-CM diagnosis codes (ICD-9-CM 800.1–800.4, 800.6–800.9, 801.1–801.4, 801.6–801.9, 803.1–803.4, 803.6–803.9, 804.1–804.4, and 804.6–804.9) as well as brain injury (851–854, inclusive of all fourth and fifth digit classifications).

**Were epidemiological sources carefully described?**

YES

All hospital discharge records were reviewed. TBI was selected using the *International* Classification of Diseases, 9th Revision, Clinical Modification codes at admission. Dates of admission and discharge, source of admission (e.g. emergency department, transfer from another acute-care institution), billed charges, payer, and discharge disposition were also reported.

**Were costs sufficiently disaggregated?**

PARTIALLY

Although hospitalisation costs were displayed by severity of injury, it would have been more helpful if the authors also gave cost estimates for all TBI and disaggregated by acute rehabilitation and outpatient services.

**Were activity data appropriately assessed?**

YES

Patient flow, disposition after discharge were adequately traced using appropriate methods. Subgroup analyses were performed on severity of injury and cause of injury.

**Were all sources of all cost values analytically described?**

YES

Total costs of hospitalisation were estimated from billed charges using cost/charge ratios from the Health Care Financing Administration Prospective Payment System.

**Were unit costs appropriately valued?**

NO

Unit costs or cost calculation were not described nor were the unit costs per item or weighted case value given.

**Were the methods adopted carefully explained?**

YES

All parameters were adequately described in the methods section. Outcome measures of interest included average length of stay in hospital, in-hospital mortality (both overall and within two days of admission), and patients' discharge disposition as well as hospitalisation costs.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

This study only assessed acute hospitalisation costs after having a TBI within the first month of care. This study did not address or attempt to estimate first-year costs or lifetime costs.

**Were the major assumptions tested in a sensitivity analysis?**

NO

There was no mention of main assumptions within the analysis section.

**Was the presentation of study results consistent with the methodology of study?**

PARTIALLY

Although the study presented results of the outcomes tested, the study did not present disaggregated costs by subgroup. Conclusions about cost analysis were adequately reflected.

**Ref: Schootman et al., (2002) National Estimates of Hospitalisation Charges for the Acute Care of Traumatic Brain Injuries.**

**Was a clear definition of the illness given?**

YES

TBIs were identified using the Centres for Disease Control and Prevention case definition [11]. All hospital discharge records that contained, in one or more diagnostic fields, an International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnostic code in the ranges 800–801, 803–804 or 850–854 were considered to be TBIs.

**Were epidemiological sources carefully described?**

YES

Rates of hospitalisation were calculated using 1996 population data available from the Bureau of the Census. The numerator consisted of the number of hospitalisations, rather than the numbers of individual patients since patient identifiers were not available.

**Were costs sufficiently disaggregated?**

YES

Costs were reported by sex, age, race, severity and hospital region. As costs were derived using cost weights, the cost estimates were inclusive of acute and rehabilitation services.

**Were activity data appropriately assessed?**

YES

Subgroup analyses were specified in the statistical analysis plan in the manuscript.

**Were all sources of all cost values analytically described?**

YES

The billed charges were used to describe the burden of TBI in the US. The NIS contains billed charges, rather than the actual economic cost of hospitalisation for TBI. Billed charges differed from the amount paid because of discounts, deductibles, co-payments and co-insurances.

**Were unit costs appropriately valued?**

YES

To obtain national estimates of the charges, sample weights available were used in the NIS in all analyses. Besides mean charges, the median charge to reduce the influence of large values on the mean was calculated.

**Were the methods adopted carefully explained?**

YES

Study methods for estimating the rates were described in a clear manner. All valid and reliable scales/measures used were justified.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

Costs were not analysed beyond one year.

**Were the major assumptions tested in a sensitivity analysis?**

NO

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions of the study were in agreement with the results reported.

**Ref: Ettaro et al., (2004) Abusive Head Trauma in Young Children: Characteristics and Medical Charges in a Hospitalised Population**

**Was a clear definition of the illness given?**

YES

All admissions with the following ICD-9-CM diagnostic codes were examined to identify head trauma events: intracranial haemorrhage following injury (852.00–852.59, 853.00–853.19); skull fracture, excluding fracture of face bones (800.00–800.99, 801.00–801.99, 803.00–803.99, and 804.00–804.99); intracranial injury of other and unspecified nature (854.00–854.19); unspecified head injury (959.01); and shaken baby syndrome (995.55).

**Were epidemiological sources carefully described?**

PARTIALLY

There was no mention of epidemiological calculation. There was mention of case identification through a review of hospital records.

**Were costs sufficiently disaggregated?**

PARTIALLY

Although the study reports hospitalisation costs only, due to cost source, the cost estimates were not able to be reported by service phase (i.e. emergency, acute and rehabilitation).

**Were activity data appropriately assessed?**

YES

Details of case identification were clearly described, with special attention given to inclusion criteria for the subgroup analyses.

**Were all sources of all cost values analytically described?**

YES

Medical and billing records were abstracted for all eligible subjects. Information gathered from the medical records included demographic information, injuries sustained, initial stated cause of injury, time/date of injury, discharge status (dead, rehabilitation institute, home, foster care), length of stay (LOS), insurance status (Medicaid, commercial insurance, or self-pay), and whether or not a child abuse report was filed with child protective services.

**Were unit costs appropriately valued?**

PARTIALLY

Hospital charges were identified from associated UB-92 forms (National Uniform Billing Committee, 1996) for all identified events. The UB-92 form is a standard financial form accepted by the Health Care Financing Administration. Only charges associated with the acute event (initial hospitalisation) were included. If the patient was admitted from an emergency department (ED) visit at CHP, the charges associated with this visit were also included in the estimate of hospital charges; but when patients were transferred from outside hospitals, the ED visit was not included.

Study based on internal estimates- unit costs were not provided.

**Were the methods adopted carefully explained?**

YES

The study clearly described the setting, study design, classification of subjects' outcome measures in a transparent manner.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

No

Only hospitalisation costs were analysed.

**Were the major assumptions tested in a sensitivity analysis?**

NO

There was no mention about any assumptions made in the analysis or any uncertainties addressed.

**Was the presentation of study results consistent with the methodology of study?**

YES

The presentation of the current study results was consistent with the methodology of the study. The study found that the hospital charges (1999 dollars) were significantly higher for abused subjects (mean±*SD*: $40,082±$58,004) versus non-abused (mean±*SD*: $15,671±$41,777).

**Ref: Vangel et al., (2005) Long-Term Medical Care Utilization and Costs among Traumatic Brain Injury Survivors**

**Was a clear definition of the illness given?**

PARTIALLY

However TBI complications were reflected by billings associated with TBI-related International Classification of Diseases, 9th revision, codes.

**Were epidemiological sources carefully described?**

PARTIALLY

Calculation of rates was not clearly mentioned in the methods section of the study. However the authors did describe source of data (i.e. participants were enrolled in the Rehabilitation Institute of Michigan Primary Care Program and were at least one-year post injury at entry into the study protocol).

**Were costs sufficiently disaggregated?**

YES

Short-term results were presented.

**Were activity data appropriately assessed?**

YES

Costs were presented by healthcare category and by source of finance.

**Were all sources of all cost values analytically described?**

YES

Healthcare utilisation and cost outcomes were codified in the following manner: billings were used as an index of utilisation, as they reflected an instance of a service, medication, or supply. Subcategories of billings included: home health care, primary care, outpatient services, medications, medical equipment and supplies, inpatient treatment, residential treatment, transportation, and case management by the State of Michigan. Costs were reflected in the charge (i.e. amounts billed for services, medication, or supplies).

**Were unit costs appropriately valued?**

PARTIALLY

Although the costs were well described there were no references to or mention of unit costs used in the study.

**Were the methods adopted carefully explained?**

YES

The authors described in detail the methods used in their study. As stated in their abstract, this was a retrospective cohort study of healthcare billings for 63 survivors of traumatic brain injury, over a 19-month period, using a state-sponsored Medicaid program. The relationship of indicators between injury severity and disability to billings and payments was investigated. Mean age at time of injury was 33 years. Mean highest Glasgow Coma Scale rating immediately after brain injury was eight.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

Costs were estimated within one year.

**Were the major assumptions tested in a sensitivity analysis?**

YES

Before analysis, the variables were screened for assumptions of univariate and multivariate parametric tests. Each of the billing outcome variables showed significant skew. Some of these variables were amenable to transformation, which improved normality and linearity to within acceptable levels for parametric analyses.

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions of the study were in agreement with the results reported.

- The study reported appropriate statistical testing (i.e. non parametric testing).

**Ref: Faul et al., (2007) Using a Cost-Benefit Analysis to Estimate Outcomes of a Clinical Treatment Guideline: Testing the Brain Trauma Foundation Guidelines for the Treatment of Severe Traumatic Brain Injury.**

**Was a clear definition of the illness given?**

YES

The authors applied the International Classification of Diseases Clinical Modification diagnosis codes found in the CDC Traumatic Brain Injury Case Definition to the 2002 National Hospital Discharge Survey (NHDS) public use dataset.

**Were epidemiological sources carefully described?**

YES

The study population and inclusion criteria used were clearly described.

**Were costs sufficiently disaggregated?**

YES

Faul et al. described in great detail the source of medical and social costs and presented the results in a consistent manner. The results were projected to estimate lifetime costs per person.

**Were activity data appropriately assessed?**

YES

BTF Adoption is used to describe the state of medical care as it relates to hospital implementation of the BTF guidelines.

**Were all sources of all cost values analytically described?**

YES

Direct medical and societal costs for TBI mortality and morbidity were calculated from *The Incidence and Economic Burden of Injuries in the United States.* Societal costs for TBI mortality were calculated by summing long-term wage and production loss costs. The average cost for rehabilitation per day was $1,423.15 in 1996, which was adjusted to be $1,631.77 in 2002 using an inflation calculator.

**Were unit costs appropriately valued?**

PARTIALLY

Average cost of direct medical, societal and rehabilitation costs were sourced from various sources but were clearly stated.

**Were the methods adopted carefully explained?**

YES

The study design used decision-modelling techniques to estimate expected outcomes for people with TBI and associated costs. Using data from various sources the authors projected the results of Brain Trauma Foundation guideline adoption to estimate the impact of widespread adoption across the United States.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

No mention of discounting costs to reflect present net value of costs for costs projected over their lifetime of the cohort.

**Were the major assumptions tested in a sensitivity analysis?**

YES

As stated in the methods section, the biggest difference in outcomes was the number of expected deaths. Because these differences come from uncertain sources, a sensitivity analysis was performed on these variables.

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions/recommendations of the study were in agreement with the results reported. The cost analysis did not use appropriate methods and statistical testing. The authors concluded that adoption of the BTF guidelines for the treatment of severe TBI would result in substantial savings in costs and lives.

**Ref: Rockhill et al., (2010) Healthcare Costs Associated with Mild Traumatic Brain Injury and Psychological Distress in Children and Adolescents**

**Was a clear definition of the illness given?**

YES

The authors clearly describe the TBI classification definition of mild TBI according to CDC criteria: International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) [31] codes indicated brief (<1 hour) or no loss of consciousness and no traumatic intracranial lesions.

**Were epidemiological sources carefully described?**

PARTIALLY

No mention was made about the hospitalisation rates found. But the authors clearly described the sources used to collect information on mild TBI patients. As stated within the methods section, the study utilised computerised records of enrolees in a large staff model HMO, Group Health Cooperative of Puget Sound (GHC) that serves _500,000 members throughout Washington State.

**Were costs sufficiently disaggregated?**

YES

The author presented cost results by health care category.

**Were activity data appropriately assessed?**

YES

Subgroup analyses were specified in the statistical analysis plan, or study concept document of the health economic analysis and referenced in the manuscript.

**Were all sources of all cost values analytically described?**

YES

Costs were determined using the HMO's automated cost accounting system. These included outpatient services for general medical or mental healthcare, inpatient medical and mental health services, emergency visits, pharmacy costs, laboratory and radiology costs.

**Were unit costs appropriately valued?**

PARTIALLY

The cost sources were clearly described but the authors fell short on detailed descriptions of unit values for costs and their source.

