

Multilevel modelling of routine data to investigate  
individual and contextual influences on disparities in  
myocardial infarction rates and outcomes for Aboriginal  
people

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“Aboriginal health” means not just the physical well-being of an individual but refers to the social, emotional and cultural well-being of the whole Community in which each individual is able to achieve their full potential as a human being, thereby bringing about the total well-being of their Community.

*National Aboriginal Health Strategy, 1989*

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**Statement of Authentication**

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

A solid black rectangular box used to redact the author's signature.

Deborah Randall

2015

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## ABBREVIATIONS USED IN THIS THESIS

- ABS: Australian Bureau of Statistics
- AIHW: Australian Institute of Health and Welfare
- AMI: Acute myocardial infarction
- APDC: Admitted Patient Data Collection
- CABG: Coronary artery bypass graft
- CD: Census District
- CHeReL: Centre for Health Record Linkage
- CR: Cardiac rehabilitation
- DALY: Disability Adjusted Life Year
- ECG: Electrocardiogram
- HDL: high-density lipoprotein
- ICC: Intraclass correlation coefficient
- ICD-10-AM: 10th revision of the International Statistical Classification of Diseases and Related Health Problems, Australian Modification
- IHD: Ischaemic heart disease
- IHOPE: Indigenous Health Outcomes Patient Evaluation
- LDL: low-density lipoprotein
- LGA: Local Government Area
- MLM: Multilevel modelling
- NSTEMACS: Non ST-elevation acute coronary syndrome
- NSTEMI: Non ST-elevated myocardial infarction
- NSW: New South Wales
- NT: Northern Territory
- OAMIMPR: Ontario AMI mortality prediction rule
- OECD: Organisation for Economic Co-operation and Development
- PBS: Pharmaceutical Benefits Scheme
- PCI: Percutaneous coronary intervention
- RBDM: Register of Births, Deaths and Marriages
- RCT: Randomised controlled trial
- SA: South Australia
- SES: Socioeconomic status
- SLA: Statistical Local Area
- STEMI: ST-elevated myocardial infarction
- USA: United States of America
- WA: Western Australia
- WHO: World Health Organization



## ABSTRACT

**Background** Heart disease is a leading cause of the health gap between Aboriginal and non-Aboriginal people in Australia. Higher incidence of acute myocardial infarction (AMI) and higher mortality from AMI are major contributors to the greater burden of disease in Aboriginal people. Much of the research on reducing rates of AMI focuses on individual risk factors, such as smoking, physical activity, cholesterol level and diabetes. However, broader contextual and structural factors, including features of the geographic areas where individuals live, and the hospitals they attend, can have an important impact on health outcomes. Identifying and quantifying contextual and individual factors that influence the higher rates of AMI events and mortality in Aboriginal people will assist in better development and targeting of interventions to tackle these disparities. In this thesis, I develop methods for classifying Aboriginal people in routinely collected hospital data, and use these data to investigate the influence of individual, area of residence, and hospital factors on rates of AMI, mortality from AMI, and procedures after AMI, in Aboriginal people in New South Wales (NSW), Australia.

**Methods** Routinely collected hospital data for the entire NSW population for the period July 2000 to December 2008 were linked to mortality data from July 2000 to December 2009 using probabilistic methods. Firstly, I investigated the recording of Aboriginal status in the hospital and deaths data, and used linked data to develop and test algorithms to enhance the reporting of Aboriginal status. Then I used (i) multilevel Poisson regression models to estimate the relative rates of first AMI events, accounting for area of residence; (ii) multilevel logistic regression models to estimate the relative mortality after AMI admission, accounting for hospital and admission; and (iii) multilevel Cox proportional hazards models to estimate the relative procedure rates after AMI admission, accounting for hospital of admission. I also sequentially accounted for other individual risk factors, such as the presence of comorbid conditions, to determine their influence on the disparities in outcomes for Aboriginal people.

**Results** Sixty per cent of the variation in recording of Aboriginal status in routinely collected hospital data was due to the hospital of admission, and status recording was worse in major city compared with more regional and remote hospitals, and in private compared with public hospitals. The number of people reported as Aboriginal, and estimated admission rates and mortality ratios, varied according to the algorithm used to enhance the reporting of Aboriginal status. After accounting for age, sex, and year of admission, rates of AMI in Aboriginal people were more than two times those in non-Aboriginal people, even when comparing within areas of residence. The disparities were particularly large for women and those in younger age groups. There was significant variation in AMI rates by geographic area, with higher rates outside of major city areas and in areas of lower socioeconomic status. The relative Aboriginal to non-Aboriginal disparity in rates was also particularly large in these areas. Aboriginal patients had a similar 30-day mortality risk to non-Aboriginal patients, after adjusting for age, sex, year and hospital, but a higher risk of dying within one year. The latter difference became non-significant after adjustment for comorbid conditions. There was a higher 30-day mortality risk for patients

admitted to smaller, more remote hospitals without on-site angiography facilities compared with larger hospitals and those with on-site angiography, respectively. Aboriginal patients had a revascularisation rate 37% lower than non-Aboriginal patients of the same age, sex, year of admission, and AMI type, but a rate 18% lower within the same hospital. Adjustment for comorbid conditions, such as diabetes and renal disease and other individual factors, explained the remaining disparity. Hospitals varied markedly in procedure rates, and this variation was associated with hospital size, remoteness, and facilities.

**Conclusions** Hospital-level interventions, such as better training of staff, are required to improve the recording of Aboriginal status, particularly in major city and private hospitals. Data linkage of routine administrative data can improve reporting of Aboriginal status, although the impact of the algorithm used to enhance reporting should be explored using sensitivity analysis. My research identified the importance of contextual influences when examining disparities in rates of AMI, and in mortality and procedures after admission for AMI. There was significant variation in overall AMI rates by area, which was partly explained by area-level disadvantage. Even when comparing within areas, Aboriginal people had higher rates of AMI than their non-Aboriginal counterparts. Priority areas for area-level interventions were those with a higher than average disparity and a higher than average rate of AMI for Aboriginal people. While disparities in longer-term mortality and procedure rates within hospitals did not persist after fully adjusting for individual risk factors such as comorbidities, these disparities will remain as long as Aboriginal people have higher rates of comorbid conditions (e.g. diabetes and renal disease) that complicate treatment and survival. For residents of rural and regional areas, both Aboriginal and non-Aboriginal, improving access to larger hospitals or those with specialist treatment facilities could improve surgical rates and outcomes after AMI. However, the main priority must be reducing the early onset of AMI and comorbid chronic conditions, such as diabetes and renal disease, and the subsequent early mortality among Aboriginal Australians. This will require major efforts in primordial, primary and secondary prevention. Priorities include targeting individual risk behaviours, such as smoking, improving the management of early symptoms of cardiac disease, reducing barriers to accessing primary care and cardiac rehabilitation services, and changing community norms about smoking and health behaviours. Interventions must acknowledge the wider historical and contextual causes of the current Aboriginal health disadvantage, and must deal with macro, contextual and individual levels of influence in order to have a significant impact.

# 1. General introduction and outline

## 1.1. The context: disparities in heart disease between Aboriginal and non-Aboriginal people

Australia has two ethnically and culturally distinct Indigenous peoples, the Aboriginal peoples and the Torres Strait Islander peoples.[1] At the 2006 Australian Census (the most relevant census to this research), there were estimated to be 517 200 Aboriginal and Torres Strait Islander people in Australia, of whom 463 900 identified as Aboriginal, 33 100 identified as Torres Strait Islander and 20 200 identified as both Aboriginal and Torres Strait Islander.[2] New South Wales (NSW), Australia's most populous State, was home to the largest proportion (28.7%) of the Aboriginal and Torres Strait Islander population in 2006 (148 200 people, 140 000 who identified as Aboriginal, 5100 who identified as Torres Strait Islander and 3100 who identified as both Aboriginal and Torres Strait Islander), but they comprised only 2.2% of the total population of the state.[2]

Australia's Aboriginal peoples are thought to have lived on mainland Australia for at least 60 000 years, and are one of the world's oldest continuing cultures.[3] Before the arrival of Europeans, they were strong and healthy hunter gatherers,[4] and were unlikely to have suffered from the chronic diseases that are so common among Aboriginal people today.[5] Estimates of the number of people living in Australia before British settlement range from 300 000 to more than 1 million.[1] The arrival of the British in 1788 was accompanied by a drastic decline in the Aboriginal population, as a result of introduced diseases as well as the often violent consequences of the rapidly expanding British pastoral industry in the 1800s.[6] With occupation of their traditional lands and disruption of their food sources, many Aboriginal people moved towards European settlements and became fringe dwellers to white society.[6] This displacement of Aboriginal people from their ancestral lands had disastrous consequences for the maintenance of their spiritual life and social systems.[1]

The history of the people of the Torres Strait differs from that of mainland Aboriginal peoples. The Torres Strait was annexed by Queensland in 1879 and, for the most part, the Islanders were not dispersed from their homelands.[1] However, the people of the Torres Strait were subject to the same government policies as Aboriginal people, policies that "attempted over time to displace, 'protect', disperse, convert and eventually assimilate" them,[6] and their social and health indicators are now similar to those of Aboriginal people.[1]

Today, Aboriginal and Torres Strait Islander people experience health disparities across a myriad of indicators, commencing in the pre-natal period and continuing across the entire life course.[7, 8] This culminates in a life expectancy that is currently estimated to be 11.5 years lower for men and 9.7 years lower for women than for their non-Indigenous counterparts.[9] While there are difficulties estimating life expectancy in Australia and internationally for indigenous peoples because of issues of identification in routine datasets, recent estimates suggest that disparities in life expectancy for indigenous peoples are greater in Australia than in New Zealand, Canada (for First Nations people) and the United States.[10]

In 2008, the Council of Australian Governments (COAG), an intergovernmental forum, including the Prime Minister of Australia and State and Territory Premiers and Chief Ministers, agreed to address Aboriginal and Torres Strait Islander disadvantage through six ambitious targets addressing life expectancy, child mortality, education and employment.[11] One of the targets was to close the gap in life expectancy within a generation (by 2031). These targets committed the Commonwealth, States and Territories to unprecedented levels of investment to close the gap in disadvantage.

Currently, Aboriginal and Torres Strait Islanders are estimated to have a burden of disease from premature disability and death that is two-and-a-half times that for other Australians.[12] Non-communicable diseases, or chronic diseases, are responsible for 70% of this 'health gap'. [12] Ischaemic heart disease (IHD) alone accounts for 14% of the gap [12] and is the leading cause of years of life lost.[13] Aboriginal and Torres Strait Islander people have been shown to have higher age-adjusted rates of incidence of, hospital admission for, and mortality from, acute myocardial infarction (AMI), the acute form of IHD.[14-17]

## 1.2. The evidence gap: to tackle disparities, we need to understand the factors that drive them

While Aboriginal and Torres Strait Islander people are often said to be over-researched, there is still a lack of understanding about the reasons for the disparity in heart disease and what factors to target in order to reduce it.[18] There is a pressing need to 'unpack' the gap in heart disease and AMI incidence and mortality, to provide better direction for policymakers to target specific interventions that will reduce not only these disparities, but also contribute to narrowing the overall health gap for Aboriginal people.

Much of the research on how to reduce rates of AMI in the general population focuses on individual risk factors, such as smoking, physical activity, excessive alcohol consumption, high cholesterol and high blood pressure levels, being overweight and obese, and having diabetes and chronic renal disease.[19-21] However, increasing attention is being paid to the influence on health of the broader contextual and structural factors that are outside an individual's direct influence.[22] People living in the same area or who are admitted to the same hospital are exposed to the same complex interplay of structural and contextual factors, such as neighbourhood socioeconomic status (SES), ease of access to services, public transport, quality of care and the presence of specialty clinical units. Reporting disparities in AMI outcomes at an average national or state level ignores these different contextual influences for the Aboriginal and Torres Strait Islander population. For example, living in more disadvantaged neighbourhoods has been found to be associated with higher cardiovascular disease incidence [23, 24] and mortality [25] even after adjusting for individual SES. Furthermore, Aboriginal and Torres Strait Islander people are over-represented in disadvantaged areas in Australia, with 15% of the Aboriginal population in NSW living in areas that are classified as being in the most disadvantaged decile of the Index of Relative Social Disadvantage in NSW in 2006 compared with only 7% of the non-Aboriginal population.[26, 27] People living in rural and remote areas have poorer access to specialist health services,[28, 29] and Aboriginal and Torres Strait Islander people make up a higher proportion of people in rural and remote areas of Australia – in 2006, 73% of the

total NSW population lived in a major city[30] compared with 42% of the Aboriginal population.[2]

One way to investigate the contextual influences on individual outcomes is to use multilevel modelling. Multilevel modelling takes into account the natural clusters within the data, such as people living in the same areas or people admitted to the same hospitals, and allows for similarities in outcomes within these clusters. If this clustering is not taken into account, then true underlying relationships at the individual level can be hidden by variations across higher-level units like hospitals or areas, and standard errors can be biased downwards for higher-level characteristics that are attributed to individuals.[31] Multilevel modelling is also a powerful analytical tool that allows investigation of the importance of these contextual levels in influencing health outcomes by quantifying the impact of these shared factors on outcomes.[32]

Due in part to the small size of the Aboriginal and Torres Strait Islander population, large, whole-of-population studies are required to investigate geographic and health service influences on heart disease disparities for Aboriginal and Torres Strait Islander people in Australia. This provides enough power to investigate the comparative risk of AMI, as well as AMI outcomes, for Aboriginal and Torres Strait Islander people, and to examine these risks for different geographic areas and for different hospitals, including small rural hospitals. Designing a study with the requisite sample size and follow-up time would be very costly and results would not be available for many years. Instead, the use of linked, routinely collected datasets offers a cost-effective and timely research solution, as these data have already been collected in the routine administration of health services, and historical data can also be accessed so it is not necessary to wait for the requisite follow-up times before data analysis.

One limitation of routinely collected data, however, is the known under-enumeration of Aboriginal and Torres Strait Islander people in hospital data.[33] Internally linking records within a dataset (identifying the multiple records for each person) and linking to other data sources can potentially improve reporting of Aboriginal and Torres Strait Islander people by combining information from independent sources of recording of Aboriginal and Torres Strait Islander status.[34]

The work presented in this thesis was nested within the Indigenous Health Outcomes Patient Evaluation (IHOPE) study, which sought to use administrative data to disentangle the influence of individual and contextual effects on health outcomes for Aboriginal people compared with non-Aboriginal people in NSW, Australia. The IHOPE study is a project grant funded by the National Health and Medical Research Council (NHMRC) and has investigated: the impact of geography on rates of serious traffic accidents for Aboriginal and non-Aboriginal people;[35] disparities in cataract surgery by areas of residence for Aboriginal people;[36] otitis media procedure rates among Aboriginal and non-Aboriginal children;[37] rates of potentially preventable hospitalisations for Aboriginal and non-Aboriginal people;[38] and disparities in childhood potentially preventable hospitalisations and in unintentional injury. For this thesis, I used the IHOPE data to investigate the rates of AMI events, the disparity in rates for Aboriginal people compared with non-Aboriginal people, and disparities in treatment and mortality after AMI.

Due to the small proportion of Torres Strait Islander people living in NSW (3.4% of the total Aboriginal and Torres Strait Islander population of NSW in 2006 identified as Torres Strait Islander and not Aboriginal[2]), Aboriginal and Torres Strait Islander people are referred to as Aboriginal people in the remainder of the thesis.

### 1.3. Aims

The overall aim of the thesis was to investigate the influence of individual, area of residence, and hospital factors on rates of AMI, mortality and procedures after AMI, in Aboriginal versus non-Aboriginal people in order to better direct interventions to lower the rates of AMI and AMI mortality in Aboriginal people.

In detail, the analyses aimed to answer the following questions:

1. How well is Aboriginal status recorded in the routinely collected hospital data in NSW and does this vary by hospital? Can application of algorithms to linked hospital records for individuals improve the reporting of Aboriginal status, and what is the impact of these algorithms on reported health disparities?
2. Is there a disparity in rates of AMI between Aboriginal and non-Aboriginal people in NSW and does it persist when taking into account area of residence? What is the influence of age, gender and area of residence on AMI event rates and the Aboriginal to non-Aboriginal disparity?
3. Is there a disparity in short- and longer-term mortality after admission with AMI when taking into account the hospital of admission? What is the influence of hospital of admission on short- and longer-term mortality?
4. Is there a disparity in the provision of revascularisation surgery after admission with AMI? Does it persist when taking into account the hospital of admission? What is the influence of hospital of admission and individual risk factors on revascularisation rates after admission?

### 1.4. Outline of the thesis

This thesis is submitted as a series of published papers as set out in the University of Western Sydney Doctorate Policy. Four published papers make up the content chapters of this thesis, each presenting original research. Five additional chapters provide an introduction to the work, and bring together the results and their implications for policy, practice and further research. A description of each chapter follows.

Chapter 1 introduces the thesis and provides the rationale for the series of research papers.

Chapter 2 provides an overview of the history and health of Aboriginal people in Australia, and the disparities observed in heart disease and AMI rates and mortality.

Chapter 3 provides a background to the methods in the thesis by introducing the strengths and limitations of observational studies using routinely collected data and provides an introduction to multilevel modelling - the main statistical modelling technique used in the study.

Chapter 4 details the datasets used in the thesis and the methods used in the analysis.

Chapter 5 investigates under-recording of Aboriginal status in hospital data from NSW, and determines the impact of the hospital, the individual and the admission on variations in recording. It also defines algorithms for enhanced reporting, and examines the impact of these algorithms on estimated disparities in cardiovascular and injury outcomes. This chapter has been published as: Randall DA, Lujic S, Leyland AH, Jorm LR. Statistical methods to enhance reporting of Aboriginal Australians in routine hospital records using data linkage affect estimates of health disparities. *Australian and New Zealand Journal of Public Health*. 2013;37(5):442-9.

Chapter 6 investigates disparities in rates of AMI between Aboriginal and non-Aboriginal people in NSW and examines the roles of age, gender, geography and area-level disadvantage in any disparities. This chapter has been published as: Randall DA, Jorm LR, Lujic S, Eades SJ, Churches TR, O'Loughlin AJ, Leyland AH. Exploring disparities in acute myocardial infarction events between Aboriginal and non-Aboriginal Australians: Roles of age, gender, geography and area-level disadvantage. *Health and Place*. 2014;28:58-66.

Chapter 7 investigates 30- and 365-day mortality after AMI admission to public hospitals in NSW for Aboriginal and non-Aboriginal people, and examines the impact of the hospital of admission on mortality outcomes. This chapter has been published as: Randall DA, Jorm LR, Lujic S, O'Loughlin AJ, Churches TR, Haines MM, Eades SJ, Leyland AH. Mortality after admission for acute myocardial infarction in Aboriginal and non-Aboriginal people in New South Wales, Australia: A multilevel data linkage study. *BMC Public Health*. 2012;12(1).

Chapter 8 examines revascularisation rates after AMI for Aboriginal and non-Aboriginal patients and investigates whether a disparity previously noted in the literature persists when accounting for hospital of admission. The analysis also examines the relative impacts of individual and hospital factors by sequentially controlling for risk factors. This chapter has been published as: Randall DA, Jorm LR, Lujic S, O'Loughlin AJ, Eades SJ, Leyland AH. Disparities in revascularization rates after acute myocardial infarction between Aboriginal and non-Aboriginal people in Australia. *Circulation*. 2013;127:811-9.

Chapter 9 summarises the main findings of the published papers, and reviews the literature to suggest interventions for addressing the disparities identified in the research.

## 1.5. Significance

The findings of this thesis 'unpack' the overall disparities in AMI rates and outcomes, to identify the contributions of hospital characteristics, area characteristics and individual factors to AMI rates and outcomes, and hence assist in targeting resources and interventions. Quantifying the variation at the hospital and area level shows the potential for health gains with hospital-level and area-level interventions.

Through the project reference group that was convened to advise the IHOPE project team, the findings of this PhD research project have been presented to senior policy makers in Aboriginal Health and representatives of the Aboriginal Community Controlled Health Services, and have already been cited in key national policy documents.[39-42] They will

contribute to guiding interventions and policies to improve health outcomes for Aboriginal people.

The methodological components of this thesis will also contribute more generally to the fields of population health and health services research, providing practical examples of how to use administrative datasets for studies of health outcomes and demonstrating how multilevel modelling can be used to get the most out of administrative data.

## 1.6. The role of the author of this thesis

I took the lead role in developing the research questions and analysis plans for all four papers that make up the thesis. I was responsible for the data management of the entire IHOPE linked dataset, and for preparing the data for analysis. I also undertook all of the statistical analysis for all four papers, wrote the first draft of each of the four manuscripts, incorporated feedback from the co-authors to produce final versions of each for submission, and took overall responsibility for the journal submission and revision processes.



## 2. Background

### 2.1. Health and heart disease in Aboriginal people

Australia has been ranked among the top seven OECD countries for life expectancy at birth since 1999;<sup>[43]</sup> however, this excellent health status is not shared by all in the population. This is most starkly evidenced by the lower life expectancy for Aboriginal and Torres Strait Islander people, currently estimated to be 11.5 years lower for Aboriginal men and 9.7 years lower for Aboriginal women than for other Australians.<sup>[9]</sup> Babies born to Aboriginal mothers are more likely to be born preterm and of low birth weight than babies born to non-Aboriginal mothers, and Aboriginal babies experience almost two times the foetal death rate and twice the neonatal death rate compared with non-Aboriginal babies.<sup>[7]</sup> Poor early childhood health, such as chronic suppurative otitis media and the associated hearing loss and impact on speech and language development, can have a life-long impact on education, opportunities, and later health.<sup>[8]</sup> Even exposures while in utero may have impacts on chronic disease outcomes in later life.<sup>[44, 45]</sup>

Using disability adjusted life years (DALYs) to quantify fatal and non-fatal health loss, Vos and colleagues calculated that Aboriginal people had a burden of disease two-and-a-half times that of other Australians.<sup>[12]</sup> These relative measures of mortality and burden of disease can indicate the scope for health improvement for Aboriginal people. In fact, Vos and colleagues estimated that reducing burden of disease among Aboriginal people to the same level as that experienced by other Australians would decrease the overall burden for Aboriginal people by 59%.<sup>[12]</sup> Overall, non-communicable diseases or chronic diseases were responsible for 70% of the gap in the burden of disease for Aboriginal people.<sup>[12]</sup> Ischaemic heart disease (IHD) alone accounted for 14% of the gap in burden of disease between Aboriginal and non-Aboriginal people in Australia.<sup>[12]</sup>

Ischaemic heart disease (IHD), also called coronary artery disease or coronary heart disease, is the most common form of heart disease among Aboriginal people in Australia.<sup>[19]</sup> IHD is a chronic condition in which a fatty material called 'plaque' slowly builds up on the walls of the arteries supplying the heart in a process called atherosclerosis.<sup>[46]</sup> This causes the arteries to narrow and can reduce blood supply to the heart. This can lead to symptoms such as angina, which is temporary chest pain or discomfort. An acute myocardial infarction (AMI), or 'heart attack', occurs if blood flow to the heart is partially or completely blocked, resulting in the heart muscle not receiving enough oxygen. This is often caused by a blood clot that forms around an area of cracked plaque. IHD can start at a young age, without obvious symptoms, and is usually well advanced by middle age.

Mortality from IHD has been estimated to be almost two times as high in Aboriginal compared with non-Aboriginal people, after adjusting for age differences in the respective populations.<sup>[17]</sup> Aboriginal people are 2.1 times as likely to have IHD as non-Aboriginal people after adjusting for age group, with the rate ratio highest (3.4) in the youngest age group of 25 to 44 year olds.<sup>[19]</sup> It is extremely difficult to estimate accurate population rates of IHD, as onset is slow and diagnosis requires detailed medical assessment with exercise stress testing or a coronary angiography.<sup>[47]</sup> However, the rates of AMI can be

more accurately ascertained because those experiencing an AMI should be taken to hospital immediately and, unless they die before getting to hospital, they will be recorded in hospital data. Rates can therefore be derived from routine hospital and mortality data. Routine hospital and mortality data collections have been used to assess incidence of and mortality from AMI in Australia and internationally.[14, 15, 48, 49] It should be noted that there may be barriers to accessing treatment for Aboriginal people, such as experiences or stories of racism, even for such a life-threatening event, and this may mean that Aboriginal AMI events are under-counted in official data.[50] Mortality rates from AMI have been declining since the 1980s in Australia and other Western countries, driven both by declines in event rates and case fatality rates.[51, 52] However, whether rates have been declining also for Aboriginal people is not known. Analysis of hospital data from between 2004 and 2006, from NSW, Victoria, Queensland, Western Australia (WA), South Australia (SA) and the Northern Territory (NT) combined, found that Aboriginal people were hospitalised for AMI at 2.5 times the rate of non-Aboriginal people.[53] Between 2002 and 2006, in Queensland, WA, SA and NT combined, Aboriginal people died from AMI at 1.7 times the rate of non-Aboriginal people.[53] Using measures combining hospitalisations and deaths for the NT, age-adjusted incidence of AMI was found to be 1.7 times as high for Aboriginal people over 20 years of age compared with non-Aboriginal people between 1992 and 2004.[54] In WA, age-specific incidence rates were calculated for people aged 25 to 74 between 2000 and 2004, and these showed that the Aboriginal to non-Aboriginal incidence rate ratio was particularly high among younger people, ranging from 25.6 among 25-29 year olds to 2.1 among 70-74 year olds.[15] The relative disparity was also higher in women. Age-adjusted case fatality rates after AMI were estimated to be 1.5 times those for Aboriginal people compared with other Australians in the period 2002 to 2003 using data from Queensland, WA, SA and NT.[14]

As explained below, the reasons for the high incidence of and mortality from AMI for Aboriginal people are individual and contextual.