**Were the methods adopted carefully explained?**

YES

The author described in great detail the study population and valid measure used.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

PARTIALLY

A discount rate of 3% was stated for costs beyond the first year; however, no justification was given for the discount rate.

**Were the major assumptions tested in a sensitivity analysis?**

NO

No mention of uncertainty of the estimates.

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions/recommendations of the study were in agreement with the results reported.

**Ref: Chen et al., (2012) Direct Cost Associated with Acquired Brain Injury in Ontario**

**Was a clear definition of the illness given?**

YES

Patients with the following diagnoses were classified into TBI category: fracture of skull, intracranial injury, late effects of injuries, poisonings and toxic effects, and other external causes. Patients with a stroke in any diagnosis position and patients with hospital-acquired ABI diagnosis were excluded.

**Were epidemiological sources carefully described?**

YES

The epidemiological sources were stated.

**Were costs sufficiently disaggregated?**

YES

Costs were presented by healthcare category within the first year and again in year two and three.

**Were activity data appropriately assessed?**

YES

Subgroup analyses were specified in a study concept document of the health economic analysis and referenced in the manuscript.

**Were all sources of all cost values analytically described?**

YES

According to the authors, patient-specific health care utilisation data were abstracted from provincial administrative databases and then linked across databases using patients' scrambled health card identifier. Given the source of cost described, the authors also provided appropriate statistical analysis that was used.

**Were unit costs appropriately valued?**

YES

Unit costs of inpatient acute care, ED visits, home care and complex continuing care were obtained from the Ministry of Health and Long-Term Care (MOHLTC) Health Data Branch website. The authors stated that each case cost was estimated by multiplying the weight by provincial cost per weighted case for acute care valued at $5,212 in 2007. This unit cost was cited in the reference.

**Were the methods adopted carefully explained?**

YES

This is a population-based cohort of patients discharged from acute hospital with an ABI code in any diagnosis position in 2004 through to 2007 in Ontario. Participants were identified from administrative data. Publicly funded health care utilisation was obtained from several Ontario administrative health care databases. Patients were stratified according to traumatic and non-traumatic causes of brain injury and whether or not they were discharged to an inpatient rehabilitation centre. Health system costs were calculated across a continuum of institutional and community settings for up to three years after initial discharge.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

This study reported costs over a one-year period but does not state whether the projected results were adjusted using a justified discount rate.

**Were the major assumptions tested in a sensitivity analysis?**

YES

The main assumptions around cost estimates used within emergency department and acute visits were clearly described and justified.

**Was the presentation of study results consistent with the methodology of study?**

YES

The authors present a well-written paper on the direct costs associated with acquired brain injury in Ontario. Their findings were consistent with previous literature that the direct costs are substantial and vary considerably by cause of injury.

**Ref: Leibson et al., (2002) Medical Care Costs Associated with Traumatic Brain Injury over the Full Spectrum of Disease: A Controlled Population-Based Study**

**Was a clear definition of the illness given?**

YES

Similar to other studies using hospital administration data. The current study used the extensive list of the International Classification of Diseases, 9th Revision-Clinical Modification (ICD-9-CM) and Mayo adaptation of H-ICDA codes used to identify cases.

**Were epidemiological sources carefully described?**

YES

The epidemiological sources were stated. The authors used the Rochester Epidemiology Project (REP) resources to estimate long-term medical costs for clinically-confirmed incident TBI across the full range of severity after controlling for pre-existing conditions and co-occurring injuries.

**Were costs sufficiently disaggregated?**

YES

Short-term costs were presented (1-6 months), medium term (6-12 months) and long term (1-6 years). Costs were aggregated together; they were not disaggregated by health care service category.

**Were activity data appropriately assessed?**

YES

The authors clearly described and referenced sources of data collection and linking/matching across data sets by patient identification code. The data source follows the cohort over six years.

**Were all sources of all cost values analytically described?**

YES

Costs were clearly described. Through an electronic data-sharing agreement signed by administration at Mayo Clinic and OMC, patient-level administrative data on health care utilisation and associated billed charges incurred at these institutions are shared and archived within the Olmsted County Healthcare Expenditure and Utilization Database (OCHEUD) for use in approved research studies

**Were unit costs appropriately valued?**

PARTIALLY

The authors referred the reader to another study to review costing methods.

**Were the methods adopted carefully explained?**

YES

The authors clearly described the study in a clear and transparent manner and presented costs by subgroup analysis.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

No justification for discounted rate was provided for costs that occurred beyond a one-year period.

**Were the major assumptions tested in a sensitivity analysis?**

NO

No mention of uncertainty or main assumption is made in the study.

**Was the presentation of study results consistent with the methodology of study?**

YES

The study conclusions were in agreement with the results reported.

**Ref: Yuan et al., (2012) Characteristics of Acute Treatment Costs of Traumatic Brain Injury in Eastern China—A Multi-Centre Prospective Observational Study**

**Was a clear definition of the illness given?**

PARTIALLY

The authors stated that the diagnosis of TBI was made by admitting neurosurgeons or emergency room physicians and confirmed by computed tomography (CT) within six hours of admission.

**Were epidemiological sources carefully described?**

PARTIALLY

Epidemiological sources were briefly stated.

**Were costs sufficiently disaggregated?**

YES

Acute costs were presented by subgroups (sex, age, cause of TBI).

**Were activity data appropriately assessed?**

PARTIALLY

It was unclear as to the pathway followed. But this study only assessed the acute phase of hospitalisation, probably due to the lack of data for the post-acute phase.

**Were all sources of all cost values analytically described?**

PARTIALLY

Unlike previous studies the authors did not elaborate extensively on the sources of cost. However the authors stated that any patient who had incomplete financial data was excluded. Total acute hospitalisation treatment costs derived from unsubsidised total hospital billings were used as the main outcome measure, as these were the most robust means of obtaining the total care costs per inpatient.

**Were unit costs appropriately valued?**

NO

No evidence of important and relevant costs and consequences for each alternative is identified. Unit values for costs were not source clearly.

**Were the methods adopted carefully explained?**

PARTIALLY

The authors could have described in more detail patient selection and data source. But they did mention that clinical variables included demographic variables, such as age, sex, date of injury, live state, place of occurrence, payment type, hospital type, ward type, and date of admission and discharge. The latter two variables were used to compute the acute LOS (days). Ward types were reclassified into the neurosurgical intensive care unit (NICU), intensive care unit (ICU), and general ward.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

No justification for discount rate was provided for costs that occurred beyond a one-year period.

**Were the major assumptions tested in a sensitivity analysis?**

NO

No mention of main assumptions, and limitations were stated.

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions of the study were in agreement with the results reported.

**Ref: Rockhil et al., (2012) Health Care Costs Associated with Traumatic Brain Injury and Psychiatric Illness in Adults**

**Was a clear definition of the illness given?**

YES

Subjects were persons 15 years or older who were diagnosed with mild or moderate to severe TBI in the emergency department (ED), hospital, or outpatient clinic in 1993, and who were enrolled in GHC but had not had an International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnosis of TBI in the year prior to the study.

**Were epidemiological sources carefully described?**

YES

The epidemiological sources were stated. This prospective cohort study used computerised records of enrolees in a large staff model health maintenance organisation (HMO), Group Health Cooperative of Puget Sound (GHC).

**Were costs sufficiently disaggregated?**

YES

Short-term and one-year results were presented by the following healthcare categories: primary care, specialty care, emergency care, medication, radiology outpatient care, ambulatory care and inpatient care.

**Were activity data appropriately assessed?**

YES

Subgroup analyses were specified in the methods document of the health economic analysis and referenced in the manuscript.

**Were all sources of all cost values analytically described?**

YES

Costs were determined using the HMO's automated cost accounting system. This system tracks all health care services provided for or paid for by GHC during the study period. These included outpatient services for general medical or mental health care, inpatient medical and mental health services, emergency visits, pharmacy costs, laboratory and radiology costs, and other health care services paid for by GHC.

**Were unit costs appropriately valued?**

PARTIALLY

Although the authors clearly described important sources and relevant costs were identified, unit values for costs were not sourced clearly.

**Were the methods adopted carefully explained?**

YES

The authors clearly described the use of data sources in the study outlining valid measures used.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

YES

Costs of health services in the Seattle/Puget Sound region were discounted 3% per year for years two and three.

**Were the major assumptions tested in a sensitivity analysis?**

PARTIALLY

There was no clear description of the main assumption used in the study, but the authors did conduct a sensitivity analysis using a Poisson model and log link in their proposed regression analysis to test for differences in costs between subgroups.

**Was the presentation of study results consistent with the methodology of study?**

YES

The conclusions of the study were in agreement with the results reported. The authors main findings were a significant interaction between moderate-to-severe TBI and psychiatric illness indicated a 3.39 times greater cost among patients with both exposures compared with those exposed to moderate-to-severe TBI without psychiatric illness.

**Ref: Farhad et al., (2013) Trends in Outcomes and Hospitalisation Costs for Traumatic Brain Injury in Adult Patients in the United States**

**Was a clear definition of the illness given?**

YES

As stated in the study the authors identified adult patients, ‡18 years of age, with a primary diagnosis of TBI using the International Classification of Disease, 9th Revision (ICD-9-CM) codes in the ranges 800.0–801.9, 803.0– 804.9, or 850.0–854. We used ICD codes 96.7, 96.70, 96.71, and 96.72 to identify patients with TBI who were mechanically ventilated.

**Were epidemiological sources carefully described?**

YES

The study used data from the Nationwide Inpatient Sample (NIS) sponsored by the Agency for Healthcare Research and Quality to determine the demographic and clinical characteristics of TBI patients for the two study periods (1993–1994 and 2006–2007).

**Were costs sufficiently disaggregated?**

NO

Costs were reported as an aggregated total for the year.

**Were activity data appropriately assessed?**

YES

Subgroup analyses were specified in a protocol, statistical analysis plan, or study concept document of the health economic analysis and referenced in the manuscript, if estimates came from one source pre-specified at the beginning of the study or if no subgroup analysis was performed.

**Were all sources of all cost values analytically described?**

PARTIALLY

National cost estimates, the Nationwide Inpatient Sample (NIS) provided both hospitalisation and discharge weights. Not all sources of costs were clearly described.

**Were unit costs appropriately valued?**

NO

The cost weight unit was not provided.

**Were the methods adopted carefully explained?**

PARTIALLY

The authors gave a brief description of the data source used. More details around costing would have been more useful.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

Results for costs did not occur beyond a one-year period.

**Were the major assumptions tested in a sensitivity analysis?**

NO

No mention of any assumptions was stated in the analysis.

**Was the presentation of study results consistent with the methodology of study?**

YES

The authors concluded that although the number of TBI admissions was reduced, a significant increase in average hospitalisation charges and in-hospital mortality rates was observed in 2006–2007 compared with 1993–1994.

**Ref: Stroup et al., (2013) Healthcare Utilisation and Costs of Veterans Screened and Assessed for Traumatic Brain Injury**

**Was a clear definition of the illness given?**

PARTIALLY

The study included a national retrospective sample of OIF/OEF veterans who received care at VA facilities in the United States between April 2007 (initiation of the mandatory TBI screen) and September 2008. The study examined the association between results of the TBI screen (positive, negative, or no screen) and patient characteristics, facility characteristics and healthcare utilisation. However the study fell short of defining TBI or explaining how they coded for the diagnosis.

**Were epidemiological sources carefully described?**

YES

The authors extracted data from various databases (namely VA National OEF/OIF Roster, VA National TBI health factors database, and comprehensive TBI evaluation databases).

**Were costs sufficiently disaggregated?**

YES

Costs were presented by outcome of TBI screen and healthcare category.

**Were activity data appropriately assessed?**

YES

**Were all sources of all cost values analytically described?**

YES

The authors examined the direct costs of health care from the VAs' (i.e. the payer/provider) perspective, where cost estimates reflect the VAs' expenditure for each veteran. Costs for outpatient care, outpatient pharmacy, and inpatient care provided by a VA facility were obtained from VA DSS NDEs. In summary, *total costs* per patient, which consisted of *total outpatient* (primary care, rehabilitation care, polytrauma care, mental health care, other specialty care, other VA outpatient, and non-VA outpatient costs), *total outpatient pharmacy* (chronic and acute medication costs), and *total inpatient* (short-term medical or surgical, SCI, psychiatric, rehabilitation, long-term care, and non-VA fee basis care) costs during the 12 months following the index date. Total outpatient costs also included costs on the day of the index visit and costs on the day of the TBI evaluation. All costs were adjusted to 2008 dollars using the Consumer Price Index.

**Were unit costs appropriately valued?**

PARTIALLY

All important and relevant costs for each health service were identified and in some cases cited in the references. However the authors did not clearly state the unit values for costs used.

**Were the methods adopted carefully explained?**

YES

The present study examined veterans who screened positive for a comprehensive TBI evaluation. A national retrospective study of OIF/OEF veterans receiving care at VA facilities between 2007 and 2008 was conducted.

The authors examined the association of the TBI screen with healthcare costs over a 12-month period following the initial evaluation.

**Were costs that went beyond one year discounted (3% to 5%) and justification given for the discount rate?**

NO

No justification for discount rate was provided for costs as the result did not extend beyond a one-year period.

**Were the major assumptions tested in a sensitivity analysis?**

NO

No mention of assumptions was stated.

**Was the presentation of study results consistent with the methodology of study?**

YES

The authors concluded that total healthcare costs of veterans who screened positive, screened negative, or had no TBI screening were $9,610, $5,184, and $3,399, respectively.

# Appendix five: Burden of traumatic brain injury in New Zealand article

**Te Ao B,** Tobias M, Ameratunga S, McPherson K, Theadom A, Dowell A, Starkey N Jones K, Barker-Collo S, Brown P, Feigin V, on behalf of the BIONIC Study Group. (2015). Burden of traumatic brain injury in New Zealand: incidence, prevalence and disability-adjusted life years. Neuroepidemiology 44:255-261

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# Burden of Traumatic Brain Injury in New Zealand: Incidence, Prevalence and Disability-Adjusted Life Years

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**Key Words**
Traumatic brain injury · Incidence · Prevalence · Disability-adjusted life years and DISMOD

**Abstract**
***Objective:*** The study aimed to estimate the incidence, prevalence and disability-adjusted life years (DALY) for traumatic brain injury (TBI) in New Zealand (NZ) in 2010. ***Methods:*** A multi-state life table model was constructed using inputs from the Brain Injury Outcomes New Zealand in the Community study for the first-ever incidence of TBI in a lifetime and its severity distribution, from the NZ Ministry of Health's Mortality Collection for the data on TBI mortality and from Statistics of NZ for the population data. The modeled estimate of prevalence was combined with the disability weights for TBI (by stage and severity level) from the Global Burden of Disease 2010 study to obtain estimates of health loss (DALYs) for TBI. ***Results:*** Approximately, 11,300 first-ever incident TBIs occurred in NZ during 2010, with 527,000 New Zealanders estimated to have ever experienced a TBI (prevalent cases). The estimated 20,300 DALYs attributable to TBI accounted for 27% of total injury-related health loss and 2.4% of DALYs from all causes. Of the total DALYs attributable to TBI, 71% resulted from fatal injuries. However, non-fatal outcomes accounted for a substantial share of the burden (29%) with mild TBI making the greater contribution of non-fatal outcomes (56%). ***Conclusions:*** The burden of TBI in NZ is substantial, and mild TBI contributes to a major part of non-fatal outcomes.


## Introduction

Traumatic brain injury (TBI) is a major cause of disability and death in New Zealand (NZ) [1]. In addition to these long-term impacts on personal and whanau/family wellbeing, TBI has major economic consequences in the society [2]. Robust information on the population-based


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epidemiology and health impact of TBI should guide health policy, including the allocation of resources to prevention, treatment and rehabilitation.

However, previous attempts to measure the impact of TBI suffer from major methodological limitations. For instance, many studies have focused solely on injuries that had been admitted to hospitals [3]. Case ascertainment often relies on clinical diagnosis alone [4, 5]. Yet, TBI is often overshadowed by other comorbid injuries [6]. Estimates based on routinely collected data may fail to identify a substantial proportion of TBI, especially mild cases [4, 7]. Approximately, 70–95% of injuries are classified as mild severity [1, 8], which have been managed in the community by primary care providers, and the patients are not hospitalized [7, 9].

The recently completed Brain Injury Outcomes New Zealand in the Community (BIONIC) study [1] was the first to assess the incidence of TBI for all severities across all age groups and in both rural and urban populations. The authors found that when community cases were included, the incidence of TBI, especially that of mild TBI, was far greater in NZ than had been previously estimated.

The current study combines incidence rates of regional brain injury from the BIONIC study with current mortality statistics and NZ population data to construct a multi-state life table model to estimate national incidence, prevalence and disability-adjusted life years (DALY) for TBI in NZ during 2010. The DALY is an integrated measure of health loss that combines both fatal and non-fatal health outcomes into a single metric [10].

## Materials and Methods

*Brain Injury Outcomes: NZ in the Community Study*

TBI was defined according to the World Health Organization (WHO) recommendations as an acute brain injury caused by mechanical energy to the head from external physical forces which resulted in the presence of one or more of the following: (1) confusion or disorientation, (2) loss of consciousness, (3) post-traumatic amnesia, and (4) other neurological abnormalities (e.g. focal signs, seizure) [11].

Incidence estimates were obtained from the BIONIC study. This is a large prospective population-based TBI register covering the total population of the Hamilton and Waikato districts of NZ (approximately 170,000 rural and urban residents). The population from Hamilton and Waikato districts has demographic and social characteristics that are reflective of the NZ population according to the 2006 NZ census data. Details on the methodology of the BIONIC study are described elsewhere [12, 13]. All cases (n = 1,369) of TBI were ascertained over a 12-month period between March 1, 2010 to February 28, 2011, using prospective and retrospective surveillance. Complete case ascertainment was assured by using multiple overlapping sources of information for all the newly hospitalized and non-hospitalized TBI cases (fatal and non-fatal). Hot pursuit methods were used to identify additional cases of TBI through cross-checks of general practitioner databases and hospital admissions.

Regional TBI incidence estimates and the definition of TBI severity utilized are reported elsewhere [1]. Our focus is on the estimation of first-ever incidence of TBI in a lifetime (n = 521); as a measure of true incidence, this is different from the injury rates (incidence and recurrent TBI) that had previously been reported [1]. TBI mortality was defined as deaths resulting from TBIs as registered in the NZ Ministry of Health's Mortality Collection (ICD10 S06.0–S06.9). Deaths from causes other than TBI are described as 'other cause' mortality. All-cause deaths and population denominator data were obtained from Statistics NZ.

*Current TBI Incidence, Prevalence and Mortality Estimates*

Age and sex structures of population census data during 2006 for Hamilton city (urban residents) and Waikato district (rural residents) were used as denominators to calculate age- and sex-specific TBI regional incidence. These data were then extrapolated over the NZ national population. Due to the low number of deaths recorded in the BIONIC study, TBI mortality rates for 2010 obtained from the national mortality collection were used.

Multi-state life tables were constructed using DISMOD II software [14, 15] as used in the Global Burden of Disease (GBD) studies for estimating the epidemiology of a disease. This software package is based on a series of algorithms reflecting the mathematical relationships between incidence, prevalence, remission, cause-specific mortality and 'other cause' mortality. The theoretical background and the application of multi-state life tables to epidemiology are discussed elsewhere [14, 16].

The model was built by first smoothing the input data using a 'moving average' interpolation, whereby smoothening out shape continuities between adjacent 5-year age groups prevents difficulties in modeling prevalence. The incidence estimates were considered more reliable than the cause-specific mortality estimates, which were derived from routine cause-of-death coding. Accordingly, the DISMOD modeling was carried out by anchoring on incidence, thereby giving less 'weight' to the excess mortality estimates. Remission was zero by definition (since at this stage we are modeling the prevalence of survivors of first ever in lifetime TBI, irrespective of disability level). Direct standardization was employed to age standardize the rate to the world population, using the WHO world standard population [17] for comparison of subgroups. Computing of 95% uncertainty intervals were performed using the 2.5th and 97.5th percentile of the distribution.

*Quantifying DALYs*

Population burden of TBI was measured in DALYs [10, 18]. DALYs can be expressed as the sum of the 'years of life lost' (YLL) and 'years lived with disability' (YLD). YLL was calculated by multiplying the number of deaths due to TBI by the remaining life expectancy at the age of occurrence in 5-year age bands. Remaining life expectancy at each age was taken from the GBD 2010 standard life table [19]. YLDs were calculated by multiplying the prevalence of the condition by severity level in each 5-year age band by the relevant disability weight, taken from the GBD 2010.

At 12 months post TBI, the proportion of participants identified as having no, mild or moderate/severe disability (defined by

**Table 1.** Modeled age- and sex-specific incidence of first TBI, 2010

| Age group, years | Rates per 100,000 | | | Number of new cases | | |
|---|---|---|---|---|---|---|
| | male | female | persons | male | female | persons |
| 0–4 | 685 (534–744) | 602 (557–651) | 644 (546–698) | 962 (750–1,044) | 811 (750–877) | 1,773 (1,500–1,921) |
| 5–9 | 591 (314–673) | 494 (458–529) | 543 (386–601) | 866 (460–986) | 691 (641–740) | 1,557 (1,101–1,726) |
| 10–14 | 563 (387–633) | 436 (404–468) | 501 (396–551) | 885 (608–994) | 649 (601–697) | 1,534 (1,209–1,691) |
| 15–19 | 556 (470–636) | 380 (357–406) | 469 (414–521) | 847 (716–970) | 562 (528–600) | 1,409 (1,244–1,570) |
| 20–24 | 466 (415–526) | 264 (249–283) | 365 (332–405) | 630 (561–711) | 359 (338–385) | 989 (899–1,096) |
| 25–29 | 342 (313–372) | 187 (180–196) | 262 (247–284) | 401 (367–436) | 235 (226–245) | 636 (593–681) |
| 30–34 | 232 (221–243) | 149 (143–155) | 189 (182–199) | 304 (290–318) | 218 (209–225) | 522 (499–543) |
| 35–39 | 173 (167–178) | 122 (119–126) | 146 (143–152) | 247 (239–255) | 194 (188–199) | 441 (427–454) |
| 40–44 | 164 (159–170) | 102 (99–104) | 132 (129–137) | 248 (240–256) | 166 (162–169) | 414 (402–425) |
| 45–49 | 192 (186–199) | 97 (94–99) | 143 (140–149) | 275 (266–284) | 146 (142–149) | 421 (408–433) |
| 50–54 | 202 (193–210) | 104 (101–106) | 152 (147–158) | 250 (239–262) | 133 (130–136) | 383 (369–398) |
| 55–59 | 164 (159–169) | 132 (128–136) | 148 (144–153) | 189 (184–195) | 156 (151–161) | 345 (335–356) |
| 60–64 | 164 (158–169) | 199 (189–207) | 182 (174–188) | 145 (140–149) | 181 (173–189) | 326 (313–338) |
| 65–69 | 112 (108–116) | 165 (159–171) | 139 (134–144) | 81 (78–83) | 126 (121–131) | 207 (199–214) |
| 70–74 | 68 (66–69) | 93 (90–97) | 81 (78–83) | 38 (37–39) | 57 (55–59) | 95 (92–98) |
| 75–79 | 83 (81–85) | 63 (62–64) | 73 (72–75) | 38 (37–39) | 35 (34–35) | 73 (71–74) |
| 80–84 | 134 (128–139) | 88 (85–89) | 111 (107–114) | 39 (37–40) | 38 (37–39) | 77 (74–79) |
| 85+ | 244 (232–256) | 145 (140–149) | 195 (186–203) | 43 (41–45) | 56 (55–58) | 99 (96–103) |

Results are indicated as point estimates with 95% uncertainty intervals in parentheses.

the Glasgow Outcome Score [20]) was sourced from the BIONIC data set and used to determine the probability of residual disability (i.e. after 12 months). If an individual had residual disability (including mild or moderate/severe TBI) at 12 months, this was assumed to persist for a lifetime [2].