## 2.2. Risk factors and comorbidities

Individual modifiable risk factors for AMI can be grouped into behavioural risk factors, such as smoking, low levels of physical activity, excessive alcohol consumption, and biomedical risk factors, including high cholesterol, high blood pressure, being overweight and obese, and having diabetes and chronic renal disease.[17, 19] There are also psychosocial risk factors such as having depression, being socially isolated and lacking social support.[46, 55] Other risk factors that are not modifiable are increasing age, being male and having a family history of early death from IHD.[19]

There have been some modest declines in smoking rates among Aboriginal people in recent years: the percentage of current daily smokers among over 15 year olds went from 49% to 45% from 2002 to 2008.[56] However, Aboriginal people are still two times more likely than non-Aboriginal people to be current daily smokers. Self-reported physical activity appears to be declining, with 47% of Aboriginal people aged 15 and over (in non-remote areas) reporting being 'sedentary' in 2004-2005 compared with 37% in 2001, and Aboriginal people are one and a half times as likely to report being 'sedentary' as are non-Aboriginal people.[41] Age-adjusted rates of chronic risky or high risk drinking were similar for

Aboriginal and non-Aboriginal Australians in data collected in 2004 to 2005; however, age-adjusted binge drinking rates were two times as high among Aboriginal people than non-Aboriginal people.[13]

Cholesterol is an essential substance for the body's normal functioning, but does not dissolve in the blood and must be transported to and from cells by two types of lipoprotein carriers, low-density lipoprotein (LDL) and high-density lipoprotein (HDL). LDL cholesterol is considered 'bad' cholesterol because it contributes to plaque and atherosclerosis, while HDL cholesterol is considered 'good' because it carries LDL cholesterol away from the arteries and back to the liver where it can be broken down.[57] Therefore, when assessing cholesterol levels, the best combination is to have low LDL cholesterol and high HDL cholesterol. There is very little population-level information on LDL and HDL cholesterol levels for Aboriginal people compared with those for the general population. In a study conducted among Aboriginal adults from in and around Alice Springs in the Northern Territory (NT), 70% of both males and females had elevated LDL cholesterol from the age of 35 onwards.[58] A recent systematic review of HDL cholesterol levels reported diverse results, but determined that very low levels of HDL cholesterol appeared to be particularly prevalent in rural and remote Aboriginal communities.[59]

Self-reported hypertensive disease (or high blood pressure) data were collected in the National Aboriginal and Torres Strait Islander Health Survey 2004-2005 and compared with the results of the National Health Survey to get comparative rates. High blood pressure was found to be more common for Aboriginal males and females (1.5 and 1.7 times as high, respectively) than non-Aboriginal males and females, and there was an earlier age of onset among Aboriginal people.[60] Age-adjusted rates of being overweight and obese have been found to be similar for Aboriginal and non-Aboriginal men, but Aboriginal women are one-and-a-half times more likely to be overweight or obese than non-Aboriginal women.[13]

Elevated depressive symptoms were found to be associated with two times the risk of cardiovascular disease in a group of Aboriginal adults from urban and remote locations around Alice Springs.[58] Although not referring to indigenous people, a systematic overview of the international literature on social support and cardiac-related mortality concluded that there was a non-linear relationship, and that social isolation was associated with a two- to three-fold increase in mortality among those who were most isolated, but that there was no difference between those with moderate and high levels of support.[61]

Cardiovascular disease, diabetes and chronic renal disease share risk factors such as obesity and old age and can also be caused by, or be complications of, each other, and are therefore considered to be comorbidities.[62] Diabetes is a risk factor for heart disease if not managed properly[63] and can also complicate treatment and survival,[64] while renal disease increases the risk of cardiovascular mortality.[65] Patients with renal impairment are also less likely to undergo diagnostic coronary angiography (a necessary step towards revascularisation) than those with normal renal function.[66] The presence of two or more of these conditions together is thought to impart excess risk of hospitalisation and mortality beyond that expected from the simple cumulative effects of the diseases.[62] These comorbidities are more prevalent among Aboriginal people than non-Aboriginal people. Type 2 diabetes accounts for 7% of the burden of disease for Aboriginal people in

Australia and for 12% of the health gap.[12] In 2004-05, the rate of diabetes/high sugar levels was 3.4 times higher among Aboriginal people than non-Aboriginal people.[13] Hospital data from NSW, Victoria, Queensland, WA, SA and NT in 2005-06 show that Aboriginal males were around 10 times as likely, and females around 18 times as likely, to be hospitalised for chronic renal disease, as non-Aboriginal males and females, respectively.[13] In 2005, incidence rates for end-stage renal disease were estimated to be 6.8 times as high for Aboriginal people as non-Aboriginal people, with the rate ratio higher in regional and remote areas.[13]

### 2.3. Impact of geographic area and hospital of admission

Much of the research about how to reduce rates of AMI and IHD focuses on targeting individual risk factors, such as those mentioned above.[20, 21] However, contextual factors such as the area where someone lives and the hospital they attend can have important impacts on cardiovascular disease, heart disease and outcomes after admission.[48, 67-70]

People living in the same area are exposed to the same complex interplay of factors, such as neighbourhood SES, ease of access to services, remoteness, public health campaigns, walkability and public transport, and social cohesion and safety. Living in more disadvantaged neighbourhoods has been found to be associated with higher cardiovascular disease incidence,[23, 24] and mortality,[25] even after adjusting for individual SES. Distance to the nearest hospital is of particular interest in the context of AMI, due to the time-critical nature of treatment after an AMI. In 2011, Hvelplund and colleagues in Denmark determined that those living further away from a hospital able to perform invasive surgery were less likely to receive invasive examination and treatment.[71] People living in regional, rural and remote areas of Australia also have poorer access to specialist health services,[28, 29] and have been shown to have higher excess deaths and avoidable mortality.[72-74]

Additionally, a growing number of international studies have demonstrated that the health system can have a substantial impact on cardiovascular disease outcomes. For example, a study in Italy reported that 10% of the variation in post-hospital mortality from IHD was attributable to the clinical unit.[75] Other hospital factors that have been linked to variation in outcomes after AMI admission or revascularisation procedures include the hospital volume (i.e. number of AMI patients admitted),[76] the hospital type (i.e. private or public, teaching or non-teaching and remoteness of location),[77] and the presence of facilities to undertake revascularisation procedures.[69, 70]

Investigating contextual influences (e.g. area of residence and hospital) on AMI outcomes and disparities is not just of interest in itself; it is also important because of the differences in the geographic distribution of the Aboriginal and non-Aboriginal populations in Australia. A higher proportion of Aboriginal than non-Aboriginal people live in rural and remote areas of Australia, with about 24% of Aboriginal people living in remote or very remote parts of Australia[2], compared with only 2.3% of the total population.[78] If geographic clustering were not taken into account, the results would be confounded by this uneven distribution. Similarly, the population distribution of Aboriginal people means that they are more likely than non-Aboriginal people to be admitted to smaller, regional hospitals that may not have

the facilities to perform cardiac procedures. As such, it is important to properly account for this in any analysis of AMI outcomes and treatment rates.

## 2.4. Prevention and treatment of AMI

There is no cure for IHD, but the development of IHD is considered avoidable, at least in many cases, given good primary care and prevention. Similarly, good secondary prevention such as medications and lifestyle changes can relieve or manage symptoms and reduce further problems.[46] The Royal Australian College of General Practitioners (RACGP) guidelines for preventive action in general practice recommend that a person's absolute cardiovascular risk be measured every two years from the age of 45 onwards for non-Aboriginal Australians and from the age of 35 onwards for Aboriginal people.[79] Gaps have been described in the risk management of cardiovascular diseases in the primary care setting in the general population, where only 74% of eligible patients had all the information recorded that was necessary to calculate absolute cardiovascular risk.[80] Another study of Aboriginal people found 53% were not adequately screened for cardiovascular risk.[81]

In terms of treatment after AMI, Australian treatment guidelines for someone presenting with acute coronary syndromes (a grouping that includes angina as well as AMI) indicate that optimal treatment depends on whether the person presents with an ST-elevation myocardial infarction (STEMI) or a non-ST-elevation acute coronary syndrome (NSTEMI), which is determined by an electrocardiogram (ECG).[82] The Australian guidelines relating to immediate treatment can be summarised as recommending: (1) early reperfusion, i.e. restoring of blood flow, for patients with STEMI; (2) risk stratification and observation for patients with NSTEMI; and (3) access to invasive procedures for patients with high- and intermediate-risk NSTEMI.[83] Reperfusion can be achieved through percutaneous coronary intervention (PCI), fibrinolysis (also called thrombolysis, a medical treatment that breaks down blood clots) or, if PCI or fibrinolysis fails, or if there are contraindications to these treatments, coronary artery bypass graft (CABG) surgery.[82] The term revascularisation refers to PCI and CABG procedures.

The choice of treatment after AMI depends on timing, but the Australian guidelines state that anyone who presents to a medical facility within 12 hours of the onset of ischaemic symptoms (narrowing or blocking of an artery) should have a reperfusion strategy implemented promptly.[82] PCI is currently considered the best treatment, as long as it is performed by a qualified cardiologist in an appropriate facility.[82] If PCI is not immediately available, fibrinolysis is considered if the additional delay to PCI, over and above the time taken to administer fibrinolysis, is more than one hour.[82] For those patients without ST-segment elevation on their initial ECG, observation is recommended to rule out other diagnoses and also for risk stratification to determine the most appropriate treatment. The guidelines recommend that NSTEMI patients with certain high-risk features are best managed with aggressive invasive therapy, such as angiography and revascularisation, except in patients with severe comorbidities. However, the guidelines also state that high risk features include the presence of known diabetes and chronic renal disease, two common comorbidities.[82]

Racial, ethnic and socioeconomic disparities in revascularisation rates after AMI have been demonstrated in a number of studies in the United States of America (USA), Europe and Australia.[84-92] A Kaiser Family Foundation study examining 81 studies in the USA that looked at racial disparities in cardiac procedures and care, found “credible evidence that African Americans are less likely than whites to receive diagnostic procedures, revascularization procedures and thrombolytic therapy”[93] among those studies classified as ‘strong’. These differences were found to persist even when accounting for factors such as age, insurance status and comorbidities.

In Australia, in one study of national hospital data, Aboriginal people were shown to have fewer cardiovascular procedures than other Australians.[94] In a Queensland public hospital study, coronary procedure rates were found to be lower among Aboriginal than non-Aboriginal patients admitted with AMI.[91] However, Bradshaw and colleagues[95] found that Aboriginal patients living in an urban area of Perth had a similar rate of overall revascularisation procedures as an age-matched comparison group of non-Aboriginal patients.

Cardiac rehabilitation is recommended for all patients who have had a myocardial infarction[96], but a study in Victoria estimated that only 14% of those admitted for AMI ended up attending rehabilitation.[97] Remoteness of residence can also impact on whether or not patients attend a cardiac rehabilitation program after an acute event.[98]

## 2.5. Social determinants of health and health service use

Theoretical frameworks can assist in conceptualising the complex and interrelated causes and causal pathways for chronic disease and disparities. The social determinants of health framework suggests that, while health is influenced by an individual’s choices, it is also influenced by structural and societal factors that are beyond the influence of individuals. This framework was introduced in the 1970s as a counterpoint to a focus solely on disease processes and the health system responses, and encompasses both the contextual, societal influences and individual risk factors like health behaviours.[99] The World Health Organization (WHO) defines the social determinants of health as the “conditions in which people are born, grow, live, work and age”.[100] Social determinants are broadly classified by WHO into ‘circumstances of daily life’ (e.g. exposures in early life, social and physical environments, work, and access to health-care responses and prevention) and ‘structural drivers’ (e.g. social stratification and inequity, societal values, biases and norms, and economic and government policies). Even an individual’s risk behaviours can be seen as a response to the external environment.[101]

Andersen and Newman put forward a multilevel framework of health service utilisation taking into account both individual determinants and risk factors as well as the influence of society and the health service system.[102] Individual determinants were divided into predisposing and enabling factors as well as illness level. The authors believed that, with equitable distribution of health services, only demographic variables and measures of illness levels would continue to be important individual factors, while social structures, beliefs and resources should have less influence.

Many social determinants are distant, spatially and temporally, from individuals and their particular health experience and may influence health through complex causal pathways, e.g. from poverty through smoking to cellular abnormalities.[103] Eades posited that the possible causal biological links between these social determinants and health outcomes in Aboriginal people could be through the frequent activation of the biological stress response that can lead to “depression, increased susceptibility to infection, glucose intolerance leading to diabetes, and high blood pressures and accumulation of cholesterol in blood vessel walls leading to heart attack and stroke”. [104] For Aboriginal Australians, the social determinants of disadvantage are further exacerbated by racism and social exclusion.[104]

## 2.6. Theoretical framework for the thesis analyses

The social determinants of health and health service utilisation frameworks provided context and structure to the analyses in this thesis, and to the interpretation of the findings. Figure 1 presents a framework for the levels of influence on the outcomes investigated in this thesis, from macro influences such as overall political and historical factors, through contextual influences, at the geographic and hospital levels, to individual factors grouped as in Andersen and Newman’s framework into predisposing, enabling and illness level.[102]

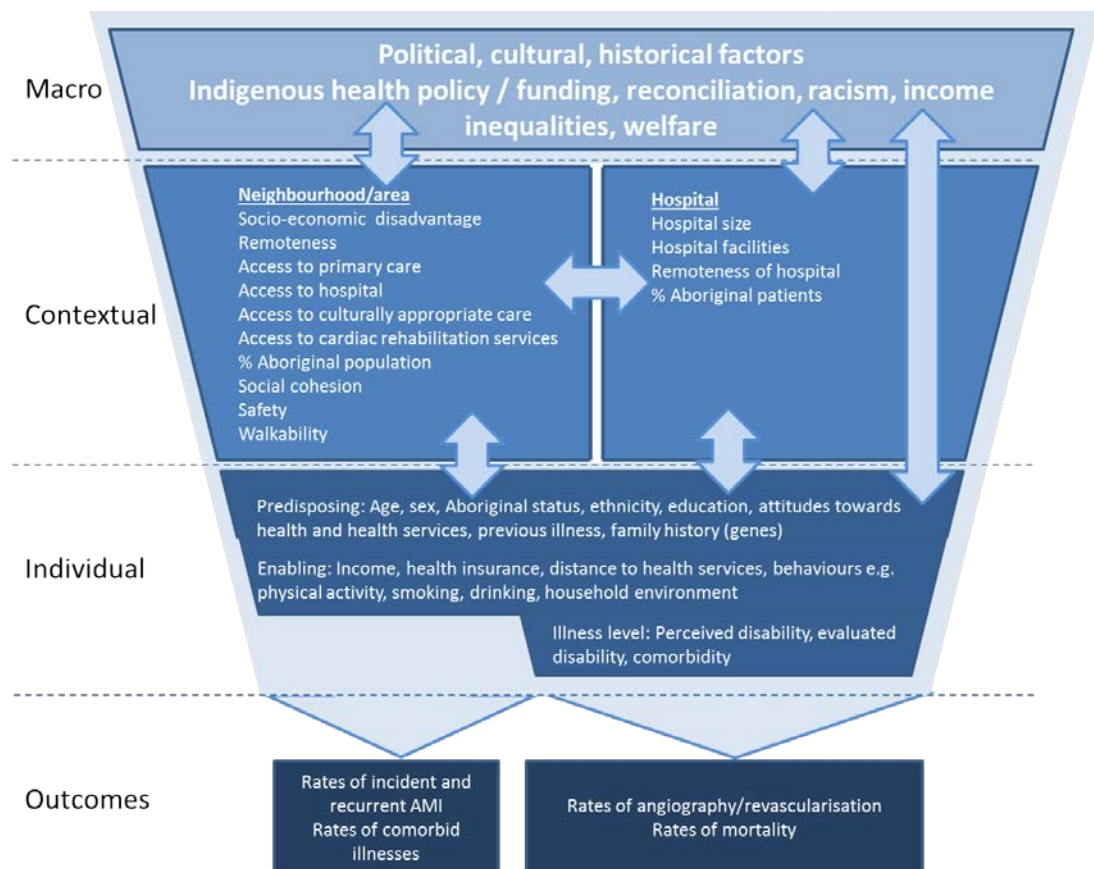


Figure 1. Theoretical framework for the thesis analyses.

## 3. Background to Methods

### 3.1. Observational data

There are two main types of epidemiological studies, observational and intervention studies.[105] Intervention studies such as randomised controlled trials (RCTs) are considered to be the 'gold standard' for investigating causal relationships because the researcher is able to assign a 'treatment' to one group and observe the outcomes in this group prospectively. In an ideal world, one would observe the *same* group of people 'treated' and also 'not treated' and compare the outcomes in both situations, but this is very rarely possible. In most studies, a control group is also recruited and followed up, and the outcomes in this group are compared with the outcomes in the treatment group. In order to determine the effectiveness of a treatment (or the negative impact of a particular risk factor), it is crucial that the treatment and control groups are 'exchangeable', that is, the only difference between the groups is whether the treatment was given or not. If this is the case, any differences in outcomes can be reasonably attributed to the treatment. In RCTs, this is achieved through random assignment to the treatment or control group of a large enough group of people so that they are similar on all measured and unmeasured potential confounders.

In observational studies, data are observed and collected as is, without manipulation of treatment or risk factors. Observational studies describe risk factors and treatments in the 'real world' and are often less costly and less time-consuming than intervention studies. Observational studies may also be necessary when it is not ethically acceptable or practical to require certain people to be exposed or unexposed to a treatment or risk factor,[105] or when a particularly rare or adverse outcome only comes to light with a very large sample size.[106] Furthermore, the generalisability of a RCT may be low due to exclusions of certain types of patients, which means the trial population is not always representative of the majority of patients undergoing treatment in normal clinical practice.[106] The downside to observational studies is that there is no inbuilt control of the possible confounding related to differences between the 'exposed' and 'unexposed' groups, although methods exist for using observational data to emulate an RCT.[107]

Routine data, such as those used in this thesis, are commonly used in epidemiological observational studies and can provide the large sample sizes that are not always available in intervention studies. This is important for studies of Aboriginal people, given the relatively small Aboriginal population. However, routine data studies have limitations as well as benefits over studies that have purpose-built data collection.

#### 3.1.1. Using linked, routinely collected data to track population health

The collection of vital statistics (e.g. births and deaths) and other health-related statistics such as hospital admission rates are crucial for tracking the health status of the population. By definition, the collection of these data is part of the routine operation of services, so little additional cost is involved in obtaining the data. The data generally capture health events for the entire population, which overcomes selection bias, although it should be noted that full capture may be influenced by individuals' choices about seeking care. The



data are collected and recorded at the time of the health event, so they are not subject to recall bias.

The Aboriginal and Torres Strait Islander Research Agenda Work Group of the National Health and Medical Research Council[108] outlined themes that they suggested were crucial to achieving health gains for Aboriginal people, including descriptive research that could be used “to inform the development of sound preventive, early diagnosis and treatment based interventions which are likely to result in meaningful health gain for Aboriginal and Torres Strait Islander peoples.” One of the strategies that came out of consultation was the use of data linkage research to monitor health disparities in a non-invasive way for Aboriginal communities.

However, administrative data are collected primarily for funding and other administrative purposes, and not for research. There are many points at which errors can occur in the data, e.g. in recording on medical records, in coding of medical records and in data entry to the electronic record, and data are often transformed through coding for funding purposes rather than clinical or research purposes.[109] This often means that not all variables that would be of interest to researchers are captured (or captured well) and, as a result, there are concerns about residual confounding and measurement error when analysing routinely collected data. For data to be useful for assessing and comparing health outcomes, other potentially confounding factors must be taken into account, such as patient age and severity of illness,[110-112] and the acknowledged under-recording of Aboriginal Australians in administrative databases.[33, 113]

### 3.1.2. Under-recording of Aboriginal people in routine data

Aboriginal Australians have repeatedly been shown to be under-recorded in administrative hospital data.[33, 113-116] The National Health Data Dictionary recommends that the following standard Indigenous status question is asked of all public hospital patients by admitting staff, “Are you of Aboriginal or Torres Strait Islander origin?”.[114, 117] The standard codes captured are:

1. Aboriginal but not Torres Strait Islander origin
2. Torres Strait Islander but not Aboriginal origin
3. Both Aboriginal and Torres Strait Islander origin
4. Neither Aboriginal nor Torres Strait Islander origin

There is an additional code 9, “Not stated/inadequately described”, that should only be used if a person refuses to answer the question or is unable to communicate, and someone who knows the patient is not available to provide the information.[117] The use of this standard question is not universal in private hospitals across Australia.[114] The under-enumeration may be due to the standard question not being asked of all patients (possibly because of inadequate training of staff in how or why to ask the question, or inadequate hospital policies for ensuring the question is asked), or it could be that Aboriginal or non-Aboriginal people refuse to answer the question when asked.

Improvements have been occurring over time, however. After an audit in which face-to-face interviews were conducted with a sample of patients across a selection of public hospitals in NSW and other Australian states, and the responses were compared with the

Indigenous status information in hospital admission records, the AIHW estimated that in 2007 the level of enumeration for Aboriginality in the NSW Admitted Patient Data Collection (APDC) was 88%, with variation across geographic areas (best in rural/remote areas).[33] According to the AIHW, the degree of Aboriginal identification in the NSW APDC is considered 'acceptable' from 2004-2005 onwards.[33] Even with 'acceptable' levels of identification, there continues to be under-enumeration. Having internally linked data, i.e. data where each person's records over time are linked together under the one person identifier, improves identification by examining the entire admission history for each patient. In such internally linked data, there are inevitably inconsistencies across one person's admission history for variables that should be constant, such as date of birth, sex, or Aboriginal status. This could be due to incorrect recording in the APDC, incorrectly linked records, or personal decisions about identifying as Aboriginal in different situations.

Chapter 5 on enhanced reporting of Aboriginal status goes into these issues in more detail, and uses multilevel modelling to investigate the impact of the individual and the hospital on rates of recording of Aboriginal status, as well as developing and comparing a number of algorithms for improving reporting.

### 3.2. Multilevel modelling

Multilevel models are powerful statistical models that are particularly useful for analysing observational data, as they are able to deal with natural clustering in the data. Many statistical analysis methods, such as linear regression, logistic regression and analysis of variance, require observations in the data to be independent, both for the assumptions to hold and for the correct estimation of effect sizes and error.[118] This may be possible in sample surveys whose design is based on principles of random sampling of individuals, but independence is extremely unusual in the 'real world'. For example, people within families, those living in the same geographic area, or those who have attended the same school or hospital, will generally have more similar outcomes than those who do not have these shared exposures or experiences. These similarities mean that each person cannot be considered to provide a completely new and unique piece of information to the analysis. As each piece of data is not completely unique, the *effective* sample size is smaller than the actual sample size.[31] Not taking this into account in the modelling can result in smaller confidence intervals around parameter estimates than are actually the case, given the clustered nature of the data. This is known as mis-estimated precision.[31]

The degree of clustering or association in the data is measured by the intraclass correlation coefficient (ICC), which can be thought of as the degree of correlation among cluster members on a particular response or outcome. Another way of describing it is the proportion of the total variation in the outcome that is due to between-cluster variation. The more similar responses are within a cluster, the more different the average response in a cluster will be from the average response in another cluster, which will increase the between-cluster variation and therefore the ICC.

Not accounting for the clustering can also result in different effect size estimates. A hypothetical example of this would be a study looking at the impact of individual socioeconomic disadvantage on time taken to get to hospital. Without accounting for

clustering by area, an average association might be found that shows a strong relationship between increasing disadvantage and increasing time to hospital (see Figure 2a). However, this ignores the fact that people cluster within geographic areas. Once this clustering is taken into account (see Figure 2b), it is clear that the average time to hospital between areas and the relationship between disadvantage and time within areas is not as strong as the previous estimate.

Multilevel models are also called random effects models, mixed effects models and hierarchical models. The levels referred to in multilevel modelling are different levels of influence, such as individuals within hospitals, individuals within neighbourhoods, or different time points for the same individual. In many cases, the levels are hierarchical (hence the hierarchical modelling), with lower levels nested entirely within higher levels. However, for multilevel models the levels do not always have to be hierarchical. In the analysis in Chapter 5 of this thesis, admissions over time were nested within individuals, but as individuals can attend more than one hospital, individuals were not nested neatly within hospitals. However, the admissions were nested within hospitals as well as individuals, in what is called a cross-classified design. The random and mixed effects terminology comes from the fact that multilevel models include both fixed and random effects, while traditional regression analyses include only fixed effects. In a multilevel model, the area level is estimated as a random variable, with each area considered a sample of all possible areas, similarly to the way individuals are considered a random sample of all individuals. The analysis therefore produces not just a fixed mean for the outcome, but estimates a variance for the areas.[119]

In a, the single-level regression equation to generate the linear relationship shown would be:

$$y_i = \beta_0 + \beta_1 x_i + e_i$$

where  $y_i$  is the outcome for each individual  $i$ , which is a linear combination of  $\beta_0$ , the intercept (or estimated time to hospital when the disadvantage score is 0), plus  $\beta_1 x_i$  (the predicted time to get to hospital for those with a disadvantage score of  $x$ ), plus a residual error term,  $e_i$ , which is the distance from the regression line to the actual time to get to hospital for that particular person. In contrast, the regression equation for a multilevel model as in b would be:

$$y_{ij} = \beta_0 + \beta_1 x_{ij} + u_j + e_{ij}$$

where  $y_{ij}$  is the outcome for each individual  $i$  in area  $j$ , which is a linear combination of  $\beta_0$ , the mean intercept, plus  $\beta_1 x_{ij}$  (the predicted time to get to hospital for those with a disadvantage score of  $x$  in area  $j$ ), plus the residual  $u_j$  (or the difference in the mean estimated time to hospital in area  $j$  compared to the overall mean), plus a residual error term,  $e_{ij}$ , which is the distance from the regression line within area  $j$  to the actual time to get to hospital for that particular person. An additional step that you can take using multilevel modelling is to allow not just the intercept to vary by higher level unit (random intercept model) but also to allow the effect of a covariate of interest to vary within the higher level unit (random slopes model) (see Figure 2c).

Not only can multilevel models correctly handle the clustering as described above, they model this clustering by estimating the between- and within-group variability.[119] This has benefits over other methods such as Generalized Estimating Equations (GEE), which treat this clustering as a nuisance.[32] With multilevel modelling it is possible to estimate the influence of the contextual levels on the outcome by partitioning the variation in the outcome, and comparing the amount of variation that is due to the lowest level, e.g. the individual, with the amount of variation that is due to higher levels, such as the hospital or neighbourhood. As in single-level regression, in which the unexplained variation can be investigated by adding explanatory variables such as age and sex, it is possible to add variables at any level in the multilevel model to try to explain the variation at the higher levels. Thus the influence of various characteristics of geographic areas or hospitals can be investigated and compared.

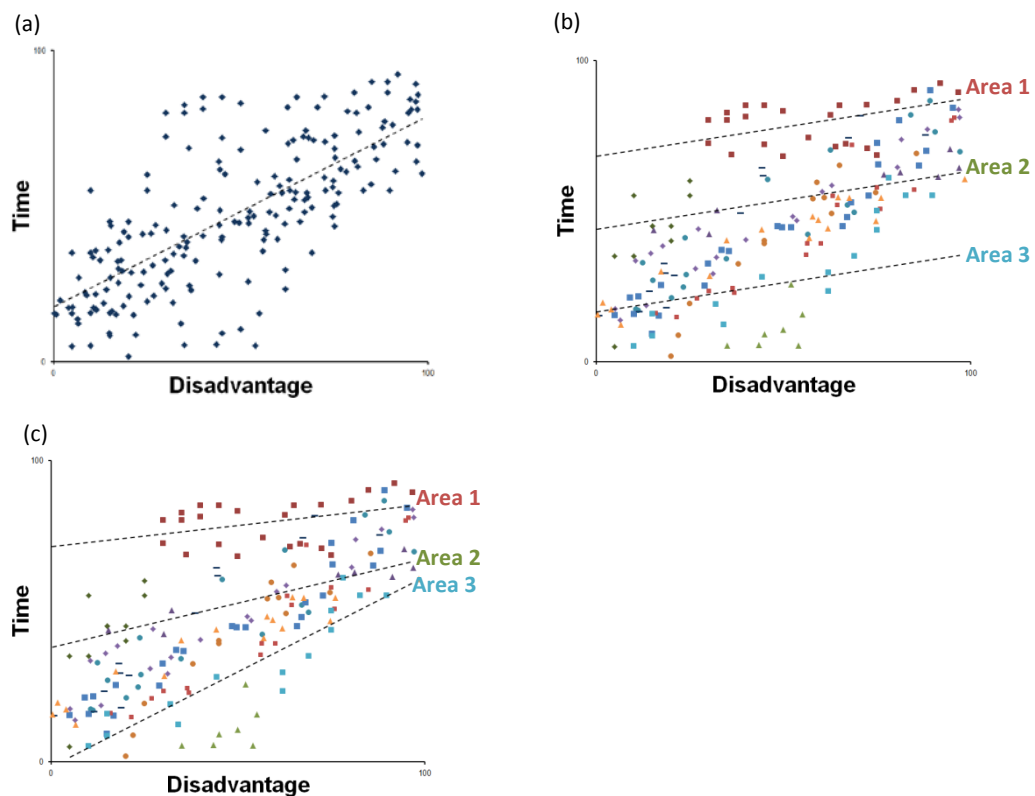


Figure 2. Hypothetical relationship between time to hospital and socioeconomic disadvantage when (a) observations are considered independent, (b) when observations are clustered within geographic areas and the average time is allowed to vary between areas (multilevel model with random intercept), and (c) when observations are clustered within geographic areas and the average time varies between areas, and the relationship between disadvantage and time is allowed to vary between areas (multilevel model with random intercept and random slope).