Disability weights are based on health state valuations on a scale from 0 (no health loss) to 1 (complete health loss, equivalent to being dead), estimated from a set of global health surveys [8, 18]. Disability weights were specific for stage (i.e. year post occurrence) and level of severity [10, 21]. A short-term (year 1) disability weight of 0.235 was assigned to all cases [10]. A long-term (year 2+) disability weight for mild and moderate/severe residual disability of 0.106 and 0.425, respectively, was also applied [10, 21]. A disability weight of 0 was attributed to those with no neurological deficit after the first year post TBI.

## Results

*Incidence*

Table 1 summarizes the estimated national incidence of first-ever in lifetime TBI in NZ during 2010. Higher incidence rates of first-ever TBI are observed among younger age groups and among males. Translating rates into counts, the model estimates that almost 11,300 first-ever TBIs occurred in NZ in 2010, 57% of them in males. Almost 43% of first-ever TBIs occurred in people aged 0–14 years. The crude incidence rate of first-ever TBI was 281 cases per 100,000 person-years (males 330 cases per 100,000, females 233 cases per 100,000). The estimated mean age at diagnosis of first TBI was 23.0 years (males 22.9 years and females 23.9 years).

*Prevalence*

Modeled prevalence estimates of TBI are summarized in table 2. The results indicate that in 2010 approximately 527,400 New Zealanders (13% of the NZ population) had experienced at least one TBI event at some time in their lives. Crude prevalence estimates were 14.8% for males and 11.4% for females. The prevalence of TBI was 23% higher in males than it was in females, adjusting for differences in age distributions. The highest prevalence occurred in the age group of 40–49 years age group in both male and female. The age distribution of TBI survivors is skewed to the right with two-thirds (68%) of prevalent cases aged 35 years and older.

*Duration of Survival*

Table 3 presents the estimated duration of survival after first-ever TBI (i.e. the time from occurrence of first TBI to death from any cause). Males were slightly younger at onset than females and also had a higher mortality. On an average, females survived nearly 5 years longer after the first TBI than males (58.9 vs. 54.3 years).

**Table 2.** Modeled age- and sex-specific prevalence of people who have had one or more TBI in 2010

| Age group, years | Rates per 100,000 | | | Number of cases | | |
|---|---|---|---|---|---|---|
| | male | female | persons | male | female | persons |
| 0–4 | 1,739 (1,580–1,836) | 1,533 (1,419–1,661) | 1,638 (1,500–1,749) | 2,441 (2,217–2,578) | 2,064 (1,911–2,237) | 4,505 (4,128–4,815) |
| 5–9 | 4,933 (4,671–5,199) | 4,286 (3,954–4,572) | 4,617 (4,313–4,886) | 7,229 (6,845–7,618) | 5,998 (5,534–6,399) | 13,227 (12,379–14,017) |
| 10–14 | 7,765 (7,348–8,190) | 6,564 (6,133–6,976) | 7,181 (6,741–7,583) | 12,199 (11,545–12,868) | 9,774 (9,132–10,387) | 21,973 (20,677–23,255) |
| 15–19 | 10,570 (9,972–11,185) | 8,626 (8,221–9,100) | 9,614 (9,097–10,143) | 16,114 (15,201–17,050) | 12,746 (12,148–13,446) | 28,860 (27,349–30,496) |
| 20–24 | 13,085 (12,311–13,924) | 10,204 (9,755–10,670) | 11,640 (11,033–12,297) | 17,675 (16,630–18,809) | 13,867 (13,256–14,500) | 31,542 (29,886–33,309) |
| 25–29 | 15,022 (14,068–15,942) | 11,286 (10,819–11,799) | 13,092 (12,444–13,871) | 17,608 (16,490–18,686) | 14,133 (13,549–14,775) | 31,741 (30,039–33,461) |
| 30–34 | 16,371 (14,390–17,297) | 12,103 (11,635–12,645) | 14,123 (13,013–14,971) | 21,427 (18,834–22,639) | 17,631 (16,949–18,421) | 39,058 (35,783–41,060) |
| 35–39 | 17,302 (12,224–18,209) | 12,771 (12,310–13,315) | 14,920 (12,267–15,762) | 24,742 (17,480–26,040) | 20,249 (19,518–21,110) | 44,991 (36,998–47,150) |
| 40–44 | 18,068 (13,020–18,951) | 13,310 (12,856–13,854) | 15,599 (12,938–16,403) | 27,265 (19,648–28,598) | 21,669 (20,929–22,554) | 48,934 (40,577–51,152) |
| 45–49 | 18,900 (13,870–19,776) | 13,774 (13,321–14,318) | 16,273 (13,596–17,047) | 27,036 (19,841–28,290) | 20,712 (20,030–21,529) | 47,748 (39,871–49,819) |
| 50–54 | 19,863 (14,851–20,749) | 14,250 (13,792–14,792) | 17,011 (14,322–17,771) | 24,691 (18,461–25,793) | 18,300 (17,712–18,996) | 42,991 (36,173–44,789) |
| 55–59 | 20,714 (15,717–21,605) | 14,799 (14,341–15,344) | 17,717 (15,029–18,475) | 23,868 (18,109–24,894) | 17,514 (16,972–18,159) | 41,382 (35,081–43,053) |
| 60–64 | 21,465 (16,477–22,365) | 15,615 (15,167–16,170) | 18,492 (15,822–19,268) | 18,961 (14,555–19,756) | 14,253 (13,844–14,759) | 33,214 (28,399–34,515) |
| 65–69 | 22,102 (17,121–23,022) | 16,533 (16,102–17,027) | 19,237 (16,612–20,025) | 15,938 (12,346–16,601) | 12,637 (12,307–13,014) | 28,575 (24,653–29,615) |
| 70–74 | 22,429 (17,448–23,360) | 17,099 (16,656–17,552) | 19,647 (17,052–20,456) | 12,533 (9,750–13,053) | 10,441 (10,170–10,717) | 22,974 (19,920–23,770) |
| 75–79 | 22,670 (17,630–23,609) | 17,398 (16,953–17,923) | 19,813 (17,292–20,766) | 10,510 (8,173–10,945) | 9,544 (9,300–9,832) | 20,054 (17,473–20,777) |
| 80–84 | 23,024 (18,058–23,956) | 17,649 (17,209–18,147) | 19,815 (17,634–21,052) | 6,705 (5,259–6,977) | 7,609 (7,419–7,824) | 14,314 (12,678–14,801) |
| 85+ | 23,792 (19,132–24,694) | 18,208 (17,766–18,691) | 19,949 (18,449–21,693) | 4,204 (3,381–4,363) | 7,101 (6,929–7,289) | 11,305 (10,310–11,652) |

Results are indicated as point estimates with 95% uncertainty intervals in parentheses.

*TBI-Related Mortality*

TBI-related deaths among males were 1.98 times higher than in females, with an annual death rate of 15 deaths per 100,000 in the males compared with 8 deaths per 100,000 in the females. Translating rates into counts, 448 deaths in 2010 were estimated to be attributable to TBI, of which 293 (66%) were male. Modeled TBI-related deaths numbered 16% fewer than those registered as being caused by TBI in routine mortality statistics (448 modeled deaths vs. 519 registered).

*DALYs Due to TBI in NZ*

As presented in table 4, TBI accounted for approximately 20,300 DALYs. This is 27% of all injury-related health loss and 2.4% of DALYs from all causes in 2010 [21]. The TBI DALYs were made up of 14,386 YLLs (71%) and only 5,891 YLDs (29%). Thus, the majority of health loss due to TBI reflects fatal outcomes. Of the nonfatal health loss from TBI, 56% (approximately 3,300 YLDs) resulted from mild cases and 44% (approximately 2,600 YLDs) from moderate to severe cases. DALY rates

**Table 3.** Modeled survival times (years) of TBI survivors, 2010

| Age at first TBI, years | Duration of survival after first TBI, years | |
|---|---|---|
| | male | female |
| 0–4 | 73.8 (73.6–74) | 79.7 (79.6–79.8) |
| 5–9 | 69.2 (27.7–69.3) | 75 (75–75.1) |
| 10–14 | 64.2 (48.2–64.4) | 70.1 (70–70.2) |
| 15–19 | 59.5 (55.9–59.7) | 65.4 (65.4–65.5) |
| 20–24 | 55.2 (53.5–55.3) | 60.8 (60.7–60.8) |
| 25–29 | 50.8 (49.7–50.9) | 56 (56–56) |
| 30–34 | 46.3 (45.5–46.4) | 51.2 (51.1–51.2) |
| 35–39 | 41.6 (41–41.7) | 46.3 (46.3–46.4) |
| 40–44 | 36.9 (36.4–37) | 41.6 (41.6–41.6) |
| 45–49 | 32.3 (32–32.4) | 36.9 (36.9–36.9) |
| 50–54 | 28 (27.7–28.1) | 32.3 (32.3–32.4) |
| 55–59 | 23.7 (23.5–23.8) | 27.7 (27.7–27.8) |
| 60–64 | 19.7 (19.5–19.7) | 23.6 (23.6–23.6) |
| 65–69 | 16.1 (16–16.2) | 19.8 (19.8–19.9) |
| 70–74 | 12.6 (12.4–12.6) | 16.2 (16.2–16.3) |
| 75–79 | 9.3 (9.2–9.3) | 12.7 (12.7–12.8) |
| 80–84 | 6.9 (6.8–6.9) | 9.8 (9.8–9.9) |
| 85+ | 4.3 (4.2–4.3) | 7 (7–7) |

Results are indicated as point estimates with 95% uncertainty intervals in parentheses.

**Table 4.** DALYs due to TBI, 2010

| | YLL | YLD (mild) | YLD (moderate severe) | % YLD due to short-term consequence | % YLD due to long-term consequence | DALYs | DALYs per 100,000 population |
|---|---|---|---|---|---|---|---|
| Current 2010 | | | | | | | |
| Boys and men | 9,823 | 1,745 | 2,153 | 39 | 61 | 13,721 | 698 |
| Girls and women | 4,564 | 1,532 | 461 | 57 | 43 | 6,556 | 318 |
| Total | 14,386 | 3,277 | 2,614 | 45 | 55 | 20,277 | 503 |

were approximately twice as high in males than in females (adjusting for differences in their age distributions). DALY rates were higher in the younger than in the older age groups, peaking in the 20–24 years age group (fig. 1).

## Discussion

The aim of this study was to estimate the first-ever incidence of TBI in a lifetime, prevalence of TBI survivors in the population, deaths attributable to TBI and loss of health attributable to TBI (denominated in DALYs) in NZ during the year 2010. Combining information from the BIONIC study with the NZ national health data, the modeled results suggest that there were approximately 11,300 first-ever TBI events in 2010 with a total prevalence of approximately 527,000. Males experienced higher rates of TBI than those of females. A high proportion of TBIs occurred among children (aged <16 years) and young adults (aged <34 years), accounting for about 75% of all the first-ever TBI cases.

Health loss attributable to TBI in NZ was estimated to be approximately 20,300 DALYs in 2010. This is over one-quarter (27%) of all losses of health attributable to intentional and unintentional injuries in that year, and almost 2.4% of all losses of health from all causes (i.e. all diseases and injuries) [22]. Importantly, we found that most of the loss of health attributable to TBI (71%) re-

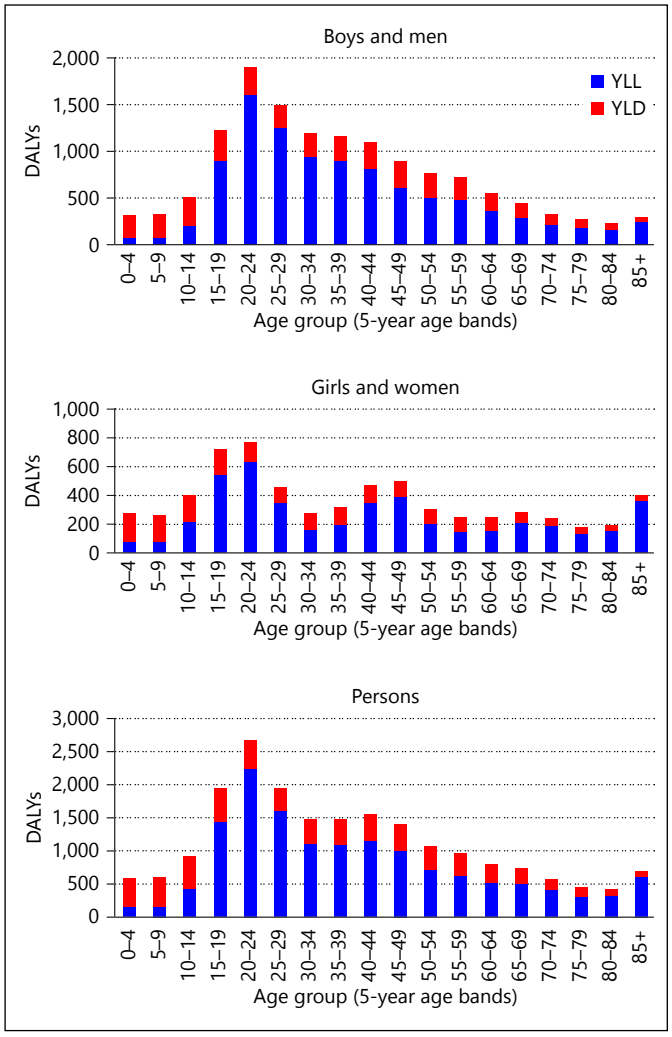


**Fig. 1.** TBI DALYs by sex and total population.

sulted from fatal injuries. However, non-fatal outcomes (i.e. disability) still accounted for a substantial share of the total TBI burden. While both moderate/severe and mild TBI contributed to this non-fatal burden, mild TBI made the greater contribution (56% of total TBI YLDs).