## 4. Methods

### 4.1. Datasets

The following datasets made up the overall IHOPE data. Figure 3 outlines the years of data included and the numbers of people and records in the datasets.

#### 4.1.1. Admitted Patient Data Collection

The Admitted Patient Data Collection (APDC) is a routinely collected administrative dataset containing records for all NSW public and private hospital separations (hospital admissions ending in a discharge, transfer, type-change or death). Patient demographics and multiple diagnoses and procedures are recorded for each separation and coded according to the Australian modification of the International Statistical Classification of Diseases and Related Problems (diagnoses) and the Australian Classification of Health Interventions (procedures).[120] The data received for the IHOPE study was for all separations between 1 July 2000 and 31 December 2008.

#### 4.1.2. Register of Births, Deaths and Marriages

The NSW Register of Births, Deaths and Marriages (RBDM) captures all deaths registered in NSW. The data received for the IHOPE study was for all deaths of NSW residents from 1 July 2000 to 31 December 2009.

#### 4.1.3. Australian Bureau of Statistics mortality data

The Australian Bureau of Statistics (ABS) codes the underlying cause of death and contributing causes of death for the RBDM notifications, as well as demographic information including date of birth, sex and Aboriginal status. The data received for the IHOPE study were for all deaths of NSW residents from 1 July 2000 to 31 December 2007.

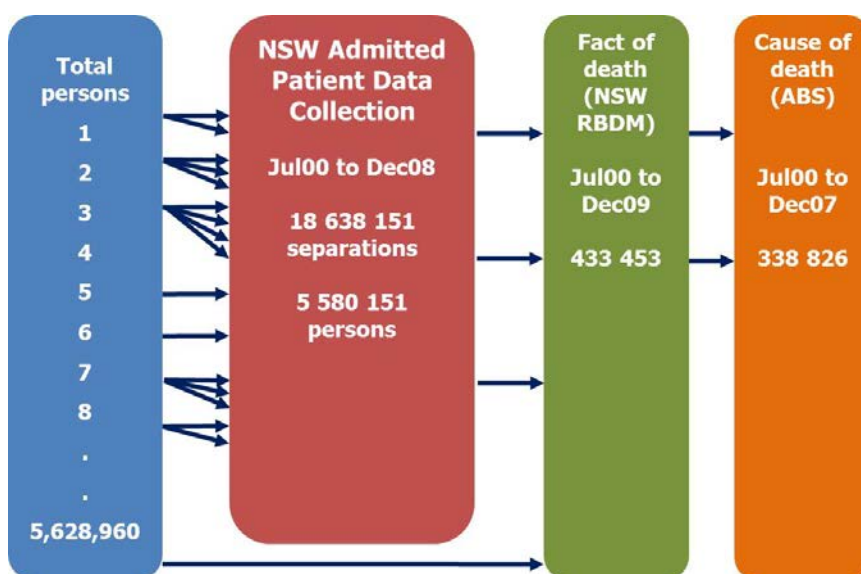


Figure 3. Data sets and numbers of records and people in the overall IHOPE study.

## 4.2. Data linkage

The APDC and RBDM deaths were linked using probabilistic methods by the Centre for Health Record Linkage (CHeReL).[121] Only identifier information from the APDC and RBDM (e.g. name, address, date of birth and sex) were supplied to the CHeReL and used for the probabilistic linkage; no health data were used in the linkage. The CHeReL uses a probabilistic linkage software called *ChoiceMaker* to link records.[122] *ChoiceMaker* uses 'blocking' methods to identify matches, either definite matches using exact blocking, where records are required to have the same information in particular fields, or possible matches using algorithms that find potential matches. 'Scoring' of the potential matches involves assigning a probability that each match is an actual match, and this is done through a combination of probabilistic decision based on machine learning technique and absolute rules, such as upper and lower probability cut-offs. The cut-offs are adjusted for each linkage to ensure that false-positive links are minimised, and any records within the cut-off points are subject to review by an individual. The ABS mortality records were linked to the RBDM records using deterministic linkage of such information as year of registration, encrypted registration number, and exact date of death. Further matches were found by allowing some variation in the date of death, or matching on date of birth, postcode and sex. The false-positive rate for the linkage was estimated to be 4 in 1000 records (0.4%), and the false-negative rate was estimated to be less than 5 in 1000 records (<0.5%). I was supplied with de-identified APDC, RBDM and ABS data and merged these using a project-specific unique person number.

## 4.3. Population data

Estimated resident populations for each SLA were required by age, sex, year and Aboriginal status for calculating population rates. The Australian Bureau of Statistics population data formed the basis for the calculation of synthetic estimates, as the amount of detail needed for the estimates of the Aboriginal population by age, sex, year and SLA were not available. Synthetic estimates of the mid-year populations of Aboriginal and non-Aboriginal people by SLA, year, age group and sex were created by my colleague, Michael Falster, using the 2001 and 2006 Australian Census data (unpublished data, Australian Bureau of Statistics) combined with year-specific population projections[123] using the method described by the Office of Economic and Statistical Research in Queensland.[124]

## 4.4. Data preparation

### 4.4.1. Data cleaning

Although the data had already been collected as part of the routine operation of NSW hospitals and the NSW mortality register, it could not immediately be used for research purposes. I undertook extensive data cleaning of the almost 19 million records in the datasets, before and after linkage, to identify unusual and implausible cases that would cause problems in analyses. These cases could have resulted from coding errors, data entry errors or false positives/missed links during the probabilistic linkage. As a general rule, I did not delete any records, but just flagged and described the problem records with a number

of dichotomous indicator variables, which I could then use to remove these problem records from specific analyses.

The data linkage added extra complexity to the data cleaning process. There were a number of cases where multiple death records were linked with the one person's hospital records, or the date of death was inconsistent between the fact of death records (RBDM) and the ABS cause of death records. Decisions on which death records were chosen in cases where there was more than one, and more detail on the data cleaning steps and exactly how many records were affected, are in Appendix C.

#### 4.4.2. Data editing

After the data cleaning, I undertook a number of data editing steps to create new variables and organise the data for analysis. The hospital data are made up of a number of *separations*, which, although similar to what is commonly known as a *hospital admission*, are an administrative construct ending with: a discharge from hospital, a transfer (either within the hospital or between hospitals), or the death of the patient. A person can have a number of separations within the same hospital stay. For example, being transferred from acute care to rehabilitation care, in a different ward of the same hospital, would generate a new separation for the new episode of care in rehabilitation. A transfer to another hospital, while still undergoing care for the same condition, is also a new separation.

Nested separations add complexity to this. These occur when a person is transferred from one hospital to another for a short stay (e.g. for an operation), and then transferred back without the original hospital separation showing a transfer or discharge. In such a case, one record may have an admission date of 1 January 2005 and a separation date of 1 February 2005. A following record for the same person may have an admission date and separation date of 15 January 2005, in the middle of the episode above. It was important to flag these nested separations so that they could be included as part of the same overall 'hospital stay', rather than the later admission date generating a new hospital stay, as the person was not discharged from the original hospital.

More detail on the data editing steps is given in Appendix C.

#### 4.5. Geocoded place of residence

The NSW APDC data were geocoded using the Freely extensible biomedical record linkage (Febri) software,[125] and each address was allocated to a Census District (CD), Statistical Local Area (SLA) and Local Government Area (LGA) for 2006 boundaries, based where possible on the resolved latitude and longitude. If the address did not resolve to one CD, SLA or LGA, then an array of probabilities that the address was in a particular CD, SLA or LGA were provided. There were two possibilities for using the information in these arrays:

1. assign the address to a CD, SLA or LGA using a random variable that weighted the choice based on the probability that that address was in that particular area; or
2. assign the address to the area with the largest probability.

After advice, I decided to use the randomly allocated CD, SLA, LGA, as this was considered less likely to create 'hot spots'. 'Hot spots' occur in geocoding when more people are

allocated to particular areas than should be. The geocoded SLA was used in Chapter 6 as the geographic level in the multilevel model. The deaths data, which provided some AMI events, were not geocoded, but had SLA recorded. This was recorded at the time of death (or the time of the reporting of the death) and therefore, not all the SLAs were reported with the 2006 boundaries. For any events allocated to an SLA that was not current in 2006, ABS correspondence tables were used to allocate these events to 2006 SLAs. The allocation was done using a probability method based on the mathematical correspondences produced by the ABS. For example, if an old SLA had been split into two in the 2006 boundaries, with 80% of the population in one SLA and 20% in another, then any events were allocated randomly with an 80% chance of going into one SLA and a 20% chance of going into the other.

## 4.6. Statistical models

Standard statistical methods were used throughout the thesis to analyse the results. Data analyses were carried out using SAS 9.3[126] and the multilevel modelling software MLwiN 2.25.[127]

### 4.6.1. Multilevel models

Multilevel modelling was used in all the Chapters to answer the main research questions. The multilevel model in Chapter 5 was a cross-classified design, with admissions as the lowest level, nested within hospitals, and within people, but with people not nested neatly within hospitals (see Figure 4a). The analyses in Chapter 6 used a 2-level hierarchical multilevel model with people (first AMI events) nested within geographical areas (SLAs) (see Figure 4b). The analyses in Chapters 7 and 8 were both 2-level hierarchical models for people (first AMI admission) within hospitals (first hospital of admission in admission sequence) (see Figure 4c).

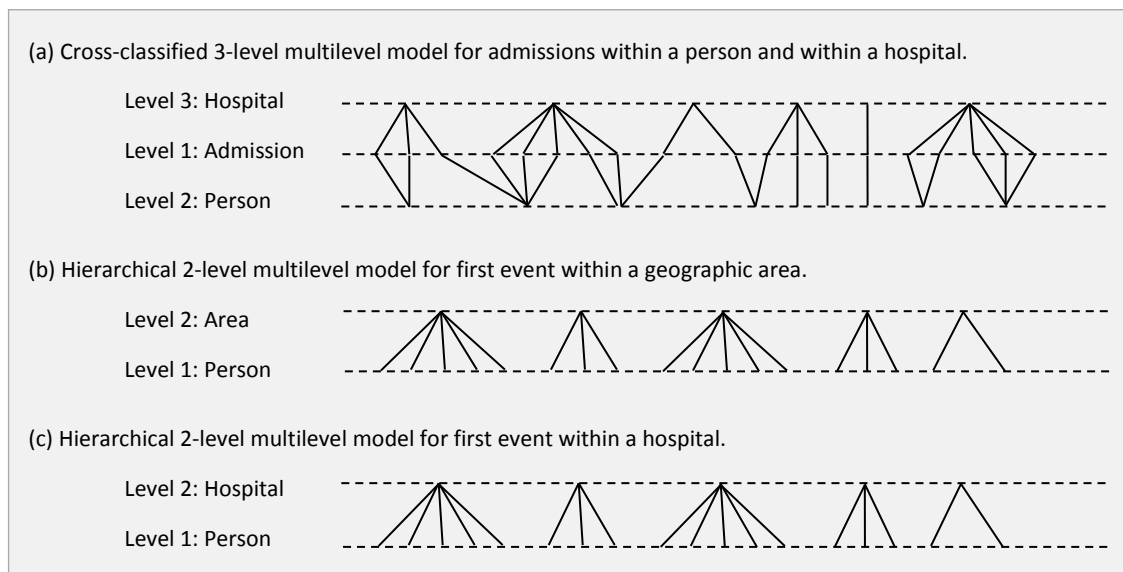


Figure 4. Diagrams of the relationship between higher- and lower-level units in the multilevel models used in the thesis.



The analysis in Chapter 6 included both a random intercept model (with the rate of AMIs allowed to vary by area) and a random slope model (with the Aboriginal to non-Aboriginal rate ratio allowed to vary by area). A reparameterisation of this random slopes model involved putting a random slope on Aboriginal status and non-Aboriginal status to get an estimate of the amount of variation in AMI rates for Aboriginal people by area, and for non-Aboriginal people by area. This was done by creating an indicator of non-Aboriginal status (1-“Aboriginal status”) and adding this to the random part of the model, not the fixed part, and removing the constant from the random part of the model. Table 1 shows a comparison between these two random slopes multilevel models estimating AMI rates for people within areas, adjusted for Aboriginal status, age group, sex and year. Model 1 is the traditional random intercept and random slope model (on Aboriginal status) that allows the estimation of overall variation in AMI rates by area, and the variation in the Aboriginal to non-Aboriginal disparity by area. Model 2 is the reparameterised model with a random slope on indicators of Aboriginal status and non-Aboriginal status that allows the estimation of area-level residuals for variation in AMI rates for Aboriginal people by area and for non-Aboriginal people by area. As can be seen from Table 1, there is no difference in the adjusted rate ratios (RRs) estimated from the model, but there is a difference in the variance parameters from the random part of the model.

Note that the variance of the Aboriginal and non-Aboriginal groups can be obtained from the original model (Model 1, Table 1). The baseline category in Model 1 is the non-Aboriginal group; the variance of this group is therefore equal to the variance of the intercept (0.080). The required variance of the Aboriginal group is obtained

$$X \sim N(\mu, \Sigma_{M1})$$

$$DX \sim N(D\mu, D\Sigma_{M1}D^T)$$

from the parameters

$$X = \begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix}$$

where  $\beta_0$  is the intercept and  $\beta_1$  is the difference between the effect for Aboriginal and non-Aboriginal people (additive on the log scale).

The transformation matrix

$$D = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

can be used to reparameterise the model to obtain the effects for the Aboriginal (top row) and non-Aboriginal (second row) groups respectively.

$$\Sigma_{M2} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} 0.080 & 0.015 \\ 0.015 & 0.249 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} = \begin{bmatrix} 0.359 & 0.095 \\ 0.095 & 0.080 \end{bmatrix}$$

This provides the variances and covariance as estimated under Model 2 (A Leyland 2015, personal communication, 24 June).

Table 1. Comparison of two random slope multilevel models of AMI events within geographic areas in NSW, one with reparameterised slope on Aboriginal status.

<b>Fixed part</b>	<b>Model 1 Random slope</b>		<b>Model 2 Reparameterised random slope</b>	
	<b>Adjusted RR</b>	<b>95% CI</b>	<b>Adjusted RR</b>	<b>95% CI</b>
Aboriginal status				
Non-Aboriginal	1.00		1.00	
Aboriginal	1.76	1.58-1.96	1.76	1.58-1.96
Age group				
25-34	1.00		1.00	
35-44	6.00	5.43-6.63	6.00	5.43-6.63
45-54	19.36	17.58-21.31	19.36	17.58-21.31
55-64	40.29	36.67-44.26	40.29	36.67-44.26
65-74	80.00	72.81-87.89	80.00	72.81-87.89
75-84	178.93	162.86- 196.58	178.93	162.86- 196.58
Sex				
Male	1.00		1.00	
Female	0.45	0.44-0.45	0.45	0.44-0.45
Year				
2002	1.00		1.00	
2003	1.00	0.98-1.03	1.00	0.98-1.03
2004	0.97	0.95-0.99	0.97	0.95-0.99
2005	0.91	0.89-0.94	0.91	0.89-0.94
2006	0.88	0.86-0.91	0.88	0.86-0.91
2007	0.88	0.86-0.91	0.88	0.86-0.91
<b>Random part</b>	<b>Variance</b>	<b>SE</b>	<b>Variance</b>	<b>SE</b>
cons/cons	0.080	0.009		
Aboriginal/cons	0.015	0.016		
Aboriginal/Aboriginal	0.249	0.051	0.359	0.063
Non-Aboriginal/Aboriginal			0.095	0.019
Non-Aboriginal/Non- Aboriginal			0.080	0.009

RR, rate ratio; SE, standard error; cons, constant.

#### 4.6.2. Risk adjustment

I investigated specific risk-adjustment strategies, developed for use with administrative data in other countries and jurisdictions, to determine whether they worked as well to control for risk differences in the NSW data. For the mortality analysis in this thesis (Chapter 7), severity of disease (or comorbidity as a proxy for severity of disease) was measured with the Ontario AMI mortality prediction rule (OAMIMPR), a mortality risk prediction tool developed specifically for use with AMI admissions and administrative hospital data.[128, 129] This rule included specific conditions, as well as age and sex. The conditions were: shock, diabetes with complications, congestive heart failure, cancer, cerebrovascular disease, pulmonary oedema, acute renal failure, chronic renal failure, cardiac dysrhythmias. International and Australian validation studies have shown that administrative hospital data under-reports comorbidities,[130, 131] however I conducted analyses to confirm the suitability of applying the prediction rule in NSW and with a younger age range than used in the Ontario study (25-84 as opposed to 50 years and over). I ran a model with mortality as the outcome using NSW data and including the OAMIMPR conditions, age group and sex, and the area under the receiver operating characteristic curve was 0.77 for 30-day mortality and 0.79 for 365-day mortality, which compared favourably with a validation study of the ICD-10 adaptation of the rule conducted in Ontario (with figures of 0.77 for 30-day mortality and 0.80 for 365-day mortality).[129] I found that the Rule provided better mortality prediction than the Charlson Comorbidity Score on its own.[112, 132] However, in the Chapter 7 study, further risk adjustment was achieved when the Ontario conditions were supplemented with additional Charlson Comorbidity Index conditions that had a significant age-, sex- and year-adjusted association with 30-day or 365-day mortality. These specific conditions were peripheral vascular disease, dementia, pulmonary disease, connective tissue disorder, liver disease, paraplegia, and severe liver disease.

For the revascularisation analysis (Chapter 8), the comorbidities included in the models were those that had been shown in other studies to impact on provision of revascularisation procedures or outcomes after AMI: shock, diabetes with complications, congestive heart failure, cancer, cerebrovascular disease, pulmonary oedema, acute renal failure, chronic renal failure, cardiac dysrhythmias,[129] chronic obstructive pulmonary disease (COPD), diabetes without complications and depression.[87] Further risk adjustment variables included were: AMI type, divided into ST-elevation myocardial infarction (STEMI, ICD-10-AM codes 'I21.0'-'I21.3'), non-ST-elevation myocardial infarction (NSTEMI, 'I21.4') and unspecified ('I21.9'); substance use (current smoking status, and alcohol and drug abuse[133]); and private health insurance (private payment status or private insurance status recorded).

All comorbidities, substance use and private health insurance measures were flagged if they were recorded on the 'index' AMI admission for the particular analysis, or on any admission up to 12 months previously. This 'look-back' period increased the chance of picking up comorbidities and risk factors that are not always well recorded in the routine hospital data.

A recent validation study of a number of comorbidities recorded on the NSW APDC has determined that there is a range in agreement between what is recorded on the routine data and a 'gold standard' self-report questionnaire, with agreement being 'good' for diabetes; 'moderate' for smoking; 'fair' for heart disease, stroke and hypertension; and 'poor' for obesity.[134] However, the recommendations from this analysis were to adjust for hospital-level factors that influence recording of comorbidities, and this is achieved in the outcome analyses in this thesis by including the hospital level in the multilevel modelling, and essentially comparing Aboriginal and non-Aboriginal rates within hospitals, where all patients were subject to the same biases around depth of coding and other systematic factors related to coding of comorbidities.

For the event rates analysis (Chapter 6), it was not possible to use these conditions and characteristics recorded on the admitted patient data to risk adjust, as these were not available on the population-level data that contributed the denominator data for the rates. Therefore, only age, sex, year of event, and area of residence were available for risk adjustment in this analysis.

#### 4.7. Ethics

Ethics approval for the study was given by the Population Health Services Research Ethics Committee, the Aboriginal Health and Medical Research Council Ethics Committee, and the University of Western Sydney Ethics Committee. A draft of each paper was sent to the Aboriginal Health and Medical Research Council Ethics Committee for advice and input before submission to a peer-reviewed journal. Draft findings were presented and discussed at meetings of the IHOPE Reference Group, a group that included representatives from the Ministry of Health and the Aboriginal Health and Medical Research Council, as well as Aboriginal researchers and Aboriginal community representatives.

## 5. Using linkage to enhance reporting of Aboriginal status

### 5.1. Publication details

Randall DA, Lujic S, Leyland AH, Jorm LR. Statistical methods to enhance reporting of Aboriginal Australians in routine hospital records using data linkage affect estimates of health disparities. *Australian and New Zealand Journal of Public Health*. 2013;37(5):442-9.

### 5.2. Aims

- To investigate under-recording of Aboriginal people in hospital data from NSW and to determine the influence of the hospital, the individual and the admission on recording.
- To define algorithms for enhanced reporting, and to examine the impact of these algorithms on reported disparities in cardiovascular and injury outcomes.

### 5.3. Main findings

- The majority of the variation in recording of Aboriginal status was due to the hospital of admission, with lower levels of agreement in recording of Aboriginal status in major city and private hospitals compared with more regional/remote hospitals and public hospitals.
- Admission and mortality ratios varied markedly between algorithms, with less strict algorithms resulting in higher admission rate ratios, but generally lower mortality rate ratios, particularly for cardiovascular disease.
- It was possible to use the linked administrative data to examine outcomes for Aboriginal versus non-Aboriginal people, using an algorithm that increased the number of people reported as Aboriginal while minimising potential bias, but sensitivity analyses were recommended to explore the uncertainties introduced by the under-enumeration of Aboriginal people.

# Statistical methods to enhance reporting of Aboriginal Australians in routine hospital records using data linkage affect estimates of health disparities

## Abstract

**Objective:** To investigate under-recording of Aboriginal people in hospital data from New South Wales (NSW), Australia, define algorithms for enhanced reporting, and examine the impact of these algorithms on estimated disparities in cardiovascular and injury outcomes.

**Methods:** NSW Admitted Patient Data were linked with NSW mortality data (2001–2007). Associations with recording of Aboriginal status were investigated using multilevel logistic regression. The number of admissions reported as Aboriginal according to six algorithms was compared with the original (unenhanced) Aboriginal status variable. Age-standardised admission, and 30- and 365-day mortality ratios were estimated for cardiovascular disease and injury.

**Results:** Sixty per cent of the variation in recording of Aboriginal status was due to the hospital of admission, with poorer recording in private and major city hospitals. All enhancement algorithms increased the number of admissions reported as Aboriginal, from between 4.1% and 37.8%. Admission and mortality ratios varied markedly between algorithms, with less strict algorithms resulting in higher admission rate ratios, but generally lower mortality rate ratios, particularly for cardiovascular disease.

**Conclusions:** The choice of enhancement algorithm has an impact on the number of people reported as Aboriginal and on estimated outcome ratios. The influence of the hospital on recording of Aboriginal status highlights the importance of continued efforts to improve data collection.

**Implications:** Estimates of Aboriginal health disparity can change depending on how Aboriginal status is reported. Sensitivity analyses using a number of algorithms are recommended.

**Key words:** Aboriginal health, data linkage, administrative data, reporting, cardiovascular disease, injury

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Large inequalities in health exist between Aboriginal and non-Aboriginal Australians.<sup>1</sup> Linked routinely collected data are a key resource to explore these disparities, because they provide whole-of-population coverage and permit person-based longitudinal analyses. However, the validity of these studies relies on the quality of recording of Aboriginal status in the data sets. Aboriginal Australians are known to be under-recorded in administrative databases.<sup>2-9</sup> The Australian Institute of Health and Welfare (AIHW) conducted two recent audits of recording in Australian public hospitals and estimated that 88% of Aboriginal people in 2007 and 91% in 2010 were correctly identified in New South Wales (NSW) public hospitals.<sup>3,10</sup>

Linkage of multiple administrative data records for one person is a way of enhancing reporting by providing multiple opportunities for recording of Aboriginal status.<sup>11-17</sup> A number of studies have looked at how data linkage can increase the number of records reported as Aboriginal in administrative hospital datasets, but only a few have examined how different methods of reporting

Aboriginal status can influence research outcomes such as admission or incidence rates or mortality ratios.<sup>17-20</sup>

This study was part of the Indigenous Health Outcomes Patient Evaluation (IHOPE) project, which uses linked hospital and mortality data to examine health outcomes for Aboriginal people in NSW compared with non-Aboriginal people. In order to estimate health disparities, investigation was first necessary into the under-recording of Aboriginal people in the data and how best to use the available linked data to enhance reporting of Aboriginal status.

We were also interested in how different decisions on how to enhance reporting could influence estimates of health disparity. To examine this, we investigated variation in recording of Aboriginal status in NSW hospital data, including both private and public hospitals, and undertook an analysis to determine which hospital-level, person-level and admission-level variables were related to being recorded as Aboriginal among patients recorded as Aboriginal at least once. We then defined algorithms to enhance reporting of Aboriginal people in NSW hospital data,

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using the full admission history for each person and linked mortality data, and examined the impact of using these, not only on numbers of admissions reported as Aboriginal but also on estimated disparities in admission rates and hospital outcomes. For the admission and outcome ratios we focused on cardiovascular disease and injuries, both leading contributors to the gap in burden of disease for Aboriginal people in Australia.<sup>21</sup>

## Methods

### Data

The NSW Admitted Patient Data Collection (APDC) includes records for all hospital separations ending in discharge, transfer, type-change or death from all NSW public and private hospitals and day procedure centres. These separations are referred to henceforth as admissions. The NSW Register of Births, Deaths and Marriages (RBDM) captures details of all deaths registered in NSW. The Australian Bureau of Statistics (ABS) codes the causes of death and also records Aboriginal status. An extract of the APDC was linked internally and linked to the RBDM and ABS death data by the Centre for Health Record Linkage (CHeReL) using probabilistic linkage based on identifiable fields such as name, sex, date of birth and address.<sup>22</sup> A combined dataset from January 2001 to December 2007 was used for the analysis. For population rates, events were taken from the APDC and divided by ABS population data. Aboriginal population estimates were obtained from the age- and sex-specific mid-year populations from ABS experimental estimates and projections,<sup>23</sup> and were subtracted from the mid-year total Estimated Resident Population for NSW<sup>24</sup> to obtain estimates for the non-Aboriginal population.

### Variables

Patients were recorded in the APDC as 'Aboriginal but not Torres Strait Islander', 'Torres Strait Islander but not Aboriginal', 'Both Aboriginal and Torres Strait Islander', 'Neither Aboriginal nor Torres Strait Islander', 'Declined to respond' or 'Unknown'. The ABS mortality data was coded as 'Aboriginal or Torres Strait Islander' or 'Non-Aboriginal or Torres Strait Islander or not stated'. Due to the small proportion of admissions recorded as 'Torres Strait Islander but not Aboriginal' in the NSW hospital data (0.1%), Aboriginal and Torres Strait Islander peoples were considered as one group for the current analysis and referred to as Aboriginal.

Other variables of interest were grouped into admission, person and hospital levels. Admission-level factors included: year of admission. Person-level factors included: age at first admission; sex; and total number of admissions. Hospital-level factors included: remoteness of hospital (based on Accessibility/Remoteness Index of Australia Plus of hospital based on postcode); and hospital type (public or private).

### Constructed variables

We defined the following six algorithms to enhance reporting of Aboriginal people in the hospital data:

- '≥2 hospitals' – recorded as Aboriginal at more than one hospital (or if admitted to just one hospital, recorded as Aboriginal in at least one admission to that hospital).
- '≥50% public' – recorded as Aboriginal on at least 50% of all public hospital admissions excluding type-change admissions within the same hospital (or if only have private hospital admissions, then at least 50% of those).
- 'Most recent public' – status taken as that recorded at the most recent public hospital admission for each individual (or most recent private if no public hospital admissions).
- 'Weight of evidence' – recorded as Aboriginal on at least two separate hospital admissions for individuals with three or more admissions, or recorded as Aboriginal on at least one admission for individuals with two or fewer admissions (counting type-change admissions within the same hospital as one admission).<sup>16,17</sup>
- 'Ever hospital' – required only one hospital admission in the entire admission history to be recorded as Aboriginal.
- 'Ever hospital or death' – required just one hospital admission or the linked death record to be recorded as Aboriginal.