Our findings are consistent with previously reported studies. Tagliaferri et al. [23] reviewed 23 studies conducted in Europe and reported an aggregate incidence rate of those hospitalized due to TBI as 235 per 100,000 person-years. However, these estimates reflect episode rates of TBI (incident and recurrent) sourced from hospitalization data. In the BIONIC study, approximately 30% of incident TBI cases were never seen in hospital. Similarly, Corrigan et al. [3] reviewed the incidence and prevalence studies regarding TBI that were conducted in the United States and abroad. The authors concluded that approximately 235,000 Americans were hospitalized for non-fatal TBI each year, but were unable to estimate the incidence of non-hospitalized events. In contrast, a prospective birth cohort study by McKinlay et al. [24] found the incidence of TBI to be much higher. The authors reported an incidence rate of 1,750 per 100,000 per year. The result was based on a population capture methodology that included people with non-hospitalized TBI. However, their findings were limited to an age group of 0–25 year age group. It is of note that high quality epidemiological design and case ascertainment are lacking in most previous studies. TBI DALYs have previously been reported for NZ in the New Zealand Burden of Disease Study [21]. These estimates are consistent with those reported here, despite differences in time period, methodology and data sources.

Strengths of this study include the use of data from a population-based TBI incidence study [1, 12, 13]. Unlike previous studies [4, 8, 9], the estimates reported here are based on the investigations conducted on TBI in both hospital and community settings across all ages and severities of injury.

The main limitation of our study is the use of routinely collected mortality data to estimate TBI mortality. However, the multi-state life table model corrects for inaccuracy in routine cause of death coding. Thus, we estimated 448 deaths from TBI in NZ in 2010, whereas 519 deaths were coded to this cause in the official mortality statistics. This correction is itself a useful output of our study and helps to inform policy makers regarding the true impact of TBI on our society. The reasons for TBI appearing to be over-reported as the underlying cause of death require further investigation so as to help us understand the coding of underlying causes of death, especially where multiple trauma is involved. Secondly, the data used on levels of disability (from the BIONIC Study) is subject to self-report bias; however, it is the best available data.

Finally, the model as currently constructed does not disaggregate by ethnicity or by socioeconomic status due to insufficient data. This clearly reduces the policy relevance and value of our findings. Despite these limitations, the model still provides an internally consistent description of TBI epidemiology (including incidence, prevalence and survival) and current burden (including both YLL and YLD).

In conclusion, the current study quantifies the substantial population health impact of TBI in NZ. Further studies are needed to extend the findings to ethnic and socioeconomic subpopulations and study trends in TBI

epidemiology and impacts over time, including recurrent TBI. Such data is essential for planning and evaluating public health interventions and clinical TBI services.


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## Disclosure Statement

The authors declare that they have no competing interests.

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# Appendix six: DISMOD II input variables

*Table 37: Input variables in DISMOD II modelling for traumatic brain injury in New Zealand, 2010*

| Age group (years) | Input Variables | | | | | |
|---|---|---|---|---|---|---|
| | Incidence *(100 000)† | | Mortality * (100 000)ǂ | | Total Population§ | |
| | Male | Female | Male | Female | Male | Female |
| 0-4 | 772.38 | 664.81 | 5.7 | 3.71 | 140,379 | 134,697 |
| 5-9 | 500.45 | 461.2 | 0.68 | 0.71 | 146,535 | 139,956 |
| 10-14 | 442.73 | 307.5 | 2.55 | 2.69 | 157,116 | 148,896 |
| 15-19 | 687.43 | 510.55 | 17.71 | 7.44 | 152,439 | 147,762 |
| 20-24 | 422.78 | 234.47 | 24.43 | 9.57 | 135,084 | 135,891 |
| 25-29 | 351.41 | 180.09 | 19.62 | 3.99 | 117,216 | 125,226 |
| 30-34 | 213.33 | 156.94 | 10.7 | 1.37 | 130,884 | 145,677 |
| 35-39 | 155.36 | 106.5 | 18.18 | 2.52 | 143,001 | 158,550 |
| 40-44 | 170.07 | 107.08 | 13.92 | 6.76 | 150,900 | 162,798 |
| 45-49 | 196.5 | 81.66 | 9.09 | 7.98 | 143,052 | 150,369 |
| 50-54 | 225.64 | 151.69 | 17.7 | 4.67 | 124,308 | 128,421 |
| 55-59 | 137.55 | 108.51 | 15.62 | 3.38 | 115,224 | 118,347 |
| 60-64 | 182.82 | 261.32 | 16.98 | 5.48 | 88,335 | 91,278 |
| 65-69 | 203.5 | 187.27 | 22.19 | 17.01 | 72,111 | 76,434 |
| 70-74 | 50.58 | 90.7 | 32.21 | 21.29 | 55,878 | 61,059 |
| 75-79 | 125.55 | 50.05 | 28.04 | 14.58 | 46,359 | 54,858 |
| 80-84 | 109.4 | 512.82 | 103.01 | 51.03 | 29,124 | 43,113 |
| 85+ | 303.03 | 143.99 | 192.42 | 112.82 | 17,670 | 39,000 |

**Notes**

† First-ever TBI incidence rates derived from the Brain Injury Outcomes New Zealand in the Community (BIONIC) study (Feigin et al., 2013).

ǂ TBI-related mortality obtained from the New Zealand Mortality Collection Database, Ministry of Health, 2010 (Ministry of Health, 2010a)

§ New Zealand general population based on 2006 census information, obtained from Statistics New Zealand. (Population projection assumes medium fertility, mortality and net migration) (Statistics New Zealand, 2010b)

# Appendix seven: Cost of traumatic brain injury in New Zealand article

**Te Ao B**, Brown P, Tobias M, Ameratunga S, Barker-Collo B, Theadom A, McPherson K, Starkey N, Dowell A, Jones K and Feigin V (2014). The cost of traumatic brain injury in New Zealand: evidence from a population based study. *Neurology; 83; 18:1645-1652.*

# Cost of traumatic brain injury in New Zealand

## Evidence from a population-based study

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### ABSTRACT

**Objective:** We aimed to estimate from a societal perspective the 1-year and lifetime direct and indirect costs of traumatic brain injury (TBI) for New Zealand (NZ) in 2010 projected to 2020.

**Methods:** An incidence-based cost of illness model was developed using data from the Brain Injury Outcomes New Zealand in the Community Study. Details of TBI-related resource use during the first 12 months after injury were obtained for 725 cases using resource utilization information from participant surveys and medical records. Total costs are presented in US dollars year 2010 value.

**Results:** In 2010, 11,301 first-ever TBI cases were estimated to have occurred in NZ; total first-year cost of all new TBI cases was estimated to be US $47.9 million with total prevalence costs of US $101.4 million. The average cost per new TBI case during the first 12 months and over a lifetime was US $5,922 (95% confidence interval [CI] $4,777–$7,858), varying from US $4,636 (95% CI $3,756–$5,561) for mild cases to US $36,648 (95% CI $16,348–$65,350) for moderate/severe cases. Because of the unexpectedly large number of mild TBI cases (95% of all TBI cases), the total cost of treating these cases is nearly 3 times that of moderate/severe. The total lifetime cost of all TBI survivors in 2010 was US $146.5 million and is expected to increase to US $177.1 million in 2020.

**Conclusion:** The results suggest that there is an urgent need to develop effective interventions to prevent both mild and moderate/severe TBI. *Neurology*® 2014;83:1645–1652

### GLOSSARY

**BIONIC** = Brain Injury Outcomes New Zealand in the Community; **CI** = confidence interval; **GCS** = Glasgow Coma Scale; **ICD-10** = International Classification of Diseases, tenth revision; **MOH** = Ministry of Health; **NMDS** = National Minimum Dataset; **NZ** = New Zealand; **TBI** = traumatic brain injury; **WIES** = Weighted Inlier Equivalent Separations.

Traumatic brain injury (TBI) is the leading cause of long-term disability in children[1] and young adults,[2] having a significant impact on the person, their family, caregivers, and society.[3] A recent TBI population-based incidence and 1-year outcomes study (Brain Injury Outcomes New Zealand in the Community [BIONIC])[2] found that the incidence of TBI in the population is far greater than previously estimated.

Previous authors have concluded that the financial burden of TBI is substantial,[4–6] with hospitalization costs accounting for 60% to 70% of overall direct medical costs.[7–11] Previous studies are limited because they focused primarily on hospitalized individuals.[12] These patients tend to have the most severe injuries. Cases of mild TBI (defined by Glasgow Coma Scale [GCS] score ≥13) constitute 95% of all cases[2] and frequently are not hospitalized. By focusing on hospitalized cases, previous studies might overstate the average cost per individual but understate the total cost of TBI to society. A further limitation of previous studies is the lack of inclusion of nonhospitalization costs of TBI.

**Supplemental data at Neurology.org**

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BIONIC Study Group coinvestigators are listed on the *Neurology*® Web site at Neurology.org.

Go to Neurology.org for full disclosures. Funding information and disclosures deemed relevant by the authors, if any, are provided at the end of the article.

This study utilized data from the population-based BIONIC Study in combination with electronic hospital records, official death records, and self-reported health services usage. The objective was to estimate the societal cost of TBI in the first year, and lifetime direct and indirect costs of TBI by severity levels for New Zealand (NZ) in 2010 projected to 2020.

## METHODS

**Estimating NZ TBI incidence and prevalence.** The BIONIC Study used multiple overlapping sources of information to capture all new TBI cases (fatal/nonfatal, hospitalized/nonhospitalized) across all ages and all TBI severities (mild, moderate, severe) in urban and rural residents of Hamilton and Waikato Districts (population approximately 173,000) from March 1, 2010 to February 28, 2011. All TBI cases consenting to participate in the study (n = 725; 53%) were followed up over 12 months post-TBI. Further details of the methodology, diagnostic criteria, and main incidence results of the study are reported elsewhere.[2,13]

Where possible, all surviving participants were interviewed at baseline and 1, 6, and 12 months postinjury. TBI severity was defined using standard definitions[14–16] (see e-Methods on the *Neurology*® Web site at Neurology.org). Baseline information included demographics, medical history, and place of residence before TBI. One-month assessment documented initial acute treatment. At 6 and 12 months, participant's use of outpatient, rehabilitation and home care services, and health status were recorded. Information on emergency department presentations and hospital admissions was obtained from the National Minimum Dataset (NMDS), NZ Ministry of Health (MOH). The NMDS includes all presentations and admissions to public or private hospitals in NZ and these are linked to individuals via National Health Index numbers.[17] Only services funded in whole or part by District Health Boards and the Accident Compensation Corporation, a no-fault personal accident insurance cover (health funders in NZ), were available.

Prevalence was modeled[18] from data on incidence, remission, and mortality using multistate life table methods.[19,20] Compared with the total NZ population census (base 2006) information, the Hamilton and Waikato populations have demographic and social characteristics that are reflective of NZ. TBI incidence and prevalence were estimated for NZ in the reference year and then projected to 2020, assuming similar trends in TBI prevalence to that estimated for 2010.