People with just one admission in the dataset were reported as Aboriginal or not based on that admission alone.

## Analysis

### Consistency of reporting

Aboriginal status was tabulated by hospital for each person in the full linked dataset, to determine whether there was variation in reporting for one person's admission history within the same hospital or between hospitals.

### Associations with recording of Aboriginal status

A cross-classified multilevel logistic regression model was used to examine factors associated with being recorded as Aboriginal in the hospital data. Given the de-identified nature of the data and the millions of people in the dataset, it was not possible to compare Aboriginal status in the APDC with a self-reported source such as a follow-up audit questionnaire. Instead, we examined recording within the linked hospital data, subsetting the overall data to include only hospital admissions for persons who had at least one admission where they were recorded as Aboriginal, and at least two admissions in total. People with at least two admissions were chosen because those with only one admission would, by definition, be reported as Aboriginal. Those admissions ending with a type-change transfer within the same hospital were excluded, because the Aboriginal status recorded on the first admission is carried over in the patient administration system. The cross-classified multilevel model accounted for the fact that the admissions were clustered within people and hospitals, but not in a strict hierarchy, i.e. people have admissions in more than one hospital. The parameters and standard errors were estimated through Markov Chain Monte Carlo methods using MLwiN version 2.24<sup>25</sup> with noninformative priors, burn-in of 250,000 iterations and 250,000 replications. The relative influence of the person and hospital on reporting of Aboriginal status was

calculated using a variance partitioning coefficient expressed as a percentage of the total variance using the Snijders and Bosker latent variable approach.<sup>26</sup>

### Enhancement

The algorithms described above were applied to an individual's admission history in the entire linked dataset. Once an individual was assigned a status based on each algorithm, this status was then copied across all of their individual admissions and the admissions reported as Aboriginal were tallied. We investigated the number of admissions reported as Aboriginal in the APDC with the original (unenhanced) Aboriginal status variable and the percentage increase (or decrease) in reporting by selected demographic groupings.

### Outcome ratios

The algorithms were used to calculate admission rate ratios and ratios of mortality after admission using subsets of the overall linked data: (1) those aged 25 years and over with a primary diagnosis of cardiovascular disease (ICD-10-AM 'I00-I99'); and (2) those aged 25 years and over with a primary diagnosis of injury (ICD-10-AM 'S00-T98'). Admission rates were calculated by dividing the number of admissions by the relevant ABS total estimated resident populations to get population rates and could include multiple admissions per person. The 30-day and 365-day mortality ratios were estimated for two patient cohorts: people admitted with their first primary diagnosis of cardiovascular disease and people admitted with their first primary diagnosis of injury. The linked NSW mortality data were used to follow-up and determine whether the cohort members died within 30 days or 365 days of their first cardiovascular or injury admission. All rate ratios were indirectly standardised, with the observed number of admissions or deaths among Aboriginal people divided by the expected number based on the age group-, sex- and year-specific rates for non-Aboriginal people. Confidence intervals around the rate ratios were calculated assuming a Poisson distribution of the observed events. All data management and analysis was carried out in SAS Version 9.2.<sup>27</sup>

### Ethics

Ethics approval for the study was given by the Population Health Services Research Ethics Committee, the Aboriginal Health and Medical Research Council Ethics Committee and the University of Western Sydney Ethics Committee.

## Results

There were 14,699,433 admissions of 4,705,100 NSW residents to 496 hospitals (296 public and 200 private) in NSW from 2001 to 2007. Non-NSW residents (n=158,941) and people with duplicate admissions containing slightly different information (n=2,905) were excluded. Tabulating the original Aboriginal status variable by hospital and person revealed that 57% of the hospitals (281; 193 public and 88 private) had inconsistent reporting of Aboriginal status for at least one person. As such, enhancement was possible within hospitals, as well as between.

### Associations with recording of Aboriginal status

There were a total of 367,655 admissions in the subset of the data for people with at least two admissions in total, with at least one of these recorded as Aboriginal. Among this group, 72% of admissions were recorded as Aboriginal. The admissions were nested within 55,368 people and within 450 hospitals. Less than a third (31%) of the people in the analysis had admissions to just one hospital, and the mean number of hospitals attended was 2.2 (median 2).

Before any variables were added into the multilevel model, the variance partitioning coefficient showed that 60.5% (95% credible interval, 56.5%-64.5%) of variation in the outcome was associated with the hospital level, 20.1% (18.1%-22.2%) with the person level, and the remaining 19.4% (17.4%-21.4%) with the admission level. The adjusted odds ratios and 95% credible intervals for the final model are shown in Table 1. The odds of being recorded as Aboriginal were significantly lower for those in the 50–74 year and 75 and over age groups, compared with the 0–24 year age group, females had higher odds of being recorded as Aboriginal than males, and odds of being recorded as Aboriginal increased substantially over the study period. Private hospital admissions were far less likely than public hospital admissions to be recorded as Aboriginal and the odds of recording increased with increasing remoteness of hospital.

### Enhancement

In the entire linked dataset, the original (unenhanced) Aboriginal status variable on the APDC recorded a total of 300,239 admissions as Aboriginal from January 2001 to December 2007. All of the algorithms increased the total number of admissions reported as Aboriginal: the '≥2 hospitals' by 4.1% (312,632); the 'at least 50% public' by 6.7% (320,224); the 'most recent public' by 8.7% (326,388); the 'weight of evidence' by 19.5% (358,832); the 'ever hospital' by 35.5% (406,700); and the 'ever hospital or death' by 37.8% (413,690).

Table 2 shows the percentage change in the number of admissions reported according to selected demographic groups compared with the original variable. There was mixed enhancement by age group for the algorithms. The '≥2 hospitals' algorithm showed increases across all age groups but a smaller increase for the youngest and oldest age groups, while the 'at least 50% public' and 'most recent public' algorithms had greater increases in the younger age groups (<50 years) than the 75 years and over group. The 'weight of evidence' algorithm showed the largest percentage increase for the 75 years and over age group. The two 'ever identified' algorithms showed increased reporting in all age groups, but particularly the older age groups. Within all the algorithms, there were similar increases for both males and females. Enhancement was highest in the earlier years for all algorithms, and decreased over time, with some small decreases in 2006 and 2007 for the '≥2 hospitals' algorithm, and in 2007 for the 'at least 50%' algorithm. All algorithms showed the highest enhancement for major city hospitals and for private hospitals.



### Outcome ratios

There were 11,137,545 admissions for people aged 25 years and over in the seven-year study period, including 886,172 admissions with a primary diagnosis of cardiovascular disease and 625,588 admissions with a primary diagnosis of injury. The admission rate ratios for cardiovascular disease (Table 3) showed that Aboriginal people were more likely than other Australians to be admitted to hospital with cardiovascular disease, after adjusting for age, sex and year, no matter whether the original (unenhanced) Aboriginal status variable or an algorithm was used. However, the rate ratio point estimate varied by method of reporting Aboriginal status. The '≥2 hospitals', 'at least 50% public' and 'most recent public' algorithms estimated slightly higher ratios than the original admission-based variable, while the 'weight of evidence' algorithm was higher again due to its higher percentage enhancement, however, the 'ever hospital' and 'ever hospital or death' algorithms resulted in markedly higher Aboriginal to non-Aboriginal admission rate ratios for cardiovascular disease admissions.

The pattern for injury admission rate ratios was similar (Table 3). The algorithms estimated admission ratios higher than the original variable, increasing in line with the level of percentage increase as reported in Table 2, and as such the ratio increased substantially for the 'ever hospital' algorithm and the 'ever hospital or death' algorithm.

There were a total of 490,750 first cardiovascular admissions and 448,721 first injury admissions for people 25 years and over during the study period. For 30-day mortality after first cardiovascular admission, the ratio was highest for the original Aboriginal status variable, and generally decreased as the algorithms became less restrictive and included more people as Aboriginal, decreasing from 1.98 for the original variable to 1.56 for the 'ever hospital' algorithm (Table 3). However, the 'ever hospital or death' algorithm reversed this trend and resulted in an estimated ratio of 1.86. There was a very similar pattern of decreasing ratios with higher levels of enhancement for the 365-day mortality after cardiovascular

**Table 1: Associations of person, admission and hospital factors with recording of Aboriginal status, 2001-2007.**

Variable	Value	% Recorded as Aboriginal	AOR	95% CI
<b>Person factor</b>				
Age group	0-24 yrs (ref)	74%	1.00	
	25-49 yrs	75%	1.05	1.00–1.10
	50-74 yrs	70%	0.86	0.81–0.92
	75+ yrs	35%	0.37	0.33–0.41
Sex	Male (ref)	70%	1.00	
	Female	73%	1.22	1.17–1.28
Total admissions	2-5 (ref)	77%	1.00	
	6-10	67%	0.52	0.49–0.55
	11-20	64%	0.45	0.42–0.49
	21+	73%	0.54	0.48–0.60
<b>Admission factor</b>				
Year of admission	2001 (ref)	65%	1.00	
	2002	67%	1.24	1.19–1.30
	2003	68%	1.48	1.42–1.55
	2004	71%	1.95	1.86–2.04
	2005	74%	3.04	2.90–3.20
	2006	76%	4.38	4.17–4.61
	2007	79%	6.39	6.06–6.73
<b>Hospital factor</b>				
Hospital type	Public (ref)	75%	1.00	
	Private	22%	0.01	0.01–0.02
Hospital remoteness*	Major city (ref)	59%	1.00	
	Inner regional	71%	1.61	0.91–2.85
	Outer regional	82%	2.28	1.28–4.05
	Remote/very remote	91%	9.32	3.85–22.56

**Notes:**

Percentage recorded as Aboriginal and associations of person, admission and hospital factors with recording of Aboriginal status were examined within people with at least one admission recorded as Aboriginal and with at least two admissions in total. Adjusted odds ratios came from a cross-classified multilevel model with admissions nested within people and nested within hospitals.

% identified, percentage of admissions recorded as Aboriginal; AOR, adjusted odds ratio; CrI, credible interval; ref, referent group in the analysis.

\* Australian Standard Geographic Classification using the Accessibility/Remoteness Index of Australia Plus (ARIA+) based on postcode of hospital.

admission, although the 'weight of evidence' algorithm did not follow this trend.

For 30-day mortality after injury admission, there was variation in the ratios calculated when using the different methods of reporting Aboriginal status, from a low of 1.18 to a high of 1.53 (Table 3). Also, the '≥2 hospitals', 'at least 50%' and 'ever hospital or death' algorithms estimated a significantly higher 30-day mortality after injury for Aboriginal people compared with other Australians, while the 'most recent public', 'weight of evidence', 'ever identified' and the original variable did not. The highest 30-day mortality ratio of 1.53 was estimated by the 'ever hospital or death' algorithm. Every ratio estimated for 365-day mortality after injury admission showed a higher risk of death for Aboriginal people compared with other Australians. Again, the 'every hospital or death' algorithm resulted in the highest mortality ratio.

## Discussion

Aboriginal people are not recorded as such on every admission to hospital. Our study investigated variation in the recording of Aboriginal status in NSW hospitals, examined whether linked data could improve the known under-recording, and how enhancement using linked data influenced estimates of health disparities. The aim of this study was not to identify an individual as Aboriginal or not, but to use statistical means to explore the sensitivity of estimates of health disadvantage for Aboriginal people to the way Aboriginal status is determined and reported using linked hospital data.

The variation in recording of Aboriginal status between hospitals and within an individual's admission history demonstrated that it was possible to enhance reporting of Aboriginal people within and also between hospitals. We identified a number of factors that were significantly related to being recorded as Aboriginal, including being younger and being admitted in more recent calendar years,

**Table 2: Percentage change in hospital admissions reported as Aboriginal by enhancement algorithms compared with original variable, 2001-2007.**

	Original variable	Percentage change by algorithm					
		≥2 hospitals	≥ 50% public	Most recent public	Weight of evidence	Ever hospital	Ever hospital or death
	N	%	%	%	%	%	%
<b>Total admissions</b>	300,239	4.1	6.7	8.7	19.5	35.5	37.8
<b>Age group</b>							
0-24 yrs	104,580	1.0	7.6	9.1	15.5	28.4	28.6
25-49 yrs	109,173	6.9	6.4	9.9	20.2	33.3	33.8
50-74 yrs	78,795	4.5	6.1	7.3	20.0	38.0	42.1
75 yrs and over	7,123	2.6	2.9	1.1	62.4	138.7	181.2
Missing	568	7.6	3.5	10.2	16.2	112.9	112.9
<b>Sex</b>							
Male	135,333	4.1	6.4	8.2	21.3	37.8	40.6
Female	164,890	4.1	6.8	9.1	18.1	33.6	35.5
<b>Year of admission</b>							
2001	33,875	12.0	13.8	16.7	27.7	47.3	51.8
2002	37,026	10.8	11.6	14.6	26.8	45.5	49.2
2003	39,262	8.6	10.6	12.1	25.1	43.3	46.3
2004	41,452	6.4	8.5	9.9	21.6	37.8	40.6
2005	45,373	1.9	4.9	6.8	17.4	32.5	34.2
2006	49,646	-1.5	2.4	4.3	13.8	27.8	29.0
2007	53,605	-3.4	-0.2	1.8	10.7	23.0	23.8
<b>Hospital type</b>							
Public	293,683	3.7	4.0	6.1	16.6	29.3	31.4
Private	6,556	23.6	123.7	126.7	151.1	310.9	322.1
<b>Hospital remoteness*</b>							
Major city	96,977	7.5	9.5	15.4	32.0	60.5	65.2
Inner regional	67,450	4.7	8.4	10.4	20.6	36.7	38.3
Outer regional	97,469	2.1	4.1	4.1	11.5	19.6	20.5
Remote	37,559	-0.5	2.6	0.1	5.7	8.8	10.3
Not classified	784	10.1	22.7	17.3	36.6	67.0	67.1

Notes:

\* Australian Standard Geographic Classification using the Accessibility/Remoteness Index of Australia Plus (ARIA+) based on postcode of hospital.

confirming that recording of Aboriginal status in NSW hospital data has been improving over time.

The variance partitioning coefficient attributed more of the variation in the odds of being recorded as Aboriginal to the hospital of admission than to the person and the individual admission, suggesting that variations in hospital practices or environment may play the biggest role in levels of recording. Higher levels of recording in regional and remote hospitals, as shown in our study, were also reported by the national audit of Indigenous identification in hospitals.<sup>3</sup> Poor recording in private hospitals was mentioned for several jurisdictions in Australia in a 2005 report,<sup>4</sup> but was not mentioned specifically for NSW. In fact, NSW private hospitals have been shown to have low levels of missing data on the Aboriginal status variable,<sup>3,4</sup> but this does not appear to translate into better ascertainment of Aboriginal status.

The algorithms investigated in the current study produced varying levels of enhancement over and above the original Aboriginal status variable. The 'ever hospital' and 'ever hospital or death' algorithms markedly increased the number of admissions reported as Aboriginal. However, given the percentage of admissions correctly recorded was estimated to be about 88% in 2007,<sup>3</sup> an increase

of more than 35% suggests that the 'ever identified' algorithms may be over-reporting Aboriginal admissions. This possible over-reporting by 'ever identified'-type algorithms has been pointed out by other studies<sup>6,15,16,28</sup> and may be due to data entry errors or incorrect linkages that accrue over time. While all algorithms increased reporting of Aboriginal people overall, the '≥2 hospitals' and 'at least 50%' algorithms showed a decrease in the number of admissions reported as Aboriginal in the final years of the data. This occurred because the algorithms applied a consistent Aboriginal status across all admissions for an individual, meaning that some individual admissions recorded as Aboriginal were not reported as such under certain algorithms.

The different algorithms resulted in variations in estimated disparities in cardiovascular and injury hospital admissions rates and mortality outcomes. The differences in admission rate ratios by the various algorithms were to be expected, as these were calculated from population rates, with increases only to the number of Aboriginal events, (and hence fewer non-Aboriginal events), not to the population denominators. Thus the under-recording of Aboriginal people in the hospital data led to under-estimates of the level of disadvantage for Aboriginal people. A recent systematic

**Table 3: Relative admission and mortality ratios for cardiovascular disease and injury admissions by the original Aboriginal status variable and enhancement algorithms, 2001-2007.**

Algorithm	Cardiovascular disease		Injury admissions	
Standardised admission ratio (95% CI)				
Original	1.52	(1.50-1.55)	1.79	(1.76-1.82)
≥2 hospitals	1.59	(1.56-1.62)	1.88	(1.85-1.92)
≥ 50% public	1.67	(1.64-1.70)	1.93	(1.90-1.96)
Most recent public	1.69	(1.66-1.72)	1.99	(1.96-2.02)
Weight of evidence	1.91	(1.87-1.94)	2.20	(2.17-2.23)
Ever hospital	2.24	(2.20-2.27)	2.53	(2.49-2.56)
Ever hospital or death	2.32	(2.28-2.35)	2.56	(2.52-2.59)
30-day standardised mortality ratio (95% CI)				
Original	1.98	(1.74-2.24)	1.28	(0.96-1.67)
≥2 hospitals	1.96	(1.72-2.22)	1.34	(1.01-1.73)
≥ 50% public	1.90	(1.67-2.14)	1.33	(1.01-1.70)
Most recent public	1.76	(1.54-2.00)	1.22	(0.92-1.58)
Weight of evidence	1.77	(1.57-2.00)	1.26	(0.98-1.61)
Ever hospital	1.56	(1.38-1.75)	1.18	(0.93-1.47)
Ever hospital or death	1.86	(1.68-2.06)	1.53	(1.25-1.86)
365-day standardised mortality ratio (95% CI)				
Original	1.92	(1.75-2.11)	1.47	(1.27-1.69)
≥2 hospitals	1.89	(1.72-2.07)	1.49	(1.29-1.72)
≥ 50% public	1.81	(1.65-1.98)	1.42	(1.23-1.63)
Most recent public	1.71	(1.56-1.88)	1.34	(1.16-1.55)
Weight of evidence	1.75	(1.60-1.90)	1.46	(1.27-1.65)
Ever hospital	1.56	(1.44-1.70)	1.37	(1.21-1.54)
Ever hospital or death	1.81	(1.68-1.95)	1.62	(1.46-1.80)

*Notes:*

SAR, standardised admission ratio; SMR, standardised mortality ratio; CI, confidence interval.

Ratios calculated by dividing observed Aboriginal events by the expected events given the age-, sex- and year-specific rates among the non-Aboriginal population or cohort group, with a value higher than one indicating a higher rate for Aboriginal people. Admission ratios may include multiple admissions per person, while the mortality ratios are based on the first admission for each person.

review of literature on different ways that have been used to report Aboriginal status in linked data studies also concluded that under-recording of Aboriginal people in administrative datasets generally led to reduced estimates of Aboriginal disadvantage.<sup>29</sup> While we found this with admission rate ratios, this was not the case with the estimated mortality ratios.

The 'ever hospital' algorithm in our study resulted in the lowest 30-day and 365-day mortality ratio after cardiovascular admission, suggesting that the additional people included as Aboriginal when applying this algorithm had a lower cardiovascular mortality rate than those reported using the original Aboriginal status variable. Similar patterns have been reported elsewhere: a recent NSW Health report found that an 'ever identified'-type algorithm resulted in lower rates of pre-term and low birth weight births among Aboriginal mothers compared with the original Aboriginal status variable;<sup>17</sup> enhancing numbers of births reported as Aboriginal in administrative data using self-reported Aboriginal status from a survey increased the estimated numbers of Aboriginal births, but decreased the overall proportions of low birth weight and low gestational age Aboriginal babies;<sup>20</sup> and an inclusive definition of Aboriginal status resulted in higher incidence of acute myocardial infarction for Aboriginal people but lower 28-day case fatality than a more restrictive definition.<sup>18</sup> These studies and ours suggest that more inclusive algorithms that increase the number of people reported as Aboriginal, and therefore result in higher estimates of Aboriginal disease rates and ratios, may result in lower estimates of outcome rates and ratios. This may be because the inclusive algorithms are more likely to include non-Aboriginal people (false-positives) or it may be due to a systematic difference in health between those people who are more often recorded as Aboriginal on the original data, and those who are only occasionally recorded. The 'weight of evidence' algorithm did not follow this pattern, however, and this could be because this algorithm showed a disproportionately higher increase in reporting in the oldest age group, and as such, the additional people included as Aboriginal with this algorithm would have been at a higher risk of mortality. The 'weight of evidence' algorithm has been reported elsewhere to increase hospital admissions more for older Aboriginal people than younger in an analysis that used not only hospital data, but a number of linked routinely collected datasets to calculate the algorithm to enhance reporting of Aboriginal status in routinely collected hospital data.<sup>17</sup>

Another algorithm that did not follow this pattern was the 'ever hospital or death' algorithm, the most inclusive definition in our study, which resulted in higher relative mortality ratios than the 'ever hospital' algorithm, for both cardiovascular and injury indicators. This was because mortality data were used to additionally enhance reporting of Aboriginal status in the hospital data, so any additional people reported as Aboriginal with this algorithm had by definition died, biasing the mortality rate upwards for Aboriginal people. Those individuals who did not have a death record did not have the same 'opportunity' to have their Aboriginal status enhanced by this linkage. This highlights an issue with using datasets that are closely related to the outcome of interest to enhance reporting, as there is

no opportunity for enhancement for those who do not experience the outcome and results in a bias in the outcome ratio.

Disregarding the 'ever hospital or death' algorithm, 30-day mortality after cardiovascular admission as estimated by the remaining algorithms was between 56% and 98% higher for Aboriginal people than other Australians. The 95% confidence intervals for these mortality ratio estimates did overlap. However, as the core group of people reported as Aboriginal by each algorithm were the same (i.e. those recorded as Aboriginal on all or most of their admissions), one would not expect the algorithms to estimate dramatically different mortality ratios. Mortality outcomes after injury admission did not vary as much as those for cardiovascular disease, but only some of the algorithms estimated a significantly higher rate of 30-day mortality after injury admission for Aboriginal people. This is partly due to the practice of treating significance as dichotomous, rather than looking at the *p*-value as a continuous probability. However, that said, the use of the 0.05 cut-off is common and may lead to a significant health disparity being reported when using one algorithm but not when using another.

The strengths of this study were its use of a large sample of hospital data for an entire population, and the focus on how using algorithms to enhance Aboriginal identification affects research outcomes. However, use of a shorter time window and more recent data may not have identified as much variation between algorithms, because of recent improvements in recording of Aboriginal status. Also, we did not have a separate self-reported source with which to compare recording in the APDC, and hence, it was not possible to account for or identify those who were in fact of Aboriginal origin but were never identified in the APDC. If this group were to be included, one would expect the population-based admission rates would increase for Aboriginal people but it is difficult to predict the impact on the cohort-based mortality outcome ratios. One study, focused on births data, found that those births that were never recorded as Aboriginal in the routinely collected data were more likely to be from urban and less disadvantaged areas, and have better health outcomes than those identified.<sup>20</sup> Finally, using the 'ever hospital' reporting of Aboriginal status as the outcome for the cross-classified multilevel analysis may have estimated the odds of being incorrectly recorded as well as correctly recorded.

Without a comprehensive audit or survey or definitive list of people who identify as Aboriginal or Torres Strait Islander and are accepted as such by their community, it is very difficult to recommend one particular algorithm as better than another. The choice may depend on the data sets available and the outcomes that are being examined. Based on the results of the current study, we have chosen to use the 'most recent public' algorithm for further studies of hospital admission rates and outcomes in adults, because of the improvement in the recording of Aboriginal status over time and the better recording in public versus private hospitals. Additionally, this algorithm is not influenced by factors associated with outcomes of interest, such as total number of admissions, or having a death record. However, this algorithm may not be the best for all situations, particularly if the outcome is specifically related

to the last admission in the admission history, such in-hospital mortality. Researchers are urged to consider the relative merits of the various algorithms, in terms of level of enhancement and potential bias, with regards to their specific research question. For example, the 'weight of evidence' algorithm results in higher levels of enhancement than the 'most recent' algorithm, and so may be preferable in studies with a primary objective of quantifying absolute excess burden in Aboriginal people.

## Conclusion

The influence of the hospital of admission on likelihood of recording of Aboriginal status highlights the importance of continuing efforts to improve the collection of Aboriginal status in hospitals, particularly major city and private hospitals. However, data linkage is useful for increasing reporting in current data. The choice of algorithm, though, has an impact not only on the absolute number of people reported as Aboriginal, but also on the size of the estimated Aboriginal to non-Aboriginal disparity in hospital admission and mortality rate ratios. Algorithms may introduce bias in the estimated research outcomes, particularly if datasets used to enhance reporting are related to the outcome of interest. It is important to run sensitivity analyses using different methods of reporting to understand how much uncertainty there is in the outcomes of interest.

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## 6. Rates of AMI events

### 6.1. Publication details

Randall DA, Jorm LR, Lujic S, Eades SJ, Churches TR, O'Loughlin AJ, Leyland AH. Exploring disparities in acute myocardial infarction events between Aboriginal and non-Aboriginal Australians: roles of age, gender, geography and area-level disadvantage. *Health and Place*. 2014;28:58-66.

### 6.2. Aims

- To investigate disparities in rates of AMI between Aboriginal and non-Aboriginal people in NSW.
- To explore the roles of age, gender, geography and area-level disadvantage in disparities in AMI events between Aboriginal and non-Aboriginal people.

### 6.3. Main findings

- Aboriginal people had higher age-, sex- and year-adjusted rates of AMI than non-Aboriginal people, and this disparity persisted when taking into account area of residence. Even within the same areas, Aboriginal people had, on average, two times the rate of AMI events than non-Aboriginal people.
- The relative disparity in AMI rates was particularly high in younger age groups (25-44 year olds) and for women, with Aboriginal women having the same AMI event rates as non-Aboriginal men.
- There was significant variation in AMI rates by geographic area, with higher rates outside major city areas and in lower socioeconomic areas. The relative disparity in AMI rates was also particularly high in lower socioeconomic and more regional and remote areas.
- 'High rate, high disparity' areas that had both a higher than average rate of AMI for Aboriginal people and a high Aboriginal to non-Aboriginal disparity should be priority areas for targeted interventions.



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# Exploring disparities in acute myocardial infarction events between Aboriginal and non-Aboriginal Australians: Roles of age, gender, geography and area-level disadvantage

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## ABSTRACT

We investigated disparities in rates of acute myocardial infarction (AMI) between Aboriginal and non-Aboriginal people in the 199 Statistical Local Areas (SLAs) in New South Wales, Australia. Using routinely collected and linked hospital and mortality data from 2002 to 2007, we developed multilevel Poisson regression models to estimate the relative rates of first AMI events in the study period accounting for area of residence. Rates of AMI in Aboriginal people were more than two times that in non-Aboriginal people, with the disparity greatest in more disadvantaged and remote areas. AMI rates in Aboriginal people varied significantly by SLA, as did the Aboriginal to non-Aboriginal rate ratio. We identified almost 30 priority areas for universal and targeted preventive interventions that had both high rates of AMI for Aboriginal people and large disparities in rates.

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## 1. Main text

Aboriginal Australians are currently estimated to have a life expectancy 11.5 years lower for males and 9.7 years lower for females than other Australians (Australian Bureau of Statistics, 2009b), and a total burden of disease that is 2.5 times higher (Vos et al., 2009). Ischaemic heart disease (IHD) alone accounts for 14% of this gap in burden of disease (Vos et al., 2009) and IHD mortality has been estimated to be three times higher in Aboriginal compared with non-Aboriginal people (Gray and Thomson, 2011). Higher incidence of acute myocardial infarction (AMI) among Aboriginal people is likely to be a major contributor to higher mortality from IHD and its sequelae in this population.