**Cost of illness model.** An incidence-based cost of illness model (bottom up approach) was developed to estimate the economic cost of TBI in NZ. All costs are expressed in US dollars using purchasing power parity conversion rate of 1.49 (NZ$).[21]

**Costs.** The types and unit costs of each health service are shown in table e-1. The cost analysis included direct health care costs (e.g., hospitalizations, outpatient rehabilitation services), indirect costs (e.g., productivity loss for person with TBI), and out-of-pocket expenses (e.g., aids, home modification).

***Hospital inpatient and outpatient costs.*** TBI hospitalizations were confirmed by *ICD-10* codes S06.0 to S06.9. NZ has a national health service with government-run hospital care available free of charge. There is one major hospital in the Waikato Region that provides care for the region[22] (see e-Methods for background of NZ health system). The cost of hospital care is assessed from hospital reimbursements from the MOH. Hospitalization costs were determined using weighted discharge value (i.e., Weighted Inlier Equivalent Separations [WIES]) for all NMDS events by the MOH.[17] The national price for financial year 2010/2011 per WIES was US $2,959.98.[23] Because the hospital services are provided by the publicly owned District Health Boards (not patient charges), the costs are internal weighted estimates (based on Disease Related Groups and length of stay) of the cost of each type of care. WIES cost weight includes medical costs, ward stay, medication, laboratory tests, diagnostic imaging, and nursing and other ward staff.

***Community and home support.*** Although most formal care for home support services is funded by the state, providers contracted with the government provide the bulk of services. As such, no accurate information exists on individual charges for TBI-related community and home support. To estimate the cost of these services, a resource-based costing approach was used where a common price was applied to each resource (e.g., cost per hour per therapist).

Number of visits to therapists (i.e., visiting nurses, physiotherapists, medical specialists, occupational therapist, speech therapist, general practitioners, counselors, psychologists, and social workers) over the month before each BIONIC assessment (i.e., 1, 6, and 12 months post-TBI) was assessed via patient and significant other questionnaires. The cost of therapy visits was estimated by multiplying visit number by resource unit cost. Similarly, hours of home support (home help and personal care) were estimated using BIONIC follow-up questionnaire data by multiplying the number of hours provided by the current cost of care for the service (in US$, 2010). Finally, the cost of basic maintenance and home modification support resulting from TBI was estimated by combining information obtained from the patient, family, or caregiver survey responses with current market prices.

Direct costs included hospitalization and emergency department visits, regardless of whether they resulted in an admission, and the number of therapy visits provided to individuals living at home included home help and personal care services. All categories were summed together to estimate average cost per case.

**Lifetime direct costs associated with TBI.** At each follow-up, BIONIC participants were questioned about direct medical resources used relating to their TBI. At 12 months post-TBI, the proportion of participants identified as having a moderate to severe disability (defined by the Glasgow Outcome Scale) was sourced from the BIONIC dataset and used to determine the probability of needing ongoing health resources (i.e., after 12 months). If an individual had residual disability (including mild or moderate/severe TBI) at 12 months, this was assumed to persist for a lifetime. A weighted average cost for adults and children identified as having a moderate to severe TBI was then calculated (i.e., average direct cost per case × probability of having a moderate/severe disability). The discounted lifetime health care costs (see statistical analysis section) occurring in each year were then summed together with the first-year costs.

**Productivity loss.** First, production losses within 12 months of injury were estimated only for a friction period after the loss of paid work.[24,25] Short-term productivity loss was valued using a friction cost approach, which assumes that individuals absent from paid employment because of disablement or early mortality will be replaced after a specific time period.[25] In line with previous cost of illness studies, a friction period of 3 months was used.[26] Second, at 12-month follow-up, the proportion of participants reporting a decrease in income was identified. The value of time lost from employment or productive activity up to age 65 years was estimated for adults in paid workforce and adults

in unpaid productive activity before injury. Costs of productivity were estimated using reported loss of income from BIONIC case record forms combined with Statistics NZ data on average weekly earnings linked to occupation for those who were in the paid workforce.[27] Because of lack of accurate information, cost of informal care (including care for childhood TBI) or compensation was not included in our analysis.

**Statistical analysis.** SPSS statistics version 20 (IBM Corp., Armonk, NY) was used to analyze data. Costs per person and total cost for NZ are presented as means with 95% confidence intervals (CIs) for a given year and over a lifetime. Significance of differences between the costs of mild and moderate/severe TBI was tested using *t* tests and Wilcoxon rank sum tests. Significance level was set at $p < 0.05$ (2-sided). Multivariate probabilistic uncertainty analyses including a 5,000 replications Monte Carlo simulation were undertaken using @Risk software version 6 (2013; Palisade Corporation, Ithaca, NY) to test the uncertainty of the estimates and strength of the results. Calculation of sensitivity analysis used gamma distributions for cost estimates. A discount rate of 3.5% was used for lifetime cost projections as recommended by the NZ Treasury[28,29] and PHARMAC (NZ Pharmaceutical organization).[30]

## RESULTS

**Incidence and prevalence of TBI in NZ.** In 2010, 11,301 first-ever TBI cases were estimated to have occurred in NZ, 57% of whom were male. The majority (75%) were younger than 35 years. Taken together, the total number of patients with TBI in NZ (including prevalent cases) was estimated to be 527,388. In 2020, the number of first-ever cases was estimated to increase to 13,591 and the number of prevalent cases (period prevalence) was expected to increase to 641,104 cases.

**Average first-year per-person cost of TBI in NZ.** A detailed breakdown of 12-month follow-up resources used and average per-person costs is presented in table 1. Of the 725 cases, approximately 64% were not initially hospitalized for their TBI. Of those who were hospitalized, survivors spent on average 2.6 days (95% CI 1.8–3.3) in hospital. After discharge, most patients used general practitioner (36% [263]), allied health (18% [133]), and specialized medical (14% [105]) services at follow-up. Total direct health care costs over 12 months per patient amounted to US $3,783 (minimum US $26, maximum US $112,115). On average, 17% (124) reported having lost income due to their injury; costs attributable to production losses were estimated at US $2,000 (minimum US $163, maximum US $13,252), with an average total first-year cost of US $4,123 per person (95% CI $3,442–$4,997). This amount reflects the high proportion of mild TBI (95%) identified in the

**Table 1** Proportion and cost per case for the categories of resource use during the first year and cost of all traumatic brain injury in New Zealand

| | Users, % (n = 725) | Resources per patient (mean no. of days or no. of visits) | Cost per category, US$ | |
|---|---|---|---|---|
| | | | Mean | 95% CI[a] |
| Health care | | | | |
| Emergency department | 42 | | $181 | |
| Initial hospitalization | 36 | 2.6 | $2,936 | $2,119–$3,893 |
| Hospital readmission | 4 | 6.5 | $4,704 | $2,410–$7,692 |
| Outpatient care | 6 | 6.1 | $1,791 | $967–$3,975 |
| Specialized medical care | 14 | 9.6 | $2,333 | $1,731–$2,968 |
| Allied health care | 18 | 21.4 | $4,221 | $3,410–$5,161 |
| General practice | 36 | 9 | $954 | $835–$1,081 |
| Nursing | 4 | 19.1 | $2,259 | $1,091–$3,964 |
| Radiology | 1 | 3.8 | $2,379 | $534–$4,918 |
| Community services | 3 | | $21,299 | $10,706–$34,809 |
| Out-of-pocket expenses | 4 | | $693 | $236–$1,288 |
| Other expense | 100 | | $144 | $142–$146 |
| Total direct medical costs per person | 100 | | $3,783 | $3,091–$4,670 |
| Non–health care (indirect) loss in productivity | 17 | | $2,000 | $1,658–$2,385 |
| Total 1-y costs per person | 100 | | $4,123 | $3,442–$4,997 |
| Ongoing direct medical costs[b] | 5 | | $17,402 | $6,276–$33,403 |
| Long-term productivity[b] | 3 | | $30,960 | $16,923–$47,775 |
| Total lifetime cost per person[b] | 100 | | $5,922 | $4,777–$7,858 |

Abbreviation: CI = confidence interval.
[a] Bootstrap results are based on 1,000 bootstrap samples.
[b] 3.5% discount rate used.

study and the high proportion of cases not needing acute hospitalization.

**Average first-year cost by TBI severity.** Table 2 summarizes resources used and average per-person cost in survivors who had a mild or a moderate/severe TBI. Most cases (n = 691 of 725; 95%) were mild (GCS score ≥13) and 34 cases were moderate/severe (GCS score ≤12). A consistent pattern of resource usage was found in the mild cohort, with cost composition varying over the 12-month follow-up period; general practice (n = 253; 37%) and allied health services (n = 119; 17%) were the most frequently used. In contrast, a higher percentage of those with moderate/severe TBI (n = 30; 88%) required initial hospitalization (minimum US $583, maximum US $73,367) with an average length of stay of 13.4 days (95% CI 7.3–19.6). Of those who were hospitalized, 12% (4 of 34) were readmitted. Cost of hospital readmission was significantly greater than for those with mild injuries (Wilcoxon rank sum $z = -2.191$, $p = 0.028$). Of the 34 admitted, after discharge allied health services (41%), general practitioner (32%) and specialized medical care (29%) were the most frequently utilized services, with 12% having some community home care support. One-year cost per case for mild (95% of all cases) and moderate/severe TBI was US $3,395 (95% CI $2,803–$4,021) and US $21,379 (95% CI $11,957–$31,505), respectively. Because of the higher cost of hospitalization, 1-year cost of moderate/severe TBI was significantly greater than for mild TBI (Wilcoxon rank sum $z = -5.914$, $p \leq 0.0001$). However, because of the large number of mild cases, total costs of mild TBI (10,771 × $3,395) was 3 times that of moderate/severe TBI (530 × $21,379).

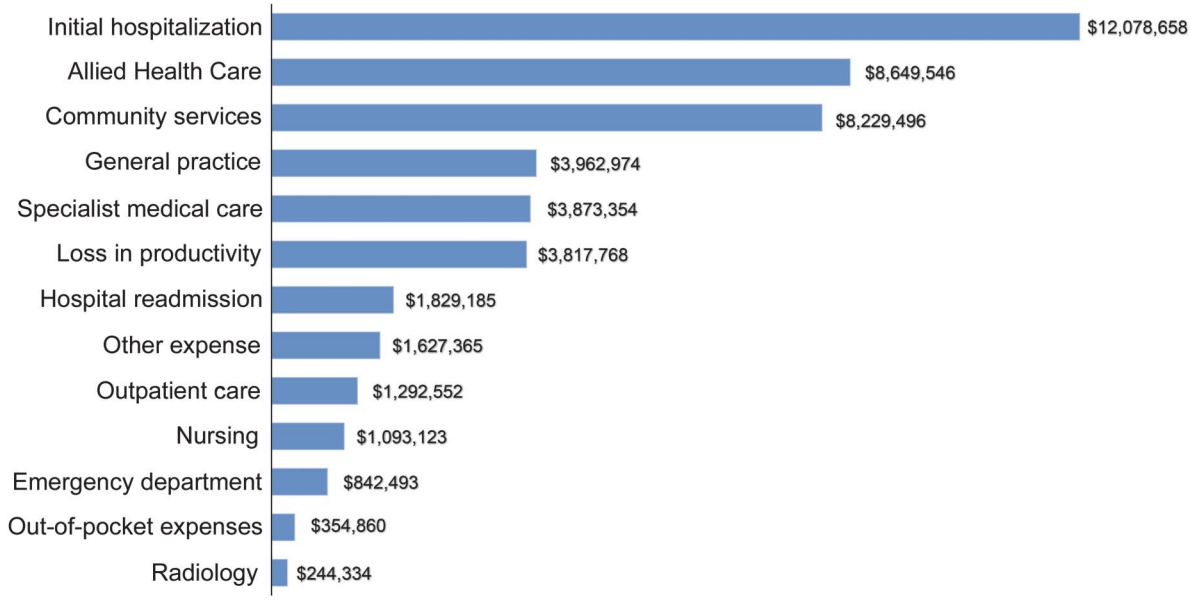
**Total first-year incidence and prevalence costs.** Details of primary cost drivers during the first year for all TBIs are in the figure. When applied to all TBI survivors in NZ (table 3), the total first-year costs of all new cases of TBI that occurred in NZ during 2010 were estimated to be US $47.9 million (95% CI $35.7–$59.3 million). Using a prevalence-based approach,