Age-specific incidence of AMI has been found to be higher for Aboriginal people in the Northern Territory (NT) (You et al., 2009) and in Western Australia (WA), with the relative disparity particularly high in younger people and women (Katzenellenbogen et al., 2010),

and the disparity persisting in urban, regional and remote areas (Katzenellenbogen et al., 2012). However, this research did not look at the influence of place of residence on AMI incidence or the disparity in incidence between Aboriginal and non-Aboriginal people.

While much of the research about how to reduce rates of IHD focuses on individual risk factors (Goldstein et al., 2004; Graham et al., 2007) the area in which someone lives can also have an important impact on IHD incidence (Chaix, 2009; Diez Roux, 2003). People living in the same area tend to be exposed to the same complex interplay of risk and protective factors including ease of access to services, exposure to public health campaigns, delivery of preventive interventions through primary care, walkability and public transport, and social cohesion and interactions. Studies of area of residence and IHD have shown that social disadvantage of areas has an impact on rates of AMI and IHD (Davies et al., 2009), even after adjustment for individual socio-economic status (Diez Roux et al., 2001).

Identifying the relative contributions of individual factors and geography to disparities in AMI risk, and how disparities vary by area, can assist with making choices about which intervention strategies (universal or targeted) are likely to be most effective,

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and where they should be targeted. However, inductive analyses at small area level require substantial population sizes. We took advantage of the availability of linked whole-of-population data for the state of New South Wales (NSW), which has the largest population of Aboriginal Australians of all the States and Territories, to explore in detail the roles of age, gender, geography and area-level disadvantage in disparities in AMI events between Aboriginal and non-Aboriginal people.

## 2. Methods

### 2.1. Study design

This was an observational study using routinely collected and linked hospital and mortality data for NSW, Australia between July 2000 and December 2007 and estimated resident population data for the same years.

### 2.2. Setting

NSW is the most populous state in Australia with an estimated 6.8 million residents (in 2006), 2.2% of whom identified as Aboriginal and/or Torres Strait Islander. NSW is home to approximately 30% of Australia's Aboriginal peoples, the largest percentage of all the States and Territories in Australia. In 2006, 73% of the total NSW population lived in a major city ([Population Health Division, 2006](#)) compared with 42% of the NSW Aboriginal population ([Australian Bureau of Statistics, 2006a](#)).

### 2.3. Data

The Admitted Patients Data Collection (APDC) is a routinely collected administrative dataset containing records for all NSW public and private hospital separations (hospital admissions ending in a discharge, transfer, type-change or death). Patient demographics and multiple diagnoses and procedures are recorded for each separation and coded according to the Australian modification of the International Statistical Classification of Diseases and Related Problems (diagnoses) ([National Centre for Classification in Health, 2006](#)). The NSW Register of Births, Deaths and Marriages (RBDM) captures all deaths registered in NSW. The Australian Bureau of Statistics (ABS) codes the underlying cause of death and contributing causes of death for the RBDM notifications, as well as including demographic information such as date of birth, sex and Aboriginal status. APDC data (July 2000 to December 2007), RBDM (July 2000 to December 2007) and ABS Mortality Data (July 2000 to December 2007) were linked using probabilistic methods by the Centre for Health Record Linkage ([Centre for Health Record Linkage, 2012](#)). We were supplied with de-identified APDC, RBDM and ABS data and merged these using a project-specific unique person number.

Estimated resident populations for each of 199 Statistical Local Areas (SLAs) in NSW were obtained by age, sex and Aboriginal status using the 2001 and 2006 Australian Census data (unpublished data, Australian Bureau of Statistics) and combined with year-specific population projections ([Australian Bureau of Statistics, 2009a](#)) to obtain synthetic estimates of the mid-year populations of Aboriginal and non-Aboriginal people by SLA, year, age group and sex ([Office of Economic and Statistical Research \(OESR\), 2010](#)).

### 2.4. Subjects

We used the linked data to identify NSW residents aged 25 to 84 who were admitted to a public or private hospital with a

primary diagnosis of AMI (ICD-10-AM: I21) or a diagnosis of AMI in the second or third diagnosis field, accompanied by a primary diagnosis of IHD (ICD-10-AM: I20-I25) ([Randall et al., 2012](#)), or who died with an underlying or contributing cause of death coded as AMI (ICD-10-AM: I21). The death record cases were restricted to those with a coded cause of death of AMI rather than IHD after an internal validation study was run examining the concordance between the coded cause of death and diagnoses recorded in linked hospital records. In this study, the broader IHD definition resulted in a poor positive predictive value (PPV), and the AMI as underlying or contributing COD had a higher PPV, sensitivity and specificity than IHD as underlying COD. We chose the first such event for each person in the period January 2002 to December 2007 as the index event for analysis, with at least an 18 month clearance period for previous AMI events. These first-ever events in the study period thus consisted of first-ever AMI events as well as events for those people who may have had a previous AMI before July 2000. This variable clearance period (where not all patients had exactly the same clearance period) is suitable for the current study because time trends were not the main focus and outcomes were not investigated. Additionally, this minimised the number of prevalent cases included in the analysis. We performed a sensitivity analysis using the last three years of data (2005 to 2007) to investigate the impact on the relative Aboriginal to non-Aboriginal ratio of AMI index events of using various clearance periods of up to four years to remove prevalent AMI cases. For each individual with an index event, we had information on age, sex, Aboriginal status, SLA of residence, and date of event (either date of admission or date of death). We excluded non-NSW residents and those whose address was not able to be assigned to an SLA from the analysis.

### 2.5. Variables

We used the following individual-level variables: (i) age (in 10-year age groups); (ii) sex (male and female); (iii) year of index event (from 2002 to 2007); and (iv) Aboriginal status.

An audit of NSW public hospitals in 2007 found that Aboriginal people were correctly recorded as Aboriginal on 88% of admissions ([Australian Institute of Health and Welfare, 2010](#)). We classified subjects whose index AMI event was a hospital record as Aboriginal if they were recorded as such in their most recent public hospital record (for any diagnosis type). This method for enhancing reporting of Aboriginal status is not biased by the number of hospital records available for individuals (which is related to their level of morbidity) and takes advantage of improved recording of Aboriginality in more recent years ([Randall et al., 2013](#)). We classified subjects whose index AMI event was a death record as Aboriginal if this was recorded in the death record or their most recent public hospital record (if there was one). This increased the number of AMI index events reported as Aboriginal by 7% compared to using Aboriginal status as recorded in the index event record alone (either hospital admission or death record). We also conducted a sensitivity analysis using two other definitions; (i) status as recorded on the index event record; and (ii) ever having been recorded as Aboriginal on any record (hospital or death) in the dataset ('ever identified'). Due to the small proportion of admissions recorded as 'Torres Strait Islander but not Aboriginal' in the NSW hospital data (0.1%), and the fact that Torres Strait Islanders were not coded separately in the mortality data, we considered Aboriginal and Torres Strait Islander peoples as one group for the analysis (referred to as 'Aboriginal').

We used two area-level variables, assigned on the basis SLA of residence at the time of the index event: (i) remoteness, classified according to the Accessibility/Remoteness Index of Australia (ARIA+) and grouped into four categories (major city, inner



regional, outer regional, remote/very remote) (Commonwealth Department of Health and Aged Care, 2001); and (ii) socio-economic status (SES) based on the ABS Socio-Economic Index for Areas Index of Relative Socioeconomic Disadvantage (SEIFA IRSD), divided into NSW population quintiles (Australian Bureau of Statistics, 2006b).

### 3. Statistical analysis

We calculated age-standardised AMI event rates using direct standardisation to the 2001 Australian Population. We used single-level and multilevel Poisson models to estimate rate ratios (RRs) for the disparity in AMI events between Aboriginal and non-Aboriginal people, using first AMI events grouped by year as the numerator and estimated mid-year populations by SLA as the denominator. In the multilevel model, we investigated trends in events by year (also stratified by Aboriginal and non-Aboriginal people) and interactions between Aboriginal status and all other variables (age, sex, year, remoteness, and SES) to determine whether the influence of the other variables on AMI rates were the same for Aboriginal and non-Aboriginal people. In order to aid interpretability of the interaction terms, they were presented as new composite variables, such as 'non-Aboriginal males', 'non-Aboriginal females', 'Aboriginal males', and 'Aboriginal females' with one reference category, in this case, 'non-Aboriginal males'. The multilevel analysis included a random intercept and allowed the overall rate of AMI events to vary by SLA. Variation at the SLA level ( $\tau^2$ ) was expressed as a median rate ratio, which was the median of the rate ratios of pair-wise comparisons of people with identical characteristics taken from randomly chosen SLAs. This was an extension of the technique described by Merlo and colleagues (Merlo et al., 2006) for calculating median odds ratios for multilevel logistic regression models and was calculated using the formula:

$$\text{median rate ratio} = e^{0.95\sqrt{\tau^2}}$$

To investigate the variation in AMI events for Aboriginal and non-Aboriginal people across SLAs, the model was reparameterised to include a random slope for both Aboriginal and non-Aboriginal rates. The relative differences in the rates of AMI in each SLA compared to the average (the area residuals) were calculated for Aboriginal and non-Aboriginal people, and the linear relationship between these residuals was assessed using Pearson's correlation coefficient. Finally, to investigate whether the magnitude of the relative Aboriginal to non-Aboriginal disparity differed between SLAs, a random slope for Aboriginal status was added to the random intercept model. Estimated Aboriginal to non-Aboriginal RRs by SLA were generated from this model by adding the fixed effect for Aboriginal status to the slope residuals for each SLA (the degree to which the disparity in a SLA differed from the disparity in the 'average' SLA) and exponentiating. The estimated RRs by geographic area used 'shrunk' residuals from the multilevel models that borrow information from the average to stabilise area-level estimates (Merlo et al., 2005). We tested specific spatial models including a spatial multiple membership model and a conditional autoregressive (CAR) model, and these did not improve model fit over the Poisson multilevel model or change the parameter estimates and as such were not preferred over the multilevel model. Confidence intervals were calculated at the 95% level. Data analyses were carried out using SAS 9.3 (SAS Institute, 2010) and in the multilevel modelling software MLwiN 2.25 (Rasbash et al., 2012) using iterated generalised least squares (IGLS) estimation.

### 4. Results

We identified a total of 65 548 index AMI events between 2002 and 2007 for NSW residents aged 25 to 84 years (1168 Aboriginal and 64 380 non-Aboriginal). Of these index events, 78% were for people admitted to hospital (80% and 78% for Aboriginal and non-Aboriginal people, respectively) and 22% were for those who died of AMI with no linked AMI hospital admission. The age-standardised rate of first AMI events in the study period was 464 per 100 000 for Aboriginal people and 234 per 100 000 for non-Aboriginal people (Table 1). Among the 25 to 84 year olds included in the study, the average age at first AMI was 56 for Aboriginal people and 68 for non-Aboriginal people. Rates of AMI increased markedly by age group for both Aboriginal and non-Aboriginal people and males had higher rates than females. There was no clear trend by year for AMI rates in Aboriginal people, but AMI rates decreased steadily for non-Aboriginal people from 2002 to 2007. AMI rates were higher in inner regional, outer regional and remote areas than in major cities, and increased with increasing socio-economic disadvantage for both Aboriginal and non-Aboriginal people.

Using a single-level Poisson regression model adjusting for age group, sex and year of event, we estimated that the rate of AMI events in Aboriginal people was 2.30 (95% CI 2.17–2.44) times higher than in non-Aboriginal people. When a random intercept for area was added, allowing the rate of AMI events to vary between SLAs and comparing Aboriginal and non-Aboriginal people within SLAs, the Aboriginal RR decreased slightly to 2.10 (95% CI 1.98–2.23). Table 2 shows the RRs for the adjusted multilevel model including all individual-level variables. Consistent with the age-standardised rates, this model demonstrated that the rate of AMI events increased dramatically with age, and was higher in males than females. Overall, there was a downward trend in total AMI events by year ( $p$  for linear trend  $< 0.01$ ). A stratified analysis showed a significant decreasing trend in non-Aboriginal AMI events ( $p$  for linear trend  $< 0.01$ ), while the trend in Aboriginal events was of a similar magnitude but did not reach significance ( $p$  for linear trend = 0.08).

We identified a significant interaction between Aboriginal status and age group ( $p < 0.01$ ) and Aboriginal status and sex ( $p < 0.01$ ), but there was no significant interaction between Aboriginal status and year ( $p = 0.94$ ). Fig. 1 plots these interactions. For age, the significant interaction was evidenced by the large disparity in the younger age groups that decreased steadily with age. Within age strata, the Aboriginal to non-Aboriginal RR was 4.75 (95% CI 3.48–6.49) among 25–34 year-olds decreasing to 0.95 (95% CI 0.77–1.18) for 75–84 year-olds. The significant interaction effect by sex was due to the higher disparity for females than males, with a stratified RR of 2.33 (95% CI 2.12–2.57) for females and 1.98 (95% CI 1.84–2.13) for males.

After adjusting for the individual-level variables, we identified significant variation in the overall AMI event rate according to SLA of residence ( $\tau^2 = 0.82$ ,  $p < 0.01$ ). This variation equated to a median rate ratio of 1.31; in other words, for any population group defined by age, sex, year and Aboriginal status from two randomly chosen areas, the rate of AMI events in one area was on average 31% higher than in the other area. Area-level variation was even greater for AMI rates in Aboriginal people, with a median rate ratio of 1.77, suggesting that area of residence had a greater impact on AMI rates in Aboriginal people than in non-Aboriginal people. The correlation between the Aboriginal and non-Aboriginal area-level residuals was 0.72, indicating that there was reasonable agreement in those areas with high and low rates for both Aboriginal and non-Aboriginal people. However, there was significant variation in the Aboriginal to non-Aboriginal disparity by area ( $p < 0.01$ ). The Aboriginal to non-Aboriginal RRs by SLA from

**Table 1**  
Age-standardised rates of AMI by individual- and area-level factors, 2002 to 2007.

	Aboriginal			Non-Aboriginal		
	n	ASR <sup>a</sup>	(95% CI <sup>b</sup> )	n	ASR <sup>a</sup>	(95% CI <sup>b</sup> )
Total	1168	464	(434–496)	64380	234	(232–236)
<b>Individual factor</b>						
Age group						
25–34	44	37	(27–49)	399	7	(6–8)
35–44	215	198	(172–226)	2542	43	(41–45)
45–54	314	411	(366–459)	7791	144	(141–148)
55–64	262	624	(550–704)	12679	302	(297–307)
65–74	225	1140	(994–1301)	16684	596	(587–605)
75–84	108	1612	(1320–1948)	24285	1237	(1222–1253)
Sex						
Male	723	576	(526–628)	42770	331	(328–334)
Female	445	363	(326–403)	21610	143	(141–145)
Year						
2002	177	478	(399–567)	10927	248	(243–252)
2003	199	503	(425–589)	11139	248	(244–253)
2004	207	512	(434–598)	10976	241	(236–245)
2005	181	413	(345–489)	10490	227	(222–231)
2006	191	423	(356–497)	10335	220	(216–224)
2007	213	470	(399–549)	10513	220	(216–225)
<b>Area factor</b>						
Remoteness of residence						
Major city	280	319	(278–365)	34628	218	(216–221)
Inner regional	378	492	(434–555)	20878	258	(254–261)
Outer regional	356	586	(519–658)	8243	248	(243–254)
Remote/very remote	154	592	(488–709)	631	251	(232–272)
SES <sup>c</sup> quintile						
1 Least disadvantaged	21	225	(129–358)	9511	173	(170–177)
2	98	329	(256–415)	10306	207	(203–211)
3	170	381	(318–451)	13784	246	(242–250)
4	327	468	(410–531)	15746	261	(257–265)
5 Most disadvantaged	552	579	(524–636)	15033	277	(273–282)

<sup>a</sup> Age-standardised rate per 100 000.

<sup>b</sup> Confidence interval.

<sup>c</sup> Socio-economic status.

**Table 2**  
Adjusted RRs<sup>a</sup> for individual-level variables from the multilevel Poisson regression model with random intercept for area.

	RR <sup>a</sup>	95% CI <sup>b</sup>	p-Value
Aboriginal			
No (ref)	1.00		< 0.01
Yes	2.10	1.98–2.23	
Age group			
25–34	1.00		< 0.01
35–44	6.01	5.44–6.64	
45–54	19.36	17.58–21.31	
55–64	40.29	36.67–44.26	
65–74	79.92	72.74–87.80	
75–84	178.75	162.70–196.39	
Sex			
Male (ref)	1.00		< 0.01
Female	0.45	0.44–0.45	
Year			
2002 (ref)	1.00		< 0.01
2003	1.00	0.98–1.03	
2004	0.97	0.95–0.99	
2005	0.91	0.89–0.94	
2006	0.88	0.86–0.91	
2007	0.88	0.86–0.91	

<sup>a</sup> Rate ratio.

<sup>b</sup> Confidence interval.

the random slope multilevel model are shown in Fig. 2, grouped by remoteness. Aboriginal people had higher rates of AMI events than non-Aboriginal people in almost all SLAs in NSW, and in many SLAs, this disparity was significant at the 95% confidence level (those areas where the confidence limits do not cross 1). This is a

relative measure and could be influenced by areas with particularly low rates of AMI in non-Aboriginal people, so areas of particular note were those where the relative rate was higher for Aboriginal people and the rate of AMI events for Aboriginal people was higher than average. These “high rate, high disparity” SLAs were spread throughout NSW, and are highlighted on the map in Fig. 3.

We added the area-level variables of remoteness and SES into the fully-adjusted individual-level model one at a time to see how much of the variation in overall AMI rates by SLA they explained (Table 3). Adding remoteness of residence demonstrated that rates of AMI events were significantly higher outside the major city areas, but remoteness only explained 6% of the area-level variation. In contrast, SES explained 37% of the variation by area, and there was a clear gradient of higher AMI rates with increasing area disadvantage. Interactions between remoteness ( $p < 0.01$ ) and SES ( $p < 0.01$ ) and Aboriginal status are shown in Fig. 4. These show increasing disparities in AMI rates between Aboriginal and non-Aboriginal people with increasing remoteness and increasing socioeconomic disadvantage.

#### 4.1. Sensitivity analysis 1: Clearance of prevalent cases

To identify the influence of the duration of the clearance period, we estimated the Aboriginal to non-Aboriginal AMI RR for the years 2005 to 2007 in a multilevel model accounting for age group and sex. This yielded RRs of 2.26 (95% CI 2.09–2.45) with no clearance period, 2.20 (95% CI 2.03–2.39) with a one-year clearance, 2.17 (95% CI 2.00–2.35) with a two-year clearance, 2.15 (95% CI 1.98–2.33) with a three-year clearance, and 2.11 (95% CI 1.94–2.29) with a four-year clearance.

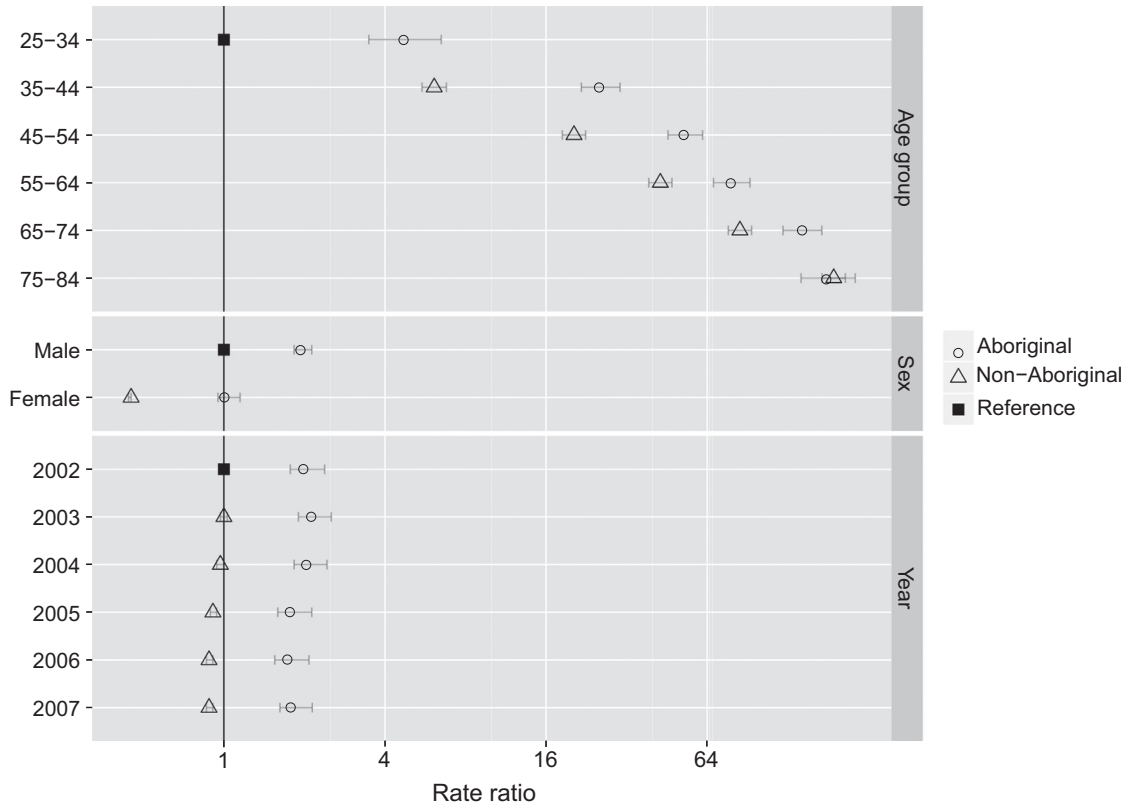


Fig. 1. RRs<sup>a</sup> from interactions between individual factors and Aboriginal status from multilevel Poisson regression models with a random intercept for Statistical Local Area adjusted for the remaining individual-level factors. RRs are relative to the reference category. <sup>a</sup>Rate ratio.

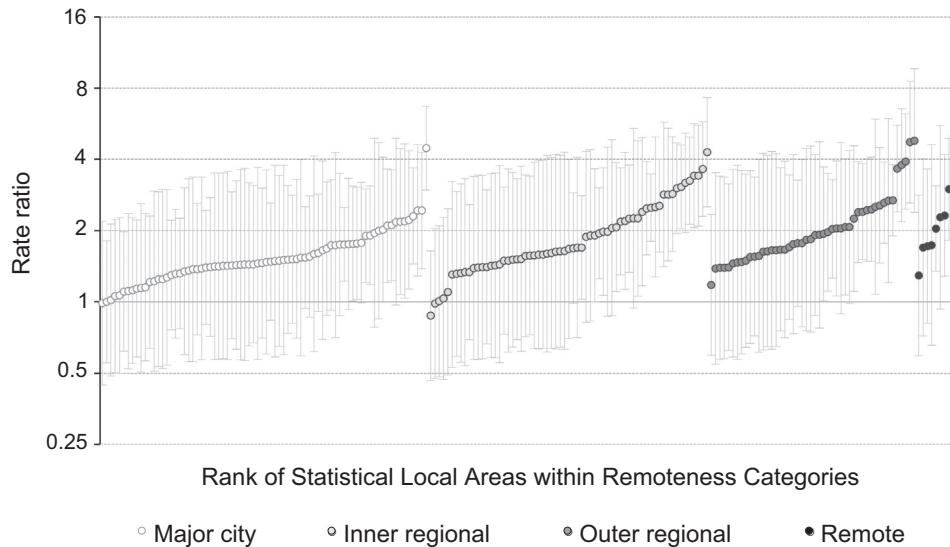


Fig. 2. Aboriginal to non-Aboriginal RR<sup>a</sup> for AMI by Statistical Local Area and remoteness categories from the multilevel Poisson model adjusted for age, sex and year, with a random slope for Aboriginal status. <sup>a</sup>Rate ratio.

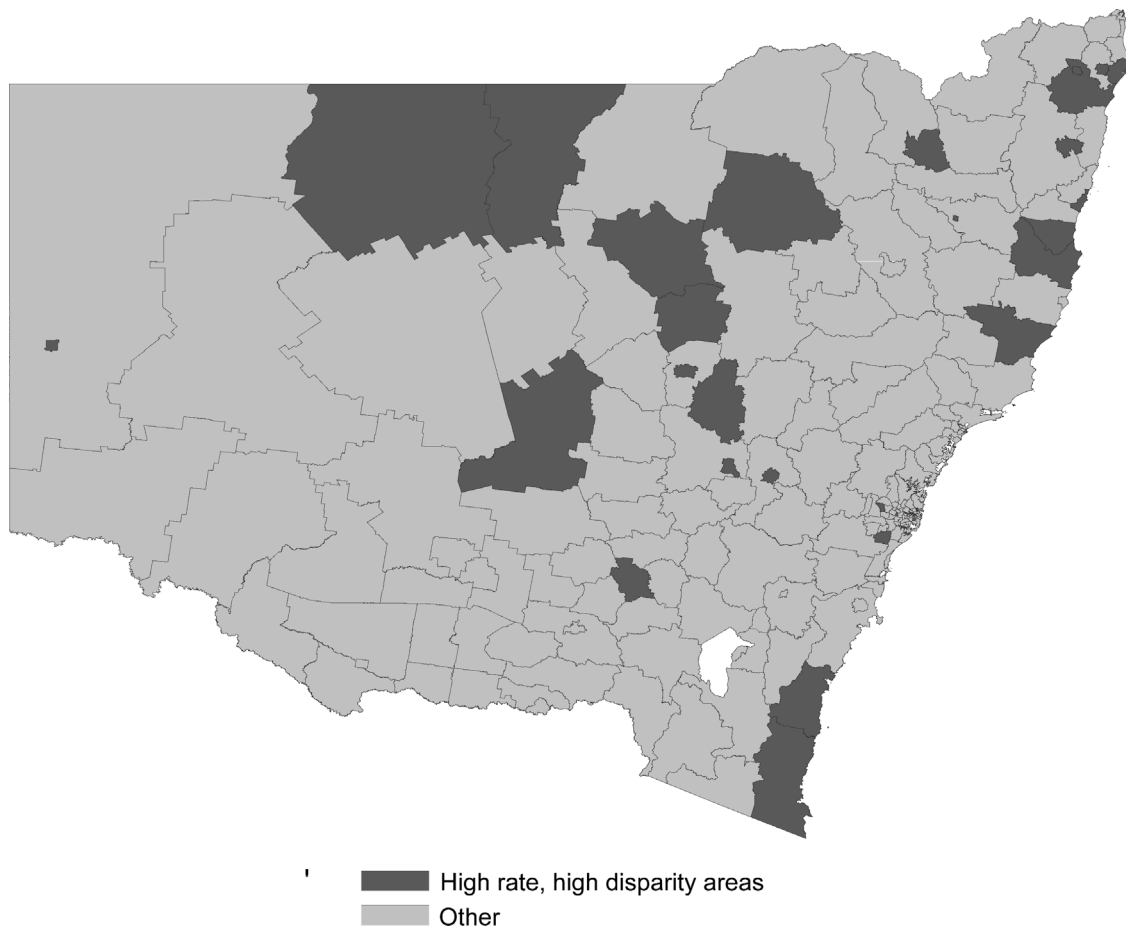
4.2. Sensitivity analysis 2: Reporting of Aboriginal status

We explored two alternative ways of classifying Aboriginal status: Aboriginal status as recorded on the AMI index event (either hospital admission or death record); and ‘ever identified’ as Aboriginal in any record in the entire linked dataset. Index event records classified 1091 subjects as Aboriginal and the ‘ever identified’ algorithm classified 1953 as Aboriginal, compared with 1168 for the method used in the main analysis. When entered into a multilevel model adjusted for age group, sex, year and SLA the

Aboriginal to non-Aboriginal RR estimated using Aboriginal status from index event records was 1.95 (95% CI 1.83–2.08); while that estimated using the ‘ever identified’ algorithm was 2.58 (95% CI 2.44–2.72).