**Table 2** Cost (in US$) of TBI in New Zealand by severity

| | Mild TBI (GCS ≥13) | | | Moderate/severe TBI (GCS ≤12) | | |
|---|---|---|---|---|---|---|
| | % of all mild (n = 691) | Mean | 95% CI[a] | % of all moderate/severe (n = 34) | Mean | 95% CI[a] |
| Health care | | | | | | |
| Emergency department | 41 | $181 | | 44 | $181 | |
| Initial hospitalization | 34 | $1,888 | $1,450–$2,394 | 88 | $11,074 | $4,979–$18,143 |
| Hospital readmission | 3 | $3,774 | $1,475–$7,155 | 12 | $9,587 | $5,385–$12,140 |
| Outpatient care | 6 | $1,067 | $528–$1,584 | 15 | $7,584 | $467–$21,256 |
| Specialized medical care | 14 | $2,254 | $1,599–$3,236 | 29 | $3,090 | $1,134–$6,111 |
| Allied health care | 17 | $3,939 | $3,189–$4,938 | 41 | $6,613 | $2,811–$11,182 |
| General practice | 37 | $960 | $842–$1,126 | 32 | $815 | $467–$1,283 |
| Nursing | 4 | $1,548 | $829–$2,495 | 12 | $6,703 | $705–$17,592 |
| Radiology | 1 | $1,252 | $362–$2,160 | 3 | $6,883 | —[b] |
| Community services | 3 | $19,894 | $9,133–$35,711 | 12 | $28,320 | $1,869–$71,156 |
| Out-of-pocket expenses | 4 | $763 | $232–$1,439 | 15 | $328 | $208–$453 |
| Other expense | 100 | $144 | $141–$146 | 100 | $152 | $151–$153 |
| Total direct medical costs per person | 100 | $3,079 | $2,519–$3,668 | 100 | $20,591 | $11,405–$32,002 |
| Non-health care (indirect) loss in productivity | 16 | $1,973 | $1,591–$2,399 | 35 | $2,250 | $1,186–$3,617 |
| Total 1-y costs per person | 100 | $3,395 | $2,803–$4,021 | 100 | $21,379 | $11,957–$31,505 |
| Ongoing direct medical costs[c] | 4 | $6,466 | $3,778–$10,448 | 27 | $53,856 | $9,964–$127,981 |
| Long-term productivity loss[c] | 3 | $32,753 | $18,544–$50,393 | 6 | $12,134 | −$98,042–$122,310[d] |
| Total lifetime cost per person[c] | 100 | $4,636 | $3,756–$5,561 | 100 | $36,648 | $16,348–$65,350 |

Abbreviations: CI = confidence interval; GCS = Glasgow Coma Scale; TBI = traumatic brain injury.
[a] Bootstrap results are based on 1,000 bootstrap samples.
[b] Sample size in this group was too small to estimate 95% CI.
[c] 3.5% discount rate used.
[d] Some or all bootstrap sample results are missing, so no bootstrap estimation has been performed for this item.

**Figure** Accumulated first-year costs according to cost category for traumatic brain injury




total cost for all TBIs equates to US $101.4 million (95% CI $75.8–$125 million). Assuming similar trends in TBI incidence to the reference year, the prevalence cost of TBI is expected to increase by 21% to more than US $122.6 million (95% CI $91.7–$151.3 million) in 2020.

**Estimated lifetime costs per person.** Total average lifetime cost per person was estimated at US $5,922 (95% CI $4,777–$7,858). Estimated lifetime costs for mild and moderate/severe TBI were US $4,636 (95% CI $3,756–$5,561) and US $36,648 (95% CI $16,348–$65,350), respectively (see tables 1 and 2). The results suggest that the average lifetime cost of a mild TBI is significantly lower (i.e., <15%) than the cost of moderate/severe cases. The total lifetime cost of all incident and prevalent TBI cases in NZ was US $146.5 million (95% CI $97.4–$194.7 million) in 2010 (see table 3).

**Table 3** Current and future burden of TBI (US$ 2010)

| Cost estimates for New Zealand | Current burden 2010 | Projected burden 2020 |
|---|---|---|
| Incidence (first-ever TBI) | | |
| 1-y direct health care cost | $44,077,939 | $52,476,407 |
| 1-y indirect cost | $3,817,768 | $4,576,946 |
| 1-y total cost | $47,895,707 | $57,053,354 |
| Lifetime cost | $69,357,619 | $82,437,411 |
| Prevalence (recurrent TBI) | | |
| 1-y direct health care cost | $93,254,189 | $112,782,385 |
| 1-y indirect cost | $8,132,954 | $9,836,062 |
| 1-y total cost | $101,387,143 | $122,618,448 |
| Lifetime cost | $146,499,490 | $177,177,693 |

Abbreviation: TBI = traumatic brain injury.

**Sensitivity and uncertainty analysis.** Sensitivity analysis indicated that total lifetime cost of TBI in NZ (TBI occurring in 2010) ranges between US $57.7 million and US $80.5 million (table 4). The average lifetime cost per person was US $5,381 (95% uncertainty interval $5,311, $5,485), ranging from US $4,907 (95% uncertainty interval $4,829, $5,027) for mild cases to US $39,783 (95% uncertainty interval $38,985, $40,827) for moderate/severe cases. Overall, the probabilistic sensitivity analysis revealed that the results were robust to changes in the parameter values.

**DISCUSSION** Our study utilized data from a population-based TBI incidence study to report first-year and lifetime costs of TBIs by severity levels for NZ. The results suggest that the cost per TBI was US $5,922, varying from US $4,636 for mild cases to US $36,648 for moderate/severe cases. Although the cost per case of mild TBI was significantly lower than that of moderate/severe injuries, the unexpectedly large number of mild TBI cases (95% of cases) resulted in the total cost of treating mild TBI being 3 times that of moderate/severe TBI. The total lifetime cost of all TBI survivors in 2010 was estimated at US $146.5 million.

The per-person (first-year) cost estimates reported here are much lower than those reported in previous studies.[5,6,10,11,31,32] This may be because previous studies focused primarily on patients who were hospitalized for their TBI. These patients tend to have more severe injuries and, as a result, the highest direct

**Table 4** Results of uncertainty analyses on cost estimates (US$ 2010)

| | Modeled point estimates[a] | | 95% Uncertainty interval[a] | |
|---|---|---|---|---|
| | Mean | Median | Lower bound | Higher bound |
| **All TBI cases** | | | | |
| No. of TBI cases | 11,301 | 11,300 | 9,442 | 13,158 |
| First-year direct costs | $43,606,150 | $43,604,992 | $36,433,317 | $50,772,988 |
| First-year indirect costs[b] | $4,610,589 | $4,509,371 | $3,625,360 | $5,919,230 |
| Total first-year costs | $48,216,740 | $47,470,385 | $39,662,957 | $55,273,743 |
| Lifetime direct costs[c] | $43,606,801 | $43,606,072 | $36,427,019 | $50,776,760 |
| Lifetime indirect costs[c] | $17,203,864 | $16,971,121 | $13,724,878 | $21,394,564 |
| Total lifetime costs[c] | $60,810,665 | $69,148,050 | $57,764,168 | $80,519,858 |
| Total first-year/incident TBI (cost per case) | $4,273 | $4,258 | $4,242 | $4,309 |
| Total lifetime costs/incident TBI (cost per case) | $5,381 | $5,361 | $5,311 | $5,485 |
| **Mild TBI** | | | | |
| No. of TBI cases | 10,796 | 10,794 | 9,020 | 12,570 |
| First-year direct costs | $32,810,818 | $32,810,119 | $27,412,028 | $38,204,803 |
| First-year indirect costs[b] | $4,090,254 | $4,019,579 | $3,196,114 | $5,231,018 |
| Total first-year costs | $36,901,072 | $36,262,542 | $30,296,566 | $42,225,050 |
| Lifetime direct costs[c] | $36,162,340 | $36,142,348 | $30,140,568 | $42,192,448 |
| Lifetime indirect costs[c] | $16,820,254 | $16,636,592 | $13,412,929 | $20,994,200 |
| Total lifetime costs[c] | $52,982,594 | $50,038,236 | $41,804,389 | $58,263,595 |
| Total first-year/incident TBI (cost per case) | $3,418 | $3,412 | $3,393 | $3,456 |
| Total lifetime costs/incident TBI (cost per case) | $4,907 | $4,890 | $4,829 | $5,027 |
| **Moderate/severe TBI** | | | | |
| No. of TBI cases | 505 | 504 | 422 | 588 |
| First-year direct costs | $10,358,521 | $10,358,364 | $8,654,401 | $12,061,414 |
| First-year indirect costs[b] | $477,091 | $468,089 | $372,874 | $611,809 |
| Total first-year costs | $10,835,612 | $10,759,274 | $8,989,353 | $12,528,277 |
| Lifetime direct costs[c] | $19,171,829 | $19,069,217 | $15,714,579 | $22,878,453 |
| Lifetime indirect costs[c] | $918,298 | $909,792 | $736,903 | $1,127,599 |
| Total lifetime costs[c] | $20,090,127 | $18,318,790 | $15,304,693 | $21,330,493 |
| Total first-year/incident TBI (cost per case) | $21,456 | $21,481 | $21,392 | $21,553 |
| Total lifetime costs/incident TBI (cost per case) | $39,783 | $39,641 | $38,985 | $40,827 |

Abbreviation: TBI = traumatic brain injury.
[a] 5,000 simulations.
[b] Friction cost approach.
[c] 3.5% discount rate used.

and indirect health care costs. By contrast, the present results are based on the first large prospective population-based study investigating TBI incidence and outcomes in hospitalized and nonhospitalized patients with TBI.[2,13]

Information on the total cost and pattern of health services usage post-TBI can be used for health services planning, including helping hospitals and the MOH (1) anticipate and budget for the health care services needed to detect and treat TBI, (2) assess whether new methods of testing or treating are cost effective, and (3) identify disparities and inequities in accessing and delivery of health services post-TBI. The cost per case of TBI can also inform decisions regarding cost-effective interventions to reduce TBI by providing information on the costs that can be averted through prevention activities.

There are a number of caveats regarding the interpretation of the results. First, cost estimates only report the services that people use. People with TBI that is untreated or who have access to only limited health care services and compensation beyond the

acute injury phase will have spuriously lower reported costs. This is true in NZ where marginalized groups have disproportionately lower access to health care services. Further study is needed to identify the additional community and home services that are needed by those who experience TBI. Second, accurate information on some funded health services (e.g., primary care, home/vehicle modification, vocational rehabilitation) is difficult to obtain. Although there are electronic records containing this information, there are no central, accessible data with complete health services usage. Given the access to nationwide hospitalization data, it is likely that any missed cases were mild rather than moderate or severe. Third, extrapolating costs from one region to the entire county is subject to error, particularly if differences in lifestyles, clinical practices, and treatment options affect rates and health services usage. Fourth, our methodology did not provide accurate estimates of total caregiver time and effort dedicated to supporting injured persons. Caregiver time and expenses are clearly significant costs to those living at home, but estimating them requires a different methodology than used in the current study. Fifth, the lifetime cost estimates, based on short-term data, should be viewed as only approximate and highlight the need for a longitudinal study of the long-term effects of TBI including cognitive decline and dementia. Taken together, the uncertainty caused by these factors may underestimate the costs of TBI in NZ and care should be taken when extrapolating the results to other counties.

In conclusion, the findings suggest that the economic burden of TBI is significant and that improved prevention and treatment strategies are warranted. Significant cost savings may be achieved by preventing TBI, particularly for high-cost individuals. Furthermore, given the high number of mild TBI cases, public health officials should identify strategies to reduce incidence of mild injuries. The results also suggest that interventions to improve detection and treatment outcomes will be associated with significant cost savings. Further studies are required to identify cost-effective strategies for prevention, detection, and treatment, and to explore the impact of TBI on families and caregivers.