5. Discussion

We found that the age-standardised rate of first AMI events in NSW between 2002 and 2007 was 464 per 100 000 for Aboriginal



**Fig. 3.** Map of New South Wales, Australia, marking the “high rate, high disparity” Statistical Local Areas, where the rate of AMIs for Aboriginal people is higher than for non-Aboriginal people as well as being higher than the average rate for Aboriginal people.

**Table 3**

Adjusted RRs<sup>a</sup> for area-level variables from the multilevel Poisson regression model with random intercept for area.

	RR <sup>a</sup>	95% CI <sup>b</sup>	p-Value
Remoteness of residence <sup>c</sup>			
Major city	1.00		< 0.01
Inner regional	1.16	1.04–1.28	
Outer regional	1.11	1.01–1.23	
Remote/very remote	1.22	1.02–1.45	
SES quintile <sup>c</sup>			
1 least disadvantaged	1.00		< 0.01
2	1.26	1.11–1.43	
3	1.40	1.24–1.58	
4	1.46	1.30–1.64	
5 most disadvantaged	1.70	1.52–1.91	

<sup>a</sup> Rate ratio.

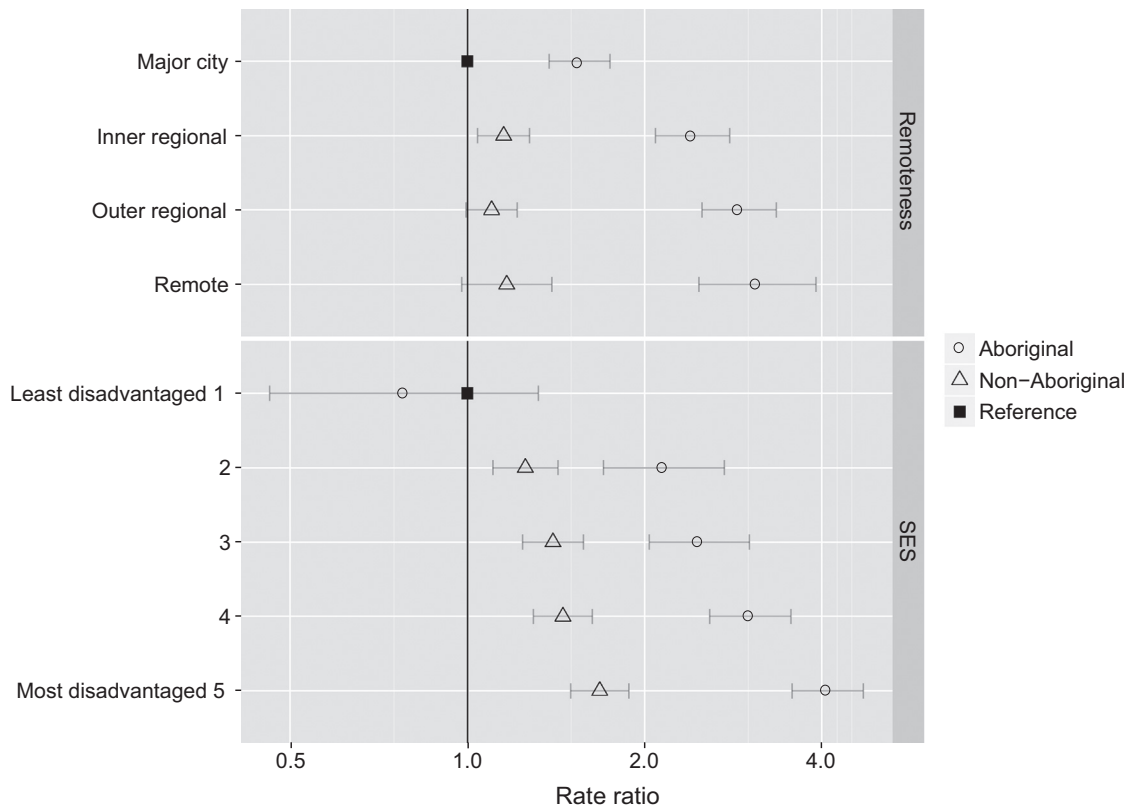
<sup>b</sup> Confidence interval.

<sup>c</sup> Area-level factors added one at a time to the fully adjusted individual-level model (adjusted for Aboriginal status, age, sex and year) due to being highly associated.

people and 234 per 100 000 for non-Aboriginal people. After adjusting for age, sex and year of event, the rate of AMI events in Aboriginal people was 2.3 times higher than in non-Aboriginal people (95% CI 2.17–2.44). This disparity persisted, only slightly reduced (RR 2.10, 95% CI 1.98–2.23), when we accounted for SLA of residence using a multilevel model. The disparity in AMI rates was particularly high in the younger age groups, and was larger in females than in males. AMI rates in NSW for all people decreased by 12% over the study period, and while there was also a decrease

over time for Aboriginal people, this trend was not significant. It must be noted, however, that the decreasing trend found in this study may have been due to the short clearance period and the possibility that there were prevalent cases of AMI in the earlier years of the study. Conversely, the number of confirmed AMI events may have increased over time due to the roll-out of the troponin test, a more sensitive and specific biochemical marker for the diagnosis of AMI (Alpert et al., 2000). The change in definition of an AMI to include the troponin test in 2000 resulted in events previously defined as angina being defined as small AMIs and has been shown to increase the number of NSTEMI events identified (Roger et al., 2010). However, a validation study in WA found that the hospital administrative data underestimated the number of AMIs defined with the new troponin biomarker in 2003 (Sanfilippo et al., 2011). There is no equivalent validation study in NSW, so it is difficult to estimate how the new definition impacted on trends in our study.

We identified significant variation in AMI rates by area of residence both overall and for Aboriginal people. The SES of an area accounted for a greater proportion of this variation than its remoteness, and the rate of AMI events was highest in the most disadvantaged areas. AMI rates were higher in Aboriginal than non-Aboriginal people in almost all SLAs in NSW, and the size of this disparity varied significantly by area. Combining information from the variation in AMI rates by area for Aboriginal people and variation in the Aboriginal to non-Aboriginal disparity by area highlighted almost 30 “high rate, high disparity” areas for Aboriginal people. These were predominantly SLAs classified as inner and outer regional areas, comprising mainly medium to large sized



**Fig. 4.** RRs<sup>a</sup> from interactions between area factors and Aboriginal status from multilevel Poisson regression models with a random intercept for Statistical Local Area, adjusted for age, sex and year. RRs are relative to the reference category. <sup>a</sup>Rate ratio.

rural towns and their hinterlands, and were more likely to be situated in Northern NSW.

The main strengths of the study include the large Aboriginal population size of NSW and the complete population coverage that was available using linked routinely collected data. This allowed us to look at small-area variation in AMI rates and also to compare across years. Additionally, our application of multilevel modelling techniques allowed us to account for clustering by area of residence and produce “shrunk” small-area estimates, which are not as prone to random fluctuations as crude or standardised rates. However, the linked data brought with them some limitations. In particular, data were only available from July 2000 onwards, so it was not possible to remove all prevalent cases of AMI using a substantial clearance period. We used a minimum of an 18-month clearance period to maximise the amount of data available for analysis, and conducted a sensitivity analysis to investigate the impact of longer clearance periods on the Aboriginal to non-Aboriginal AMI RR. The RRs attenuated slightly with longer clearance periods, suggesting that using an 18-month clearance may have overestimated the disparity. However, this effect was likely to be minimal in comparison with the potential for underestimation associated with the known under-recording of Aboriginal status in hospital (Australian Institute of Health and Welfare, 2010) and death (Australian Bureau of Statistics, 2008; Taylor et al., 2012) data, particularly in more urban areas. We used a ‘most recent’ algorithm to enhance reporting of Aboriginal status, which increased the numbers of AMI events reported as Aboriginal by 7% (15% in major cities), but our sensitivity analysis using an ‘ever identified’ algorithm produced a far higher Aboriginal to non-Aboriginal rate ratio, suggesting that our estimates of the disparity were indeed conservative. Differences in recording of Aboriginal status by area may have increased the geographic variability in Aboriginal AMI event rates; however, our

enhancement algorithm differentially increased numbers of events reported as Aboriginal in major cities, redressing at least in part the differential under-recording in urban areas. The probabilistic linkage may have resulted in some false positive links as well as missed links but quality assurance measures at the Centre for Health Record Linkage ensure that these are kept to a minimum. At the time of extraction of the current study data, the false positive rate was estimated to be 4/1000 records (0.4%) and the false negative rate was estimated to be < 5/1000 records (< 0.5%).

The standardised rates found in our study were not as high as those found in a study in the NT from 1992 to 2004, also using an 18-month clearance period (647 per 100 000 for Aboriginal residents and 381 per 100 000 for non-Aboriginal residents) (You et al., 2009). The NT study also found that while the non-Aboriginal AMI rates for people aged over 40 years decreased over the study time period, rates increased in non-Aboriginal 20–39 year olds and Aboriginal people aged 20 years and over. The differences in results are not unexpected due to the earlier time period in their study and the higher proportion of people in the NT who live in regional and remote areas, but the definition used to identify incident AMI events was also broader than that used in the current study.

The incidence of AMI in 25–74 year old Aboriginal and non-Aboriginal people (Katzenellenbogen et al., 2010) and the relationship with remoteness (Katzenellenbogen et al., 2012) was examined in WA between 2000 and 2004. The first study found similar results to ours: a greater relative disparity in rates of AMI for younger Aboriginal people and for females, but the magnitude of the disparities was larger. The study had a much longer clearance period (15 years) than ours, but used an ‘ever identified’ method for reporting Aboriginal status. The different analysis method (stratified standardised rates vs multilevel modelling) makes it difficult to directly compare the results by remoteness with our

study. Consistent with our results, the WA study found that AMI incidence for Aboriginal people was higher than for non-Aboriginal people in all remoteness strata. However, in contrast, there was not a clear pattern of increasing disparities for Aboriginal people with increasing remoteness. Comparisons between our findings and those of other Australian studies must be made with caution, not only because of the methodological differences, but also potential differences in culture, geographic distribution of Aboriginal people, and access to and provision of services in different States and Territories.

The higher rate of AMI events in Aboriginal people compared with non-Aboriginal people, particularly in younger age groups, points to the importance of primary care and interventions to prevent the early development of heart disease and contributing conditions such as diabetes. In an audit of randomly selected primary care clients in various locations in Australia, Peiris et al. (2009) identified gaps in the preventive care of Aboriginal Australians: 53% of the sample were not adequately screened for cardiovascular disease (CVD) risk and under-screening was higher in younger age groups. While these health care gaps were similar to those found in non-Aboriginal care settings, improvements are more urgently needed for Aboriginal Australians.

While we found that Aboriginal women had a lower rates of AMI than Aboriginal men, the relative disparity between Aboriginal and non-Aboriginal women was greater than in men. This greater disparity for women was also found in WA for AMI incidence (Katzenellenbogen et al., 2010) and in national data for coronary heart disease prevalence (Penm, 2008). One possible reason for this is the relatively higher rate of smoking and diabetes mellitus in Aboriginal women when compared with non-Aboriginal women (Penm, 2008). However, in research on predicting risk of coronary heart disease using the Framingham Index (which includes both smoking status and whether diabetes has been diagnosed) Wang and Hoy found that risk was particularly under-estimated for Aboriginal women (Wang and Hoy, 2005). The reasons for the greater risk of coronary heart disease for Aboriginal women (relative to non-Aboriginal women) after accounting for known risk factors needs to be further investigated.

Our study found that the SES of the area was a more influential area-level factor than remoteness in explaining variation in rates of first AMI events. Davies et al. (2009) found that area-level SES was influential in explaining differences in AMI rates across areas in Scotland. The possible reasons for the impact of area-level SES on rates include clustering of individuals with certain SES characteristics within areas and the association between individual SES and AMI risk factor prevalence, however, studies that have been able to adjust for individual SES as well as area-level SES have found a unique contribution of the SES of an area to rates of chronic heart disease (Diez Roux et al., 2001; Sundquist et al., 2004).

The higher proportion of Aboriginal people living in more disadvantaged areas where there is a higher rate of AMI did not explain the higher rates of AMI for Aboriginal people overall; rather we found an increase in the disparity with increasing disadvantage. This may point to a higher sensitivity among Aboriginal people to the factors associated with lower SES, such as poverty and lower education levels, which increase the risk of AMI. Another possibility is that there were unmeasured factors specific to Aboriginal people and correlating with SES, such as stress (Brown and Blashki, 2005), experience of racism (Larson et al., 2007) and early life predisposition to cardiovascular disease (McNamara et al., 2012) that increased the risk of AMI for Aboriginal people living in the more disadvantaged areas.

Our small-area analysis identified almost 30 “high rate, high disparity” SLAs, mainly in inner regional and outer regional areas of Northern NSW. These present priority areas for the introduction

of both universal and targeted preventive intervention opportunities and will therefore be disseminated by the study team to the NSW Ministry of Health, the Aboriginal Health and Medical Research Council and other relevant organisations. Further research to characterise these areas may highlight possible reasons for the burden in these areas, such as access to primary prevention services, physical environment, social cohesion and social norms, and point to the types of interventions that are needed. In a study on smoking during pregnancy in WA, Aboriginal women mentioned smoking as a ‘normal’ and accepted behavior (Wood et al., 2008), suggesting that targeting whole communities, and not just individuals, is important in order to reduce individual behaviours such as smoking.

Unfortunately, there is only limited evidence about what interventions are likely to be effective. While longer term outcomes are yet to be assessed, the Audit and Best Practice for Chronic Disease (ABCD) Extension project has shown improvements in delivery of best practice services for prevention, detection and management of chronic diseases within Aboriginal primary health care settings (Schierhout et al., 2010). The Kanyini Vascular Collaboration has a number of research projects underway to evaluate primary and secondary prevention to improve Aboriginal health, including a trial of a polypill (containing low dose aspirin, a statin and two blood pressure lowering medicines) for those at a high risk of cardiovascular disease (Kanyini Vascular Collaboration, 2013). The results of these trials will provide direction for interventions to improve management of cardiovascular risk among Aboriginal people. Implementation research, conducted in partnership with Aboriginal communities, to support the wide-scale adoption of findings from these and other current research projects, is a pressing priority.

## 6. Conclusion

Rates of first AMI events occurring in the 7.5 year study period were higher in Aboriginal compared with non-Aboriginal people. The disparity was greatest in the younger age groups and in females. There was significant variation in overall AMI rates by area that was partly explained by area-level disadvantage. There was also significant geographic variation in Aboriginal AMI rates and the disparity in rates between Aboriginal and non-Aboriginal people, pointing to potential priority areas for implementing universal and targeted preventive interventions.

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## 7. Mortality after AMI admission

### 7.1. Publication details

Randall DA, Jorm LR, Lujic S, O'Loughlin AJ, Churches TR, Haines MM, Eades SJ, Leyland AH. Mortality after admission for acute myocardial infarction in Aboriginal and non-Aboriginal people in New South Wales, Australia: a multilevel data linkage study. *BMC Public Health*. 2012;12(1).

### 7.2. Aims

- To investigate 30- and 365-day mortality after admission for AMI to public hospitals in NSW for Aboriginal and non-Aboriginal people.
- To examine the impact of the hospital of admission on outcomes.

### 7.3. Main findings

- There was no difference in short-term mortality outcomes for Aboriginal people compared with non-Aboriginal people admitted to the same hospital and of the same age, sex, year of admission.
- There were poorer longer-term mortality outcomes for Aboriginal people compared with non-Aboriginal people of the same age, sex, year and hospital of admission.
- The higher longer-term mortality was partly associated with the higher comorbidity burden among Aboriginal people, and did not persist once comorbidities were adjusted for.
- For patients with the same individual characteristics, such as age, sex, and comorbidities, there was an average 34% increase in the odds of dying by attending a hospital with worse mortality outcomes compared with a better performing hospital.
- There was a higher risk of short- and long-term mortality for all patients admitted to smaller, more remote hospitals and hospitals without on-site angiography facilities.



RESEARCH ARTICLE

Open Access

# Mortality after admission for acute myocardial infarction in Aboriginal and non-Aboriginal people in New South Wales, Australia: a multilevel data linkage study

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## Abstract

**Background:** Heart disease is a leading cause of the gap in burden of disease between Aboriginal and non-Aboriginal Australians. Our study investigated short- and long-term mortality after admission for Aboriginal and non-Aboriginal people admitted with acute myocardial infarction (AMI) to public hospitals in New South Wales, Australia, and examined the impact of the hospital of admission on outcomes.

**Methods:** Admission records were linked to mortality records for 60047 patients aged 25–84 years admitted with a diagnosis of AMI between July 2001 and December 2008. Multilevel logistic regression was used to estimate adjusted odds ratios (AOR) for 30- and 365-day all-cause mortality.

**Results:** Aboriginal patients admitted with an AMI were younger than non-Aboriginal patients, and more likely to be admitted to lower volume, remote hospitals without on-site angiography. Adjusting for age, sex, year and hospital, Aboriginal patients had a similar 30-day mortality risk to non-Aboriginal patients (AOR: 1.07; 95% CI 0.83-1.37) but a higher risk of dying within 365 days (AOR: 1.34; 95% CI 1.10-1.63). The latter difference did not persist after adjustment for comorbid conditions (AOR: 1.12; 95% CI 0.91-1.38). Patients admitted to more remote hospitals, those with lower patient volume and those without on-site angiography had increased risk of short and long-term mortality regardless of Aboriginal status.

**Conclusions:** Improving access to larger hospitals and those with specialist cardiac facilities could improve outcomes following AMI for all patients. However, major efforts to boost primary and secondary prevention of AMI are required to reduce the mortality gap between Aboriginal and non-Aboriginal people.

**Keywords:** Hospital performance, Acute myocardial infarction, Ischaemic heart disease, Aboriginal health, Health outcomes, Multilevel modelling, Data linkage

## Background

The health of Aboriginal and Torres Strait Islander Australians is worse than that of other Australians across every conceivable health indicator [1]. The determinants of the disproportionate ill-health among Aboriginal people include higher levels of behavioural, biomedical and psychosocial risk factors, in combination with lesser

access to appropriate health services and lower socio-economic status (SES) [1-5].

While the determinants are complex, the results are clear – Aboriginal Australians have a burden of disease which is two-and-a-half times that of non-Aboriginal Australians [1], and an estimated gap in life expectancy that is greater than that in other developed countries [6]. Ischaemic heart disease (IHD) accounts for 14% of the gap in burden of disease [2], and Aboriginal Australians have higher age-adjusted rates of incidence, hospital admission and mortality for acute myocardial infarction

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(AMI), the acute form of IHD [3,7-9]. While several studies have compared rates of invasive interventions [7,9-11], none has quantified the impact of hospital care on variations in short-term and long-term outcomes for Aboriginal and non-Aboriginal people after admission for AMI.

This study investigated short- and long-term mortality after admission for Aboriginal and non-Aboriginal residents of New South Wales (NSW) admitted to hospital with AMI and also investigated the impact of hospital of admission on outcomes.

## Methods

### Study design

Observational cohort study using linked hospital and mortality data.

### Data sources

The NSW Admitted Patients Data Collection (APDC) includes records for all NSW public and private hospital separations (hospital admissions ending in a discharge, transfer, type-change or death). Patient demographics and multiple diagnoses and procedures are recorded for each separation and coded according to the Australian modification of the International Statistical Classification of Diseases and Related Problems (diagnoses) and the Australian Classification of Health Interventions (procedures) [12]. The NSW Register of Births, Deaths and Marriages (RBDM) captures details of all deaths registered in NSW.

### Probabilistic linkage

The APDC from 1 July 2000 to 31 December 2008 was linked with the RBDM from 1 July 2000 to 31 December 2009. Personal identifiers (including full name, date of birth, sex and address) from the datasets were linked using probabilistic methods by the Centre for Health Record Linkage [13]. The researchers were supplied with de-identified APDC and RBDM data and merged these using a project-specific unique person number.

### Setting

NSW is the most populous state in Australia with an estimated 6.8 million residents in 2006, 2.2% who identify as Aboriginal and/or Torres Strait Islander [14]. Approximately 30% of Australia's Aboriginal peoples live in NSW, the largest percentage of all the States and Territories in Australia. In 2006, 73% of the total NSW population lived in a major city [15] compared with 42% of the NSW Aboriginal population [16]. The median age of Aboriginal people in NSW in 2006 was 20.6 years [17] while the median age for non-Aboriginal people was 38.6 years [18].

### Participants

The participants were NSW residents aged 25 to 84 who were admitted to a public hospital with a primary diagnosis of acute myocardial infarction (AMI, ICD-10-AM code 'I21') or ischaemic heart disease (IHD, ICD-10-AM codes 'I20'-'I25') with a diagnosis of AMI in the second or third diagnosis fields, and where the admission was classified as both 'acute care' and 'emergency'. Only first admissions to public hospitals were included, because the linkage for private hospitals was not of the same quality as for public hospitals. The first such admission in the period July 2001 to December 2008 was chosen as the index admission for analysis, with at least a one-year clearance period for previous admissions for AMI. The cohort thus consisted of cases whose index admission was their first-ever as well as those who had an AMI admission prior to July 2000. A sensitivity analysis excluding previously-admitted cases with clearance periods of between one and four years found no significant difference in the Aboriginal to non-Aboriginal 30-day and 365-day mortality ratios. Patients were excluded if they had missing data or appeared to be duplicate admissions (244 non-Aboriginal and 3 Aboriginal records). The excluded records had the same percentage of deaths within 30 days as the final data set (9%). The final data set included 60047 patients (1183 Aboriginal, 58864 non-Aboriginal) admitted to 174 public hospitals in NSW.

### Analysis variables

The main outcomes were 30-day and 365-day all-cause mortality after hospital admission. The main variable of interest was whether the patient identified as Aboriginal. This was determined based on the standard question, "Are you of Aboriginal or Torres Strait Islander origin?", recorded in the hospital data. In 2007, an audit was conducted and the percentage of Aboriginal and Torres Strait Islander patients correctly identified in NSW public hospitals was estimated to be 88% [19]. While identification is thought to have improved over time, there were no audits previously published for NSW [20]. However, the Australian Institute of Health and Welfare used an under-identification factor of 30% to correct expenditure data for 1998-99 and 2001-02 for NSW hospital data [20]. Probabilistic linkage provided opportunities for identification across the entire admission history for each individual but in the absence of an external source of Aboriginal status to validate identification algorithms, we defined Aboriginal people in our study (Aboriginal and/or Torres Strait Islander) based on the most recent public hospital admission recorded for each person. This was thought to be the most accurate method due to improvements in identification over time [19,20]. A sensitivity analysis was carried out using two alternative

definitions: identified as Aboriginal on every admission ('all admissions') or on at least one admission ('ever identified').

Comorbidities were measured with the Ontario AMI mortality prediction rule (OAMIMPR) [21] conditions, developed in Ontario, Canada for risk adjustment specifically after AMI admission, and were supplemented with additional Charlson Comorbidity Index conditions [22] that had a significant age-, sex- and year-adjusted association with 30-day or 365-day mortality. All comorbidities were collected with a one-year look-back that included any comorbid conditions recorded on the APDC for each person for a full year before the AMI admission as well as on the admission record. Socio-economic status was classified using the ABS Socio-Economic Index for Areas Index of Relative Social Disadvantage (SEIFA IRSD) based on Statistical Local Area (SLA) of residence, and divided into population quintile groups. Remoteness of residence was ascertained using the Accessibility/Remoteness Index of Australia (ARIA+) for SLA of residence, grouped into four categories (major city, inner regional, outer regional and remote/very remote). The hospital of analysis was the first hospital of admission in the AMI admission episode. There were three hospital-level variables: hospital remoteness (ARIA + group of the hospital based on postcode), hospital size (the average number of all acute admissions per year between 2001 and 2008, calculated for each hospital and divided into five groups at the 50th, 75th, 85th and 95th percentiles for hospitals), and the presence or absence of on-site cardiac angiography facilities.

### Statistical analysis

Characteristics of Aboriginal and non-Aboriginal people admitted with AMI were compared using  $\chi^2$  tests. Comorbidities were additionally compared using age-, sex- and year-adjusted prevalence ratios calculated using a log-Poisson model. A series of multilevel logistic regression models with 60047 AMI patients clustered within 174 hospitals investigated: the relative odds of 30-day and 365-day mortality after admission for Aboriginal people compared with non-Aboriginal people with step-wise adjustment of individual and hospital factors; how much of the variation in mortality related to the hospital of admission; what individual characteristics are associated with 30-day and 365-day mortality; and what hospital characteristics might explain residual variation between hospitals. The number of AMI patients per hospital in the final models ranged from 1 to 2691, with a median of 65. Only 5% of hospitals had two or fewer patients. Multilevel modelling accounts for the clustering of patients within hospitals and also partitions the residual variation into the between-hospital variation and within-hospital variation [23]. All multilevel models

had a random intercept allowing the hospital mortality rate to vary, and we also tested random slope models to see if the odds ratio for Aboriginal status varied between hospitals. The hospital-level variance can be expressed as a percentage of the total variance, also called the intraclass correlation coefficient (ICC), or can be converted into a median odds ratio (MOR), which is the median of the odds ratios of pair-wise comparisons of patients with identical characteristics taken from randomly chosen hospitals [24]. Data analyses were carried out using SAS 9.1.3 [25] and MLwiN 2.22 [26].

### Ethics approval

Approval for the study was given by the NSW Population and Health Services Research Ethics Committee, the Aboriginal Health and Medical Research Council of NSW Ethics Committee, and the University of Western Sydney Human Research Ethics Committee.

## Results

### Patient characteristics

Aboriginal patients with AMI were significantly younger than non-Aboriginal patients with just over half of the Aboriginal patients aged 25–54 years compared with only one-fifth of non-Aboriginal patients (Table 1). Aboriginal patients were also more likely to be female, more likely to be living in an area classified as most disadvantaged, and more likely to be living in an outer regional or remote area. Aboriginal patients were significantly less likely to be admitted to a major city hospital, a hospital with 18400 or more average acute admissions per year, or one with on-site angiography facilities. Due to the marked demographic differences, age-, sex- and year-adjusted prevalence ratios were calculated to compare the prevalence of comorbidities. These showed that Aboriginal patients were more likely than non-Aboriginal patients of the same age, sex and year of admission to have acute and chronic renal failure, paraplegia, congestive heart failure, diabetes with complications, and pulmonary disease (Figure 1).

### Short- and long-term mortality after admission

Of the 1183 Aboriginal patients admitted with AMI, 70 died within 30 days of admission (5.9%) and 127 died within one year of admission (10.7%). Of the 58864 non-Aboriginal patients admitted with AMI, 5474 died within 30 days (9.3%) and 9148 died within one year (15.2%). When accounting only for hospital of admission through the random intercept multilevel model, Aboriginal patients with AMI had lower odds of dying within 30 days than non-Aboriginal patients (odds ratio (OR) 0.61; 95% CI 0.48-0.78; Table 2, Model 1A). However, after adjusting for age, sex and year of admission there was no significant difference in 30-day mortality

**Table 1 Individual and hospital characteristics of Aboriginal and non-Aboriginal people admitted with acute myocardial infarction**

	Aboriginal (n = 1183)		Non-Aboriginal (n = 58877)		$\chi^2$ p-value
	N	%	N	%	
<b>Individual characteristic</b>					
Age group					
25-34	47	4.0	421	0.7	<.001
35-44	257	21.7	2829	4.8	
45-54	360	30.4	8579	14.6	
55-64	265	22.4	13144	22.3	
65-74	180	15.2	15410	26.2	
75-84	74	6.3	18481	31.4	
Sex					
Male	727	61.5	39950	67.9	<.001
Female	456	38.5	18914	32.1	
Comorbid conditions <sup>a</sup>					
Diabetes with complications	279	23.6	8903	15.1	<.001
Cardiac dysrhythmias	185	15.6	12539	21.3	<.001
Congestive heart failure	154	13.0	8350	14.2	.254
Pulmonary disease	136	11.5	5236	8.9	.002
Chronic renal failure	96	8.1	4143	7.0	.152
Acute renal failure	47	4.0	2729	4.6	.282
Cerebrovascular disease	36	3.0	2552	4.3	.030
Paraplegia	25	2.1	1341	2.3	.707
Cancer	15	1.3	1773	3.0	0.01
Peripheral vascular disease	12	1.0	1108	1.9	.029
Shock	11	0.9	1195	2.0	.008
Pulmonary oedema	9	0.8	685	1.2	.199
Connective tissue disorder	8	0.7	743	1.3	.073
Dementia	5	0.4	506	0.9	.105
Severe liver disease	2	0.2	103	0.2	.962
Liver disease	1	0.1	113	0.2	.615
Socio-economic status <sup>b</sup>					
1 <sup>st</sup> quintile - least disadvantaged	23	1.9	7832	13.3	<.001
2 <sup>nd</sup> quintile	109	9.2	9946	16.9	
3 <sup>rd</sup> quintile	186	15.7	12726	21.6	
4 <sup>th</sup> quintile	299	25.3	13102	22.3	
5 <sup>th</sup> quintile - most disadvantaged	566	47.8	15258	25.9	

**Table 1 Individual and hospital characteristics of Aboriginal and non-Aboriginal people admitted with acute myocardial infarction (Continued)**

Remoteness of residence <sup>c</sup>					
Major city	307	26.0	34695	58.9	<.001
Inner regional	359	30.3	16319	27.7	
Outer regional	366	30.9	7300	12.4	
Remote/very remote	151	12.8	550	0.9	
<b>Hospital characteristic</b>					
Remoteness of hospital <sup>c</sup>					
Major city	389	32.9	39456	67.0	<.001
Inner regional	247	20.9	11384	19.3	
Outer regional	414	35.0	7297	12.4	
Remote/very remote	133	11.2	726	1.2	
Average acute admissions per year					
Less than 1200	88	7.4	1245	2.1	<.001
1200-3899	182	15.4	3730	6.3	
3900-7084	138	11.7	3842	6.5	
7085-18399	443	37.4	19977	33.9	
18400 or more	332	28.1	30070	51.1	
On-site angiography					
Yes	315	26.6	25694	43.6	<.001
No	868	73.4	33170	56.4	

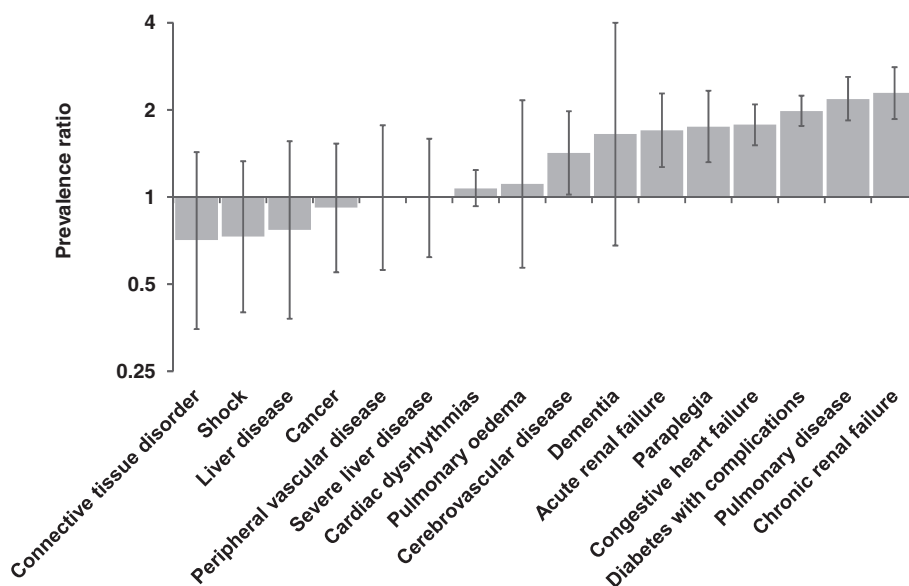
<sup>a</sup> Comorbid conditions with one-year look-back, including comorbidities on current admission and any admissions in the previous year.

<sup>b</sup> Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

<sup>c</sup> Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence for individuals or hospital postcode for hospitals.

between Aboriginal and non-Aboriginal AMI patients (AOR 1.07; 95% CI 0.83-1.37; Model 2A). Accounting for comorbidities, remoteness of residence, and socio-economic status (Model 5A) reduced the adjusted odds ratio to 0.95 (0.73-1.23), indicating no significant difference in 30-day mortality. A random slope effect for Aboriginal status was tested, but there was no significant variation in the Aboriginal to non-Aboriginal 30-day mortality ratio across hospitals.

The unadjusted results for 365-day mortality were similar to the 30-day model: Aboriginal patients were less likely to die within 365 days of admission than non-Aboriginal patients admitted to the same hospital (OR 0.64; 95% CI 0.53-0.77; Table 2, Model 1B). However, after adjusting for age, sex, and year of admission, Aboriginal patients had significantly higher odds of dying within 365 days than non-Aboriginal patients admitted to the same hospital (AOR 1.34, 95% CI 1.10-1.63; Model 2B). Again, there was no random slope effect for Aboriginal status in this model. After comorbidities were accounted for there was no longer a significant



**Figure 1** Relative adjusted prevalence of comorbidities for Aboriginal compared with non-Aboriginal people with AMI. Prevalence ratio adjusted for age, sex and year of admission, for Aboriginal compared with non-Aboriginal people with AMI. A value over 1 indicates that Aboriginal people have a higher prevalence of the condition, and a value under 1 indicates that non-Aboriginal people have a higher prevalence. Comorbid conditions calculated with one-year look-back, including comorbidities on current admission and any admissions in the previous year.

difference between Aboriginal and non-Aboriginal 365-day mortality (AOR 1.12, 95% CI 0.91-1.38; Model 3B).

In the fully-adjusted individual-level model for 30-day mortality (Model 5A), the percentage of unexplained variation due to the hospital of admission (or the Intra-class correlation coefficient) was 2.72%. This can be expressed as a median odds ratio (MOR) of 1.34. In the fully-adjusted 365-day mortality model (Model 5B), the hospital of admission accounted for 2.58% of the unexplained variation in the outcome (MOR 1.33).

Table 3 shows odds ratios for selected individual covariates from the fully-adjusted individual-level models (Models 5A and 5B). There were no significant differences in 30-day or 365-day mortality between males and females. Older age was strongly related to both 30-day and 365-day mortality. Area of residence was not a significant predictor of 30-day or 365-day mortality, but remoteness was already being largely accounted for by adjusting for hospital of admission. Living in an area classified as the most disadvantaged was associated with higher 30-day mortality, and there was higher 365-day mortality in all the more disadvantaged quintiles compared with the least disadvantaged group. Of the comorbidities included in the model, shock was most strongly related to risk of mortality, particularly 30-day mortality. Severe liver disease, cardiac dysrhythmias, dementia, cancer and acute renal failure were associated with at least a doubling in the odds of dying within 30

and 365 days of admission. Most of the other comorbidities were significantly associated with an increased risk of either 30-day or 365-day mortality. Diabetes with complications was related to a slightly lower risk of 30-day mortality but a slightly higher risk of 365-day mortality.

Table 4 shows the relative odds of 30-day and 365-day mortality for the hospital characteristics, added one at a time to the fully adjusted individual-level model. Hospital remoteness was a significant predictor of both 30-day and 365-day mortality; those patients admitted to an outer regional or a remote hospital had significantly higher odds of mortality than those admitted to a major city hospital. Those admitted to hospitals with 7084 or less acute patients per year had higher odds of both 30-day and 365-day mortality than those admitted to hospitals with higher numbers of acute admissions per year and there was a significant trend across groups ( $P < 0.001$  for both 30-day and 365-day models). Those admitted to a hospital with on-site angiography had lower odds of 30-day and 365-day mortality than those admitted to a hospital without these facilities. When all three hospital level variables were added they accounted for 37% of the hospital level variation in both the 30-day and 365-day mortality models.

#### Sensitivity analysis

The two alternative classifications for Aboriginal status, 'ever identified' and 'all admissions', identified 1479

**Table 2 Relative odds of 30-day and 365-day mortality for Aboriginal compared with non-Aboriginal people with stepwise adjustment for covariates**

30-day mortality models				
Model	Adjusted for:	OR	95% CI	p-value
1A	Hospital of admission <sup>a</sup>	0.61	0.48-0.78	<.001
<b>Individual covariates</b>				
2A	+ Age group, sex, year of admission	1.07	0.83-1.37	.612
3A	+ Comorbid conditions <sup>b</sup>	0.98	0.76-1.27	.886
4A	+ Remoteness of residence <sup>c</sup>	0.95	0.73-1.24	.728
5A	+ Socio-economic status <sup>d</sup>	0.95	0.73-1.23	.684
<b>Hospital covariates<sup>e</sup></b>				
6A	+ Remoteness of hospital <sup>c</sup>	0.94	0.72-1.22	.617
7A	+ Average acute admissions per year (- Remoteness of hospital)	0.95	0.73-1.23	.676
8A	+ On-site angiography (- Average acute admissions per year)	0.94	0.73-1.23	.665
365-day mortality models				
Model	Adjusted for:	OR	95% CI	p-value
1B	Hospital of admission <sup>a</sup>	0.64	0.53-0.77	<.001
<b>Individual covariates</b>				
2B	+ Age group, sex, year of admission	1.34	1.10-1.63	.003
3B	+ Comorbid conditions <sup>b</sup>	1.12	0.91-1.38	.282
4B	+ Remoteness of residence <sup>c</sup>	1.11	0.90-1.37	.317
5B	+ Socio-economic status <sup>d</sup>	1.11	0.90-1.36	.345
<b>Hospital covariates<sup>e</sup></b>				
6B	+ Remoteness of hospital <sup>c</sup>	1.09	0.89-1.35	.401
7B	+ Average acute admissions per year (- Remoteness of hospital)	1.11	0.90-1.36	.336
8B	+ On-site angiography (- Average acute admissions per year)	1.10	0.90-1.36	.350

OR, odds ratio; CI, confidence interval.

<sup>a</sup> Hospital of admission adjusted for in a two-level random intercept model with patients nested within hospitals.

<sup>b</sup> Comorbid conditions with one-year look-back, including comorbidities on current admission and any admissions in the previous year.

<sup>c</sup> Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence for individuals or hospital postcode for hospitals.

<sup>d</sup> Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

<sup>e</sup> Hospital covariates added one at a time to the adjusted models.

(2.5%) and 631 (1.1%) AMI patients as Aboriginal, respectively, compared with the 'most recent' which identified 1183 (2.0%) of patients as Aboriginal. When entered into the fully-adjusted individual-level models, the 'ever identified' definition produced similar results to the 'most recent' definition, but the 'all admissions' definition resulted in higher odds of both 30-day and 365-day mortality for Aboriginal compared with non-Aboriginal patients (Table 5).

## Discussion

Our study is, to the best of our knowledge, the first to investigate disparities in mortality outcomes between Aboriginal and non-Aboriginal people after admission for AMI in NSW, home to 30% of Australia's Aboriginal population [14]. The overall population size and the large number of Aboriginal people residing in NSW made it

possible to use multilevel modelling to examine mortality outcomes, and it is the first study of AMI hospital outcomes nationally to account for clustering of patients within hospitals and to quantify the contribution of the admitting hospital to variation in mortality outcomes.

Aboriginal and non-Aboriginal people with AMI admitted to NSW hospitals were very different. Aboriginal patients were younger, more likely to live outside of major centres and in disadvantaged areas, and more likely to be admitted to lower volume hospitals outside major centres and those without on-site angiography facilities. After adjusting for age, sex and year, they were more likely to present with comorbid conditions, including acute and chronic renal failure, diabetes, congestive heart failure and pulmonary disease. Aboriginal people in Australia have a younger age distribution than non-Aboriginal people, so it is not unexpected that

**Table 3 Adjusted odds ratios for selected individual covariates for 30-day and 365-day mortality multilevel models**

	30-day mortality			365-day mortality		
	AOR	95% CI	p-value	AOR	95% CI	p-value
Sex						
Male (ref)	1.00		.211	1.00		.853
Female	1.04	0.98-1.11		1.01	0.95-1.06	
Age group						
25-34	1.20	0.79-1.83	<.001	0.92	0.61-1.37	<.001
35-44	0.73	0.59-0.91		0.58	0.48-0.72	
45-54	0.80	0.70-0.92		0.74	0.66-0.83	
55-64 (ref)	1.00			1.00		
65-74	1.52	1.38-1.68		1.70	1.57-1.85	
75-84	2.30	2.10-2.53		3.09	2.86-3.34	
Comorbid conditions <sup>a</sup>						
Shock	11.54	10.12-13.16	<.001	7.94	6.94-9.09	<.001
Severe liver disease	3.80	2.36-6.11	<.001	2.60	1.63-4.17	<.001
Cardiac dysrhythmias	2.69	2.53-2.86	<.001	2.18	2.06-2.30	<.001
Dementia	2.30	1.87-2.84	<.001	2.72	2.25-3.30	<.001
Cancer	2.18	1.92-2.47	<.001	4.45	4.00-4.95	<.001
Acute renal failure	2.02	1.82-2.25	<.001	2.00	1.82-2.19	<.001
Cerebrovascular disease	1.53	1.33-1.77	<.001	1.47	1.29-1.66	<.001
Peripheral vascular disease	1.32	1.11-1.57	<.001	1.30	1.12-1.51	<.001
Pulmonary disease	1.25	1.14-1.37	<.001	1.56	1.45-1.67	<.001
Pulmonary oedema	1.22	0.99-1.51	.056	1.50	1.26-1.80	<.001
Congestive heart failure	1.20	1.12-1.30	<.001	1.81	1.70-1.92	<.001
Paraplegia	1.08	0.89-1.31	.424	1.43	1.21-1.69	<.001
Chronic renal failure	1.06	0.95-1.17	.282	1.56	1.44-1.70	<.001
Liver disease	0.97	0.55-1.69	.913	2.42	1.55-3.79	<.001
Diabetes with complications	0.89	0.82-0.97	.007	1.10	1.03-1.18	.003
Connective tissue disorder	0.81	0.62-1.04	.096	1.18	0.97-1.43	.090
Remoteness of residence <sup>b</sup>						
Major city (ref)	1.00		.223	1.00		.685
Inner regional	0.95	0.86-1.06		0.95	0.87-1.04	
Outer regional	1.08	0.94-1.24		1.00	0.89-1.12	
Remote/very remote	1.16	0.84-1.58		0.96	0.73-1.27	
Socio-economic status <sup>c</sup>						
1 <sup>st</sup> quintile - least disadvantaged (ref)	1.00		.033	1.00		<.001
2 <sup>nd</sup> quintile	1.15	0.99-1.32		1.11	0.98-1.25	
3 <sup>rd</sup> quintile	1.10	0.95-1.28		1.18	1.04-1.34	
4 <sup>th</sup> quintile	1.17	1.00-1.36		1.23	1.08-1.39	
5 <sup>th</sup> quintile - most disadvantaged	1.27	1.08-1.48		1.32	1.16-1.51	

Adjusted odds ratios for selected covariates from Model 5A for 30-day mortality and Model 5B for 365-day mortality.

AOR, adjusted odds ratio; CI, confidence interval; Ref, referent group in the analysis.

<sup>a</sup> Comorbid conditions with one-year look-back, including comorbidities on current admission and any admissions in the previous year.

<sup>b</sup> Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence.

<sup>c</sup> Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

**Table 4 Adjusted odds ratios for selected hospital covariates for 30-day and 365-day mortality multilevel models**

	30-day mortality			365-day mortality		
	AOR	95% CI	p-value	AOR	95% CI	p-value
<b>Added into adjusted<sup>a</sup> model separately</b>						
Remoteness of hospital <sup>b</sup>						
Major city (ref)	1.00		<.001	1.00		<.001
Inner regional	1.15	0.94-1.41		1.16	0.97-1.39	
Outer regional	1.56	1.26-1.94		1.54	1.27-1.87	
Remote/very remote	1.83	1.19-2.81		1.79	1.22-2.61	
Average acute admissions per year						
Less than 1200	2.03	1.57-2.62	<.001	1.98	1.58-2.49	<.001
1200-3899	1.72	1.39-2.13		1.55	1.28-1.88	
3900-7084	1.36	1.08-1.70		1.32	1.07-1.62	
7085-18399	1.14	0.96-1.35		1.14	0.97-1.34	
18400 or more (ref)	1.00			1.00		
On-site angiography						
Yes	0.74	0.64-0.86	<.001	0.72	0.63-0.83	<.001
No (ref)	1.00			1.00		

AOR, adjusted odds ratios; CI, confidence interval. Ref, referent group in the analysis.

<sup>a</sup> Adjusted for Aboriginal status, age, sex, year of admission, comorbidities, remoteness of residence, socio-economic status, and a random hospital intercept, with hospital covariates added in one at a time to the model.

<sup>b</sup> Accessibility/Remoteness Index of Australia (ARIA+) based on hospital postcode.

Aboriginal people admitted with AMI would be younger; however, higher age-specific incidence of AMI particularly among younger Aboriginal people was recently reported by a study in Western Australia (WA) [8]. These findings and ours point to the importance of targeting the early onset of AMI among Aboriginal people and preventing or managing chronic diseases that may complicate treatment or lead to poorer long-term outcomes.

Our study found that once admitted to hospital, Aboriginal patients with AMI were less likely to die within 30 days than non-Aboriginal patients admitted to the same hospital (Table 2, Model 1A). However, this finding was explained by substantial age differences: after adjusting for age, sex and year of admission, the differences in 30-day mortality was no longer significant (Model 2A). In contrast, after adjusting for age, sex and year, Aboriginal patients had 34% higher odds of dying within one year compared with non-Aboriginal patients admitted to the same hospital (Model 2B). However, this difference was no longer significant after adjusting for selected comorbidities (Model 3B), suggesting that part of the higher one-year mortality is due to the higher comorbidity burden among Aboriginal people admitted with AMI.

Our findings regarding short-term mortality differed from those of the WA study, which reported higher post-admission 28-day mortality ratios for Aboriginal compared with non-Aboriginal patients, ranging from 1.7 in 55–

74 year-old males and females to 3.6 in 25–54 year old males [8]. This discrepancy might relate to the different profile of the WA Aboriginal population (41% resident in remote or very remote areas, compared with 5% in NSW) [18], and differences in study methodology (the WA study did not account for hospital of admission).

For longer-term mortality, our findings were similar to those of a Queensland study that reported an age-adjusted risk ratio of 1.8 (95% CI, 1.5-2.2) for 365-day mortality in Aboriginal patients with AMI after admission to Queensland public hospitals [10]. We found that the significantly higher one-year mortality for Aboriginal patients did not persist after adjusting for comorbidities, but a recent study in WA found significantly higher rates of two-year cardiovascular death or recurrent AMI for Aboriginal compared with non-Aboriginal males and females after adjusting for demographic characteristics and comorbidities [27]. These findings may suggest that the Aboriginal to non-Aboriginal disparity in mortality is greater in WA than in NSW. However, it is difficult to compare these findings directly because our study had a shorter length of follow-up for all-cause mortality, adjusted for hospital of admission, and did not examine mortality and recurrent AMI as a combined outcome. An increase in the Aboriginal to non-Aboriginal mortality ratio with increasing time after discharge has been shown in the Northern Territory for those admitted with acute coronary syndrome and surviving to discharge,



**Table 5 Relative odds of 30-day and 365-day mortality by different algorithms for identifying Aboriginal people in the hospital data**

	30-day mortality			365-day mortality		
	AOR	(95% CI)	p-value	AOR	(95% CI)	p-value
Most recent <sup>a</sup>						
Non-Aboriginal (ref)	1.00		.684	1.00		.345
Aboriginal	0.95	0.73-1.23		1.11	0.90-1.36	
Ever identified <sup>b</sup>						
Non-Aboriginal (ref)	1.00		.582	1.00		.510
Aboriginal	0.94	0.74-1.18		1.06	0.88-1.28	
All admissions <sup>c</sup>						
Non-Aboriginal (ref)	1.00		.005	1.00		<.001
Aboriginal	1.55	1.14-2.10		1.61	1.25-2.07	

AOR, adjusted odds ratios, adjusting for age, sex, year of admission, comorbidities, remoteness of residence, socio-economic status.

CI, confidence interval. Ref, referent group in the analysis.

<sup>a</sup> Identified as Aboriginal in their most recent public hospital admission.

<sup>b</sup> Identified as Aboriginal in at least one public hospital admission.

<sup>c</sup> Identified as Aboriginal on all public hospital admissions.

with the disparities in mortality appearing at six months and Aboriginal patients being about three times more likely to die than non-Aboriginal patients after four years [28]. However, caution must be taken when comparing Aboriginal peoples across Australia due to the differences in culture, geographic distribution, and access to and provision of services.

Our study showed that differences between hospitals impacted on mortality outcomes for both Aboriginal and non-Aboriginal patients. After adjustment for patient factors, 2.72% of the remaining variation in 30-day mortality was attributable to differences between hospitals. This equates to a median odds ratio of 1.34, indicating a median difference of 34% in the odds of dying between randomly chosen pairs of hospitals. Almost 40% of this hospital-level contribution to variation in mortality was explained by hospital remoteness, hospital size and cardiac facilities. Patients admitted to smaller hospitals, and those in outer regional and remote areas, had a higher risk of short-term mortality, while patients admitted to a hospital with on-site angiography facilities had a reduced risk of dying. Recently, in the United States, condition-specific hospital volume was shown to be related to 30-day post-admission mortality after AMI, up to a threshold value, which was lower for hospitals with cardiac revascularisation services (432 vs 586 AMI admissions/year) [29]. A Canadian study also found that admission to hospitals with on-site revascularisation facilities was related to improved long-term outcomes after AMI [30]. However, our findings regarding the specific impact of hospital size, remoteness and on-site angiography facilities on outcomes should be interpreted with caution, as these variables may be correlated with other unmeasured aspects of hospital

quality of care. We found no variation in the Aboriginal to non-Aboriginal mortality ratio (both short- and long-term) across hospitals.

There were limitations to our study due to using administrative data not collected for research purposes. Firstly, there was limited clinical information in the hospital data for risk adjustment; however, we used the conditions adjusted for in the Ontario AMI Mortality Risk Prediction Rule developed in Canada for use with AMI and administrative hospital data [21] and supplemented this with additional conditions from the Charlson Comorbidity Index [22]. Secondly, we were not able to remove all prevalent cases from our study because there were only a total of eight and a half years of linked data available. We did, however, test various clearance periods of up to four years and found that the Aboriginal to non-Aboriginal age- and sex-adjusted mortality ratios did not appear sensitive to the length of the clearance period. Thirdly, our sensitivity analysis using different algorithms for identifying Aboriginal people highlighted the potential for apparent disparities to be influenced by how Aboriginal status is defined. The strict definition requiring patients to be identified as Aboriginal at every hospital admission identified only 1% of admissions as Aboriginal which is half as many as the 'most recent' algorithm but generated higher relative odds of Aboriginal mortality. This may be because those people consistently identified as Aboriginal in the APDC have poorer health than Aboriginal people not consistently identified, but it may also be because the definition included a greater proportion with only a single admission, possibly skewing the sample towards people who died post-AMI. Lastly, we did not include deaths from AMI that

occurred before the patient was admitted to hospital, either sudden death or death in ambulance or Emergency Department. It is possible that Aboriginal people would be overrepresented in these early deaths from AMI, due to higher comorbidity rates or living a greater distance from the nearest hospital, but this was outside the scope of our study examining outcomes after hospital admission.

Our study and others point to the importance of prevention and early intervention to target the early onset of AMI among Aboriginal Australians. These efforts must target risk factor prevalence among Aboriginal people, including higher rates of smoking and overweight and obesity, and the earlier onset of comorbidities like diabetes and renal failure [1]. However, poor health behaviours may be a way of coping for people living under chronically stressful conditions, so psychosocial and emotional factors must also be taken into account [31,32]. Importantly, our study has demonstrated that there are gains to be made—both for Aboriginal and non-Aboriginal people—by improving access to larger hospitals and hospitals with on-site angiography or by improving the cardiac care facilities at smaller hospitals.

The population density and geographic distances in Australia pose difficult policy questions about whether it is best to transfer patients as quickly as possible to major city hospitals or whether it is efficient to increase services in less densely populated areas. Our results showed that the difference in outcomes for inner regional compared with major city hospitals was small and not significant, so boosting resources in regional centres may reduce the difference altogether, and reduce travel times to cardiac facilities for those living in regional and remote areas. One challenge is to ensure that any interventions are culturally appropriate for Aboriginal patients. While transfers can be very stressful for Aboriginal people living in remote areas, an action research study concluded that small interventions such as having dedicated liaison officers in the health system could improve cultural awareness of practitioners as well as communication and continuity of care and improve outcomes for Aboriginal patients [33].

The higher mortality among Aboriginal patients in the first year after admission also highlights the importance of improved post-AMI care including appropriate medication and lifestyle interventions. This period after discharge warrants further investigation to disentangle the impacts on mortality of comorbidity burden and differences in access to, or adherence with, follow-up care and secondary prevention.

## Conclusions

Improving access to larger hospitals or those with specialist treatment facilities could improve outcomes following

AMI for residents of rural and regional areas, both Aboriginal and non-Aboriginal. However, major efforts to boost primary and secondary prevention of AMI are required to reduce the mortality gap between Aboriginal and non-Aboriginal people.

## Competing interests

The authors declare that they have no competing interest.

## Authors' contributions

DR had overall responsibility for the design of this study, data management, statistical analysis and drafting this paper. LJ initiated the IHOPE project and provided overall oversight. LJ, SL, TC, MH, SE and AL contributed to the conception and design of the IHOPE project. SL provided advice on data management and statistical analysis. AO provided advice on clinical aspects and on hospital levels of service. AL provided oversight and advice for the design and interpretation of the statistical analyses. All authors contributed to the interpretation of findings, the writing of the paper and approved the final draft.

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## 8. Revascularisation after AMI

### 8.1. Publication details

Randall DA, Jorm LR, Lujic S, O'Loughlin AJ, Eades SJ, Leyland AH. Disparities in revascularization rates after acute myocardial infarction between Aboriginal and non-Aboriginal people in Australia. *Circulation*. 2013;127:811-9.

### 8.2. Aims

- To examine revascularisation rates after AMI for Aboriginal and non-Aboriginal patients admitted to public hospitals in NSW, accounting for hospital of first admission.
- To investigate the relative impact of individual and hospital factors on rates of revascularisation by sequentially controlling for risk factors.

### 8.3. Main findings

- There were lower rates of revascularisation for Aboriginal people compared with non-Aboriginal people of the same age, sex and AMI type, even within the same hospital.
- Aboriginal people were more likely to have certain comorbidities like diabetes and renal failure that were associated with lower rates of revascularisation; once these were accounted for, the disparity in revascularisation rates between Aboriginal and non-Aboriginal people reduced.
- Hospitals varied markedly in revascularisation rates, and this variation was associated with hospital size, remoteness, and catheterization laboratory facilities.