## AUTHOR CONTRIBUTIONS

Braden Te Ao: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval. Paul Brown: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval, statistical analysis, study supervision. Martin Tobias: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval. Shanthi Ameratunga: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval. Suzanne Barker-Collo: drafting/revising the manuscript, study concept or design, accepts responsibility for conduct of research and will give final approval, study supervision, operations and steering committee. Alice Theadom: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval, acquisition of data, statistical analysis, study supervision, obtaining funding. Kathryn McPherson: drafting/revising the manuscript, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval, obtaining funding. Nicola Starkey: drafting/revising the manuscript, study concept or design, analysis or interpretation of data, accepts responsibility for conduct of research and will give final approval, acquisition of data, study supervision, obtaining funding. Anthony Dowell: drafting/revising the manuscript, accepts responsibility for conduct of research and will give final approval, study supervision. Kelly Jones: drafting/revising the manuscript, accepts responsibility for conduct of research and will give final approval, study supervision. Valery L. Feigin: study concept or design, accepts responsibility for conduct of research and will give final approval, study supervision, obtaining funding.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## DISCLOSURE

The authors report no disclosures relevant to the manuscript. Go to Neurology.org for full disclosures.


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# Appendix eight: Unit cost

*Table 38: Unit Costs*

| Item | Unit | Price or cost per unit (NZ 2010) | Source |
|---|---|---|---|
| **HOSPITALISATIONS** | | | |
| Weighted Inlier Equivalent Separations (WIES) National price 2010/2011 | cost weight | $4,410.38 | Ministry of Health, New Zealand |
| Emergency Department | per visit | $270.00 | SMA-Costing's and Systems, Waikato District Health Board |
| Intensive Care Unit | per day | $929.20 | SMA-Costing's and Systems, Waikato District Health Board |
| Neurosurgery Ward Inpatient | per day | $640.50 | SMA-Costing's and Systems, Waikato District Health Board |
| General Ward | per day | $310.55 | SMA-Costing's and Systems, Waikato District Health Board |
| Inpatient Rehabilitation | per day | $116.98 | SMA-Costing's and Systems, Waikato District Health Board |
| Geriatric A, T & R (active rehabilitation) | per day | $119.38 | SMA-Costing's and Systems, Waikato District Health Board |
| Outpatient Ward | per day | $172.17 | SMA-Costing's and Systems, Waikato District Health Board |
| **Home Aid Equipment** | | | |
| Commode chair | per item | $191.80 | The Life Unlimited Store- Disability Resource Centre |
| Rail in bedroom | per item | $46.00 | The Life Unlimited Store- Disability Resource Centre |
| Rail in bathroom | per item | $46.00 | The Life Unlimited Store- Disability Resource Centre |
| Walking stick | per item | $48.40 | The Life Unlimited Store- Disability Resource Centre |
| Ramps | per item | $700.40 | The Life Unlimited Store- Disability Resource Centre |
| **Radiology & Imaging** | | | |
| MRI Brain Cerebral & Carotid MRA | per item | $488.38 | SMA-Costing's and Systems, Waikato District Health Board |
| Brain CT scan | per item | $133.37 | SMA-Costing's and Systems, Waikato District Health Board |
| Cerebral Angiogram | per item | $1,726.04 | SMA-Costing's and Systems, Waikato District Health Board |
| Skull X-Ray | per item | $196.61 | SMA-Costing's and Systems, Waikato District Health Board |
| EEG | per item | $177.04 | SMA-Costing's and Systems, Waikato District Health Board |
| Trans cranial Doppler | per item | $181.27 | SMA-Costing's and Systems, Waikato District Health Board |

| | | | |
|---|---|---|---|
| Knee - Bilateral X-Ray | per item | $131.08 | SMA-Costing's and Systems, Waikato District Health Board |
| Knee - Left X-Ray | per item | $131.08 | SMA-Costing's and Systems, Waikato District Health Board |
| Knee - Right X-Ray | per item | $131.08 | SMA-Costing's and Systems, Waikato District Health Board |
| Kidneys Tri-Phasic + IV Contrast CT | per item | $171.64 | SMA-Costing's and Systems, Waikato District Health Board |
| Clavicle - Left X-Ray (collarbone) | per item | $196.61 | SMA-Costing's and Systems, Waikato District Health Board |
| Clavicle - Right X-Ray | per item | $196.61 | SMA-Costing's and Systems, Waikato District Health Board |
| **VISITING NURSE** | | | |
| Resource Nurse FTF Fup | per session | $117.57 | SMA-Costing's and Systems, Waikato District Health Board |
| Nurse Practitioner Consultation | per session | $29.34 | Accident Compensation Corporation Schedule Cost of Treatment |
| NCON - Nurse Consult | per session | $54.34 | SMA-Costing's and Systems, Waikato District Health Board |
| **PHYSIOTHERAPY** | | | |
| DHB - Comm Physio FTF FSA | per session | $40.22 | SMA-Costing's and Systems, Waikato District Health Board |
| DHB - Comm Physio FTF Fup | per session | $29.10 | SMA-Costing's and Systems, Waikato District Health Board |
| DHB - Comm Physio FTF FSA | per session | $92.65 | SMA-Costing's and Systems, Waikato District Health Board |
| DHB - Comm Physio FTF Fup | per session | $67.05 | SMA-Costing's and Systems, Waikato District Health Board |
| Physio Clinic FSA | per session | $10.46 | SMA-Costing's and Systems, Waikato District Health Board |
| Physio Clinic F/up | per session | $10.46 | SMA-Costing's and Systems, Waikato District Health Board |
| Hamilton Physiotherapy FTF FSA | per session | $144.17 | SMA-Costing's and Systems, Waikato District Health Board |
| Hamilton Physiotherapy FTF Fup | per session | $76.89 | SMA-Costing's and Systems, Waikato District Health Board |
| Hamilton Physiotherapy NFTF Fup | per session | $115.33 | SMA-Costing's and Systems, Waikato District Health Board |
| ACC - Physio FTF FSA | per session | $104.75 | SMA-Costing's and Systems, Waikato District Health Board |
| T Hospital Physio Clinic Fup | per session | $38.44 | SMA-Costing's and Systems, Waikato District Health Board |
| T Hospital Physio Clinic FSA | per session | $38.44 | SMA-Costing's and Systems, Waikato District Health Board |

| | | | |
|---|---|---|---|
| Physiotherapy (PHY3) | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| **MEDICAL SPECIALIST** | | | |
| Neurosurgery Doctor Day | per session | $92.79 | SMA-Costing's and Systems, Waikato District Health Board |
| AT&R Neuropsychologist Visits | per session | $257.03 | SMA-Costing's and Systems, Waikato District Health Board |
| **Registered Specialists Costs** | per session | $102.21 | Accident Compensation Corporation Schedule Cost of Treatment |
| Acupuncture | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| Chiropractic | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| Osteopathy | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| Podiatry | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| Dentist | per session | $63.92 | Accident Compensation Corporation Schedule Cost of Treatment |
| Gastroenterology FSA | per session | $281.85 | SMA-Costing's and Systems, Waikato District Health Board |
| Gastroenterology F/up | per session | $164.94 | SMA-Costing's and Systems, Waikato District Health Board |
| Gynaecology Preadmit | per session | $117.05 | SMA-Costing's and Systems, Waikato District Health Board |
| Haematology Patient | per session | $232.00 | SMA-Costing's and Systems, Waikato District Health Board |
| Maxillo Facial Surgical F/up | per session | $157.34 | SMA-Costing's and Systems, Waikato District Health Board |
| Fracture Clinic FSA | per session | $150.71 | SMA-Costing's and Systems, Waikato District Health Board |
| Fracture Clinic Fup | per session | $127.09 | SMA-Costing's and Systems, Waikato District Health Board |
| Audiology Clinic FSA | per session | $92.09 | SMA-Costing's and Systems, Waikato District Health Board |
| **OCCUPATIONAL THERAPY** | | | |
| ACC Occ Therapy FSA | per session | $59.64 | SMA-Costing's and Systems, Waikato District Health Board |
| ACC Occ Therapy F/up | per session | $51.21 | SMA-Costing's and Systems, Waikato District Health Board |
| Occ Therapy FSA | per session | $39.60 | SMA-Costing's and Systems, Waikato District Health Board |

| | | | |
|---|---|---|---|
| Occ Therapy F/up | per session | $39.60 | SMA-Costing's and Systems, Waikato District Health Board |
| Occupational therapy (OT01) | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| **SPEECH THERAPY** | | | |
| Speech Lang Clinic Fup | per session | $181.67 | SMA-Costing's and Systems, Waikato District Health Board |
| Speech therapy (ST01) | per session | $62.94 | Accident Compensation Corporation Schedule Cost of Treatment |
| **GP** | | | |
| **Accident** | | | |
| If client is 6 years old or over | per visit | $34.20 | Accident Compensation Corporation Schedule Cost of Treatment |
| If client is under 6 years old | per visit | $37.40 | Accident Compensation Corporation Schedule Cost of Treatment |
| **Medical** | | | |
| If client is 6 years old or over | per visit | $65.00 | Ministry of Health New Zealand |
| If client is under 6 years old | per visit | $0.00 | Ministry of Health New Zealand |
| **COUNSELLOR** | | | |
| 1.1 Session/Counsel Therapy | per session | $65.14 | SMA-Costing's and Systems, Waikato District Health Board |
| **SOCIAL WORKER** | | | |
| Social Workers FTF FSA | per session | $94.74 | SMA-Costing's and Systems, Waikato District Health Board |
| Social Workers FTF FUP | per session | $74.44 | SMA-Costing's and Systems, Waikato District Health Board |
| **DAY HOSPITAL** | | | |
| Geriatric Day Hosp F | per visit | $127.24 | SMA-Costing's and Systems, Waikato District Health Board |
| **Child Development F/up** | per visit | $40.81 | SMA-Costing's and Systems, Waikato District Health Board |
| **Personal Care** | | | |
| Under 65 years | per hour | $25.38 | Disability Support Link, Waikato District Health Board |
| Over 65 years | per hour | $28.14 | Disability Support Link, Waikato District Health Board |
| **Home Help/Home Management** | | | |

| | | | |
|---|---|---|---|
| Under 65 years | per hour | $23.60 | Disability Support Link, Waikato District Health Board |
| Over 65 years | per hour | $25.45 | Disability Support Link, Waikato District Health Board |
| **Meals on wheels** | per meal | $8.00 | Disability Support Link, Waikato District Health Board |

# Appendix nine: Long-term productivity loss

Long-term productivity loss was estimated using the following data sources and calculation:

- From Statistics NZ
    - Average individual income was obtained and linked to occupation responses in the BIONIC questionnaire.
    - National median income in 2010 was used as a proxy measure for those participants in our sample that did not have individual income data. Using the median weekly wage (in 2010) of $769 yields an annual estimate of $39,988 ($769 * 52 weeks).
- From the BIONIC dataset
    - Information on income decrease (at 12 months). Two possible options (i) 50% decrease (or 0.5) and (ii) 15% decrease (or 0.85).
        - Average income reduction was used as proxy for missing data.
    - Estimate for working age remaining (i.e. 65 years (age of retirement) subtracting their age).
- This would yield: projected loss of productivity= % income decrease * individual annual income * working age remaining.

Productivity loss was estimated for four categories based on survey response to having a reduction in their income at 12 months post TBI.

1. Those who did respond to the question, and data was available for their occupation
2. Those who did not respond to the question and data was available for their occupation.
3. Those who responded to the question but no data on their occupation was available.
4. Those who did not respond to the question and no data on their occupation was available (this included those who were of working age and not working).

| | Survey response | Occupation data (linked to income) | Formula used |
|---|---|---|---|
| 1 | Yes | Yes | *loss of productivity= % income decrease(from BIONIC questionnaire) * individual annual income * working age remaining* |
| 2 | No | Yes | *loss of productivity= % income decrease (an estimate of reduction in productivity) * individual annual income * working age remaining* |
| 3 | Yes | No | *loss of productivity= % income decrease (from BIONIC questionnaire) * average annual income (using median weekly wage) * working age remaining* |
| 4 | No | No | *loss of productivity= % income decrease(an estimate of reduction in productivity) * average annual income (using median weekly wage) * working age remaining* |

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