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## Disparities in Revascularization Rates After Acute Myocardial Infarction Between Aboriginal and Non-Aboriginal People in Australia

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**Background**—This study examined revascularization rates after acute myocardial infarction (AMI) for Aboriginal and non-Aboriginal patients sequentially controlling for admitting hospital and risk factors.

**Methods and Results**—Hospital data from the state of New South Wales, Australia (July 2000 through December 2008) were linked to mortality data (July 2000 through December 2009). The study sample were all people aged 25 to 84 years admitted to public hospitals with a diagnosis of AMI (n=59 282). Single level and multilevel Cox regression was used to estimate rates of revascularization within 30 days of admission. A third (32.9%) of Aboriginal AMI patients had a revascularization within 30 days compared with 39.7% non-Aboriginal patients. Aboriginal patients had a revascularization rate 37% lower than non-Aboriginal patients of the same age, sex, year of admission, and AMI type (adjusted hazard ratio, 0.63; 95% confidence interval, 0.57–0.70). Within the same hospital, however, Aboriginal patients had a revascularization rate 18% lower (adjusted hazard ratio, 0.82; 95% confidence interval, 0.74–0.91). Accounting for comorbidities, substance use and private health insurance further explained the disparity (adjusted hazard ratio, 0.96; 95% confidence interval, 0.87–1.07). Hospitals varied markedly in procedure rates, and this variation was associated with hospital size, remoteness, and catheterization laboratory facilities.

**Conclusions**—Aboriginal Australians were less likely to have revascularization procedures after AMI than non-Aboriginal Australians, and this was largely explained by lower revascularization rates at the hospital of first admission for all patients admitted to smaller regional and rural hospitals, a higher comorbidity burden for Aboriginal people, and to a lesser extent a lower rate of private health insurance among Aboriginal patients. (*Circulation*. 2013;127:811-819.)

**Key words:** acute myocardial infarction ■ ethnic groups ■ health care disparities ■ health services accessibility ■ myocardial revascularization

Mortality rates from acute myocardial infarction (AMI) have been declining since the 1980s in Australia and other Western countries, driven both by declines in event rates and case fatality rates.<sup>1,2</sup> However, these declines may not have benefitted all population groups equally. Australia's Aboriginal and Torres Strait Islander peoples experience a significant health gap compared with other Australians and ischemic heart disease is a leading contributor to this gap.<sup>3</sup> Age-adjusted case fatality after AMI has been estimated to be 1.5 times higher for Aboriginal people compared with other Australians.<sup>4</sup> To improve case fatality and mortality rates and improve the gap in burden of disease it is important that Aboriginal patients receive the best possible treatment in hospital after admission for AMI.

Racial, ethnic, and socioeconomic disparities in revascularization rates after AMI have been demonstrated in a number of studies in the United States of America (USA), Europe, and Australia.<sup>5–13</sup> In Australia, despite the universal health care system, Aboriginal people have fewer cardiovascular procedures than other Australians<sup>14</sup> and lower adjusted rates of revascularization after AMI.<sup>12</sup> However, the population distribution of Aboriginal people means that they are more likely than non-Aboriginal people to be admitted to smaller, regional hospitals that may not have the facilities to perform revascularization, so it is important to properly account for this in an analysis of revascularization rates.

Few studies in this area have used modelling techniques to adjust for hospital-level effects<sup>6</sup> or clustering of patients within hospitals,<sup>8</sup> and this is the first Australian study to account for such clustering and examine the influence of hospitals on the

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disparity in revascularization rates for Aboriginal and non-Aboriginal patients.

Using linked data and multilevel modelling, this study aimed to (1) compare rates of revascularization procedures between Aboriginal and non-Aboriginal patients admitted with AMI, (2) quantify the influence of the admitting hospital on differences in revascularization rates; and (3) explore the role of patient and hospital factors in any disparities.

## Methods

### Study Design

The study was an observational cohort study using linked population-based administrative data sets.

### Setting

Australia has a universal health care system with free public acute hospital services and a large private sector including private hospitals and private care within the public hospitals.<sup>15</sup> New South Wales (NSW) is the most populous state in Australia with 6.8 million residents in 2006, 2.2% of whom identified as Aboriginal or Torres Strait Islander.<sup>16</sup> Approximately 30% of Australia's Aboriginal peoples live in NSW, the largest percentage of the States and Territories in Australia.<sup>16</sup> In 2006, 73% of the total NSW population lived in a major city<sup>17</sup> compared with 42% of the Aboriginal population.<sup>18</sup>

### Data Sources

The NSW Admitted Patient Data Collection from July 1, 2000 to December 31, 2008 was linked to mortality data for the same period. The Admitted Patient Data Collection includes all public and private hospital admissions ending in a discharge, transfer, type-change, or death. Diagnoses were coded according to the Australian modification of the International Statistical Classification of Diseases and Related Problems 10<sup>th</sup> Revision (ICD-10-AM, introduced in July 1998) and procedures according to the Australian Classification of Health Interventions.<sup>19</sup> The datasets were linked probabilistically using identifying fields by an independent third party organization, the Center for Health Record Linkage,<sup>20</sup> and researchers were supplied with deidentified records including a project-specific person number.

### Study Sample

The study sample subjects were all NSW residents aged 25 to 84 years who were first admitted to a public hospital in NSW with an admission classified as both acute care and emergency and with a primary diagnosis of AMI (ICD-10-AM I21) or an AMI recorded in the second or third diagnosis field along with a primary diagnosis of ischemic heart disease (ICD-10-AM I20–I25). The first such admission in the period July 2001 to November 2008 was chosen as the index admission for analysis, leaving a clearance period of at least 12 months and follow-up of 30 days. It was not possible to exclude all prevalent cases of AMI, because of the limited years of linked data available, and thus the cohort consisted of patients with their first ever AMI admission and those who may have had an AMI admission before July 2000. Patients were excluded if they had missing data for key variables (n=241), inconsistent date of death or procedure (n=17), or appeared to be duplicate admissions (n=5). The final data set included a total of 59 282 patients (n=1165 Aboriginal and n=58 117 non-Aboriginal) who were first admitted to 174 public hospitals.

### Variables

Patients were followed in the dataset after their index AMI admission to determine whether they received a revascularization procedure (ie, a percutaneous coronary intervention [PCI] or a coronary artery bypass graft [CABG]) within 30 days, at any hospital (public or private) in NSW. The time to first angiography procedure was also recorded, with the assumption that all those with a revascularization recorded

had an angiography procedure at the same time, if not separately recorded. The main explanatory variable of interest was whether the patient was Aboriginal or Torres Strait Islander (referred to as Aboriginal), which is routinely recorded in the hospital data. A recent audit of the Australian hospital data estimated that Aboriginal people are correctly identified on 88% of admissions in NSW public hospitals.<sup>21</sup> To enhance identification, we defined a person as Aboriginal based on their most recent admission. This enhanced the number of admissions identified as Aboriginal by 10% in the total hospital data.

Other variables of interest were as follows: age, sex, AMI type, comorbidities, private health insurance, substance use, remoteness, socio-economic status (SES), and hospital characteristics. AMI type was divided into ST-elevated myocardial infarction (ICD-10-AM I21.0–I21.3), non–ST-elevated myocardial infarction (I21.4), and unspecified (I21.9). The comorbidities included in the models were those that may impact on provision of revascularization procedures or outcomes after AMI, as determined by a literature search: shock, diabetes mellitus with complications, congestive heart failure, cancer, cerebrovascular disease, pulmonary edema, acute renal failure, chronic renal failure, cardiac dysrhythmias;<sup>22</sup> and chronic obstructive pulmonary disease, diabetes mellitus without complications, and depression.<sup>8</sup> Comorbidities and substance use (current smoking status [ICD-10-AM F17.1, F17.2, Z72.0] and alcohol and drug abuse)<sup>23</sup> were collated from all secondary diagnosis codes recorded at the index admission and from any diagnosis field in linked hospital admissions up to 12 months prior. Patients were identified as having private health insurance if they had private payment status or private insurance status recorded on the index AMI admission or any admission up to 12 months prior.

Remoteness of residence was classified according to the Accessibility/Remoteness Index of Australia (ARIA+) score for each person's Statistical Local Area of residence at the time of index admission. ARIA+ measures remoteness based on the road distance to 5 categories of service centers that are classified according to their population size as a proxy for availability of services.<sup>24</sup> SES was determined using the Australian Bureau of Statistics Socio-Economic Index for Areas Index of Relative Socioeconomic Disadvantage (SEIFA IRSD, divided into population quintiles) assigned to the Statistical Local Area of residence at the time of admission.<sup>25</sup> Three hospital-level variables were hospital remoteness (ARIA+ of the hospital based on postcode area), hospital size (average number of total acute admissions per year from 2001–2008 divided into 5 groups at the 50<sup>th</sup>, 75<sup>th</sup>, 85<sup>th</sup> and 95<sup>th</sup> percentiles for hospitals), and the level of catheterization facilities available (24/7 catheterization laboratory, catheterization laboratory but not 24/7, or no catheterization laboratory). Finally, a flag for those hospitals transferring >10% of their AMI patients to an interstate hospital (ie, smaller hospitals near the State border) was included to correct for any bias resulting from differential rates of interstate transfer, and also to better quantify the variation in revascularization rates between NSW hospitals.

### Statistical Analysis

Characteristics of Aboriginal and non-Aboriginal AMI patients, and of the admission and hospital, were compared using  $\chi^2$  tests. Because of the differences in the demographic profile of Aboriginal and non-Aboriginal people, particularly by age, the prevalence of comorbidities among Aboriginal and non-Aboriginal patients as determined from the admission record and any admission in the previous year was compared using age-, sex-, and year-adjusted prevalence ratios calculated using a Poisson model with robust error variances.<sup>26</sup> The relationship between comorbidities and the likelihood of revascularization was examined using age-, sex-, and year-adjusted hazard ratios from single-level Cox regression models with time to revascularization within 30 days of the index AMI admission as the outcome. Single-level and multilevel Cox regression models examined factors that were associated with time to procedure within 30 days of index AMI admission. Models were run for the following procedures: all revascularization, PCI and CABG separately, and angiography. The single-level models compared procedure rates among covariate-adjusted Aboriginal and non-Aboriginal people, whereas the random intercept multilevel models

compared rates for covariate-adjusted Aboriginal and non-Aboriginal people admitted to the same hospital, by including a random intercept for hospital of admission. Cox regression was used to censor patients who died before receiving a procedure or were lost to follow-up as a result of transfers. Cox regression produces a hazard ratio which is similar to a relative risk, describing the relative likelihood of receiving a procedure at any point in time in the first 30 days after the index admission. The multilevel Cox regression models also examined between-hospital variation in the outcome to assess the impact of hospital of admission on time to procedure. The between-hospital variation, or hospital-level variance ( $\tau^2$ ), was also expressed as a median hazard ratio, which was the median of the hazard ratios of pair-wise comparisons of patients with identical characteristics taken from randomly chosen hospitals. This was an extension of the technique described by Merlo et al<sup>27</sup> for calculating median odds ratios for multilevel logistic regression models and was calculated using the formula, median hazard ratio =  $\exp(0.95\sqrt{\tau^2})$ . Data analyses were carried out in SAS 9.2<sup>28</sup> and MLwiN 2.24.<sup>29</sup>

## Ethics

Ethics approval for the study was given by the Population Health Services Research Ethics Committee, the Aboriginal Health and Medical Research Council Ethics Committee, and the University of Western Sydney Ethics Committee.

## Results

### Patient Characteristics

Among those admitted for AMI, Aboriginal patients were more likely than non-Aboriginal patients to be younger, female, current smokers, have alcohol or drug abuse recorded in hospital, be without private health insurance, living in more disadvantaged areas, and living in regional and remote areas of NSW (Table 1). Aboriginal patients were also more likely to be first admitted to hospitals outside of major cities, with a lower volume of acute admissions per year and without any catheterization laboratory. Before any adjustments, about one-third (32.9%) of Aboriginal patients with AMI had a revascularization procedure, and 48.5% had an angiography procedure, within 30 days, compared with 39.7% and 54.3% of non-Aboriginal patients, respectively. Overall, there were  $\approx 3\times$  as many PCI procedures as CABG procedures. Aboriginal patients had a significantly lower rate of PCI procedures than non-Aboriginal people but there was no significant difference in the rate of CABG procedures.

Aboriginal patients had significantly higher age-, sex-, and year-adjusted prevalence of a number of conditions associated with lower revascularization rates (Figure), including diabetes mellitus with and without complications, chronic obstructive pulmonary disease, chronic and acute renal failure, congestive heart failure, and cerebrovascular disease.

### Disparity in Revascularization Rates

Cox regression models examining the hazard of receiving a revascularization within 30 days of admission were built up with sequential addition of covariates and a random intercept for hospital (Table 2). After adjusting for age, sex, year, and AMI type in a single-level model, there was a large disparity for Aboriginal patients in the likelihood of revascularization (0.63; 95% confidence interval [CI], 0.57–0.70; Table 2, Model 1). After adding a random intercept, and therefore accounting for the hospital of admission, revascularization rates were still significantly lower for Aboriginal patients (0.82; 95%

CI, 0.74–0.91; Table 2, Model 2) but the ratio moved closer to parity. Adjusting for comorbidities (0.90; 95% CI, 0.81–1.00; Table 2, Model 3), then substance use (0.92; 95% CI, 0.83–1.02; Table 2, Model 4) reduced the disparity further, as did adding private health insurance status (0.96; 95% CI, 0.87–1.07; Table 2, Model 5). The addition of SES, area of residence, and the indicator for those hospitals that transferred a high proportion (>10%) of their AMI patients to interstate hospitals did not change the Aboriginal to non-Aboriginal hazard ratio (Table 2, Models 6–8).

When the final adjusted model (Model 8) was rerun for PCI and CABG separately it showed that, although not significant, Aboriginal patients had higher hazard of a CABG procedure than non-Aboriginal patients (adjusted hazard ratio, 1.19; 95% CI, 0.96–1.47;  $P=0.11$ ), and lower hazard of a PCI revascularization (adjusted hazard ratio, 0.93; 95% CI, 0.82–1.05;  $P=0.21$ ).

A sequential analysis was run for angiography within the first 30 days after AMI. These results were similar to the revascularization results: there was a large disparity between Aboriginal and non-Aboriginal people after adjusting for age, sex, year, and AMI type (0.62; 95% CI, 0.57–0.67); a reduction once accounting for admitting hospital (0.81; 95% CI, 0.74–0.88); and no significant disparity remaining after adjusting for comorbidities, substance use, and private health insurance (0.94; 95% CI, 0.87–1.03).

### Individual Characteristics Associated With 30-Day Revascularization

Table 3 shows the hazard ratios for selected covariates from the final adjusted model for revascularization within 30 days (Model 8). Revascularization was less likely for females, younger (25–34 years) and older (75–84 years) age groups, those classified as non-ST-elevated myocardial infarction or unspecified AMI type, those with alcohol abuse recorded, and those with any of the comorbid conditions apart from shock, particularly dementia. Patients with shock, current smokers, and those with private health insurance were more likely to be revascularized within 30 days. There was no significant variation in revascularization rates by quintiles of SES based on area of residence. However, area of residence was closely associated with hospital of first admission, which was already being accounted for in the multilevel model. Comparing patients within hospitals, those living in inner regional areas were slightly more likely to be revascularized than those living in a major city.

### Influence of Hospital on 30-Day Revascularization

Significant variance at the hospital level remained after adjusting for individual covariates and the interstate transfer of patients ( $\tau^2=0.264$ ,  $P<0.01$ ; Model 8). This equated to a median hazard ratio of 1.63, meaning that an AMI patient had a (median) 63% greater rate of being revascularized within 30 days than a patient with identical characteristics who went to a hospital with a lower revascularization rate. To determine what factors were influencing this hospital-level variation, 3 hospital-level covariates (hospital remoteness, hospital size, and presence of a catheterization laboratory) were added to the fully adjusted model (Model 8) one at a time (because they



**Table 1. Distribution of Characteristics and Outcomes by Aboriginal and Non-Aboriginal People Admitted With Acute Myocardial Infarction**

	Aboriginal (n=1165)		Non-Aboriginal (n=58 117)		P Value*
	n	%	n	%	
Individual characteristic					
Age, y					
25–34	46	3.9	417	0.7	<0.01
35–44	254	21.8	2795	4.8	
45–54	357	30.6	8480	14.6	
55–64	260	22.3	12954	22.3	
65–74	176	15.1	15196	26.1	
75–84	72	6.2	18275	31.4	
Sex					
Male	717	61.5	39448	67.9	<0.01
Female	448	38.5	18669	32.1	
AMI type					
STEMI	475	40.8	22330	38.4	0.03
NSTEMI	439	37.7	24150	41.6	
Unspecified	251	21.5	11637	20.0	
Comorbidities					
Diabetes mellitus without complications	278	23.9	8045	13.8	<0.01
Diabetes mellitus with complications	98	8.4	3201	5.5	<0.01
Congestive heart failure	159	13.6	8564	14.7	0.30
COPD	105	9.0	4168	7.2	0.02
Chronic renal failure	95	8.2	4120	7.1	0.16
Acute renal failure	46	3.9	2740	4.7	0.22
Cerebrovascular disease	44	3.8	2848	4.9	0.08
Pulmonary edema	14	1.2	752	1.3	0.78
Depression	22	1.9	1349	2.3	0.33
Cancer	18	1.5	2433	4.2	<0.01
Peripheral vascular disease	10	0.9	1173	2.0	<0.01
Dementia	5	0.4	511	0.9	0.10
Cardiac dysrhythmias	185	15.9	12616	21.7	<0.01
Shock	10	0.9	1193	2.1	<0.01
Substance use					
Current smoking	599	51.4	15437	26.6	<0.01
Alcohol abuse	123	10.6	1260	2.2	<0.01
Drug abuse	42	3.6	336	0.6	<0.01
Private health insurance					
No	982	84.3	31756	54.6	<0.01
Yes	183	15.7	26361	45.4	
Socio-economic status†					
1 <sup>st</sup> quintile- least disadvantaged	23	2.0	7727	13.3	<0.01
2 <sup>nd</sup> quintile	108	9.3	9819	16.9	
3 <sup>rd</sup> quintile	182	15.6	12578	21.6	
4 <sup>th</sup> quintile	297	25.5	12906	22.2	
5 <sup>th</sup> quintile - most disadvantaged	555	47.6	15087	26.0	

(Continued)

**Table 1. Continued**

	Aboriginal (n=1165)		Non-Aboriginal (n=58 117)		P Value*
	n	%	n	%	
Remoteness of residence‡					
Major city	304	26.1	34290	59.0	<0.01
Inner regional	357	30.6	16090	27.7	
Outer regional	358	30.7	7202	12.4	
Remote/very remote	146	12.5	535	0.9	
Hospital characteristic					
Remoteness of hospital‡					
Major city	384	33.0	38964	67.0	<0.01
Inner regional	245	21.0	11244	19.3	
Outer regional	407	34.9	7196	12.4	
Remote/very remote	129	11.1	712	1.2	
Average acute admissions per year					
<1200	86	7.4	1225	2.1	<0.01
1200–3899	181	15.5	3687	6.3	
3900–7084	136	11.7	3799	6.5	
7085–18399	434	37.3	19707	33.9	
18400+	328	28.2	29699	51.1	
Catheterization laboratory					
No	856	73.5	32784	56.4	<0.01
Yes, not 24/7	98	8.4	4315	7.4	
Yes, 24/7	211	18.1	21018	36.2	
Outcome					
Revascularization within 30 days§					
Any PCI or CABG	383	32.9	23076	39.7	<0.01
PCI	290	24.9	17800	30.6	<0.01
CABG	95	8.2	5567	9.6	0.10
Angiography within 30 days	565	48.5	31567	54.3	<0.01

24/7 indicates 24 h a day, 7 days a week; AMI type, acute myocardial infarction type; CABG, coronary artery bypass graft; COPD, chronic obstructive pulmonary disease; NSTEMI, non-ST-elevated myocardial infarction; PCI, percutaneous coronary intervention; and STEMI, ST-elevated myocardial infarction.

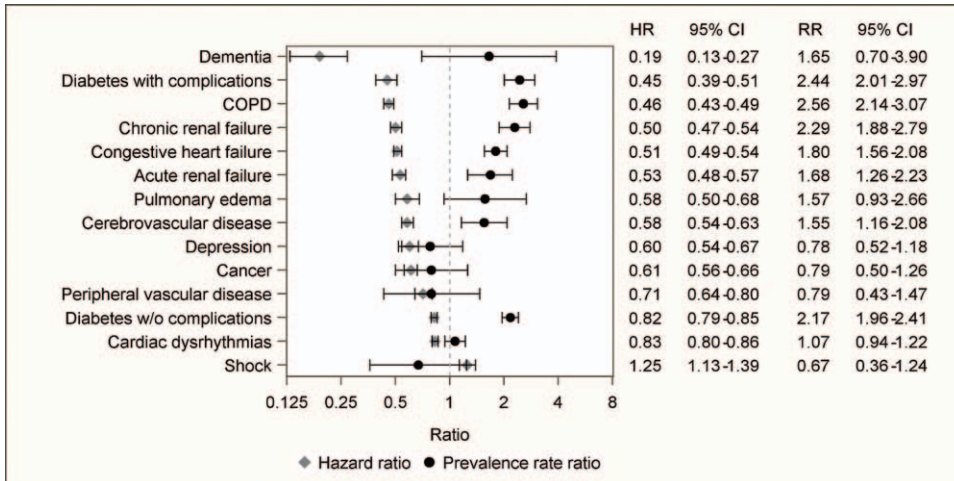
\*P value from a 2-tailed  $\chi^2$  test.

†Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

‡Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence or postcode of hospital.

§The number of PCI and CABG procedures will not add to the total revascularization procedures, as a person could have had >1 procedure within 30 days.

were highly associated). Revascularization within 30 days was significantly less likely for patients admitted to nonmajor city hospitals (Model 9, Table 4), smaller hospitals with <18400 acute admissions per year (Model 10, Table 4), or hospitals without catheterization laboratories (Model 11, Table 4). Even those admitted to a hospital with catheterization, but not a 24/7 laboratory, were significantly less likely to be revascularized within 30 days than those admitted to a hospital with 24/7 catheterization. When all of the above hospital-level covariates were included in the model at once, they accounted for 51% of the residual variation between hospitals.



**Figure.** Adjusted hazard ratios for likelihood of being revascularized by selected comorbidities,\* and adjusted Aboriginal to non-Aboriginal prevalence rate ratios for the same comorbidities, adjusted by age, sex, and year of admission. CI indicates confidence interval; COPD, chronic obstructive pulmonary disease; HR, hazard ratio; and RR, rate ratio. \*Comorbidities that could impact on revascularization rates or outcomes after AMI, chosen from literature search.

**Discussion**

Our results showed that Aboriginal patients had a 37% (30%-43%) lower rate of revascularization at any point in the first 30 days after admission with AMI compared with non-Aboriginal people of the same age, sex, year of admission, and AMI type. However, this did not account for the fact that Aboriginal people were more likely to be first admitted to smaller hospitals without specialist cardiac facilities. This is attributable to proportionately fewer Aboriginal people living in major cities near the larger hospitals.<sup>18</sup> After additional adjustment for hospital of admission, Aboriginal patients had an 18% (9%-26%) lower rate of revascularization compared with covariate-adjusted non-Aboriginal patients first admitted to the same hospital. Thus, much of the observed population-level disparity was driven by the hospital of admission.

These results contrast with those reported in racial disparities research from the USA: when the hospital of admission was accounted for in an analysis of Medicare patients, the

disparity in the rate of revascularization procedures between black and white Americans increased.<sup>6</sup> This may be because black Americans are more likely than white Americans to live in cities and closer to larger hospitals.<sup>30</sup> Unlike in the US, the disparity in revascularization rates for Aboriginal Australians is related to rural disparities in cardiac care.

Even so, in the current study, a disparity between Aboriginal and non-Aboriginal people remained after adjustment for hospital of admission. This was further reduced once comorbidities were accounted for, with Aboriginal patients now having a 10% (0%-19%) lower rate of revascularization than covariate-adjusted non-Aboriginal patients. For some of these comorbidities, revascularization may be contraindicated: deterioration in renal function in patients with chronic renal failure is a risk after contrast administration for angiography or the use of cardiopulmonary bypass.<sup>31</sup> However, one study found survival benefits after revascularization for high-risk non-ST elevated acute coronary syndrome patients, who were more likely to have diabetes mellitus and previous heart failure, and did not find the same benefits for the

**Table 2. Sequentially Adjusted Aboriginal to Non-Aboriginal Hazard Ratio for Receiving a Revascularization Procedure Within 30 Days of AMI Admission**

Model	Sequentially Adjusted For:	Variables and Random Effects Added to the Model:	AHR	95% CI	P Value
1	Demographics	+ Age, sex, year, AMI type*	0.63	0.57, 0.70	<0.01
2	Hospital of admission	+ random intercept†	0.82	0.74, 0.91	<0.01
3	Comorbidities	+ Selected comorbidities‡	0.90	0.81, 1.00	0.05
4	Substance use	+ Current smoking, alcohol and drug abuse	0.92	0.83, 1.02	0.12
5	Private health insurance	+ Private health insurance	0.96	0.87, 1.07	0.50
6	Socioeconomic status	+ Socio-economic status§	0.97	0.87, 1.08	0.55
7	Remoteness	+ Remoteness of residence¶	0.97	0.87, 1.07	0.52
8	Border hospital	+ Hospital transfers patients interstate#	0.96	0.87, 1.07	0.50

AHR indicates adjusted hazard ratio; AMI, acute myocardial infarction; and CI, confidence interval.

\*Single-level model.

†Multilevel model accounting for clustering of patients within hospitals with a random intercept.

‡Comorbidities: diabetes mellitus without complications, diabetes mellitus with complications, congestive heart failure, chronic obstructive pulmonary disease, chronic renal failure, acute renal failure, cerebrovascular disease, pulmonary edema, depression, cancer, peripheral vascular disease, dementia, cardiac dysrhythmias, and shock.

§Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

¶Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence.

#Hospital has transferred 10% or more of their AMI patients to an interstate hospital where they are lost to follow-up in our study.

**Table 3. Hazard Ratios for Selected Individual Covariates From the Fully Adjusted Multilevel Model**

	AHR	95% CI	P Value
<b>Sex</b>			
Male (ref)	1.00		<0.01
Female	0.70	0.68, 0.72	
<b>Age group</b>			
25–34	0.62	0.53, 0.73	<0.01
35–44	0.93	0.88, 0.98	
45–54	1.01	0.97, 1.05	
55–64 (ref)	1.00		
65–74	0.92	0.89, 0.95	
75–84	0.60	0.57, 0.62	
<b>AMI type</b>			
STEMI (ref)	1.00		<0.01
NSTEMI	0.58	0.56, 0.60	
Unspecified	0.64	0.62, 0.67	
<b>Comorbid conditions</b>			
Dementia	0.20	0.14, 0.28	<0.01
COPD	0.60	0.56, 0.65	<0.01
Cancer	0.64	0.59, 0.70	<0.01
Congestive heart failure	0.66	0.63, 0.70	<0.01
Cerebrovascular disease	0.66	0.61, 0.71	<0.01
Chronic renal failure	0.69	0.64, 0.74	<0.01
Depression	0.73	0.66, 0.82	<0.01
Pulmonary edema	0.74	0.63, 0.87	<0.01
Acute renal failure	0.74	0.68, 0.81	<0.01
Diabetes mellitus with complications	0.81	0.75, 0.88	<0.01
Cardiac dysrhythmia	0.86	0.83, 0.89	<0.01
Diabetes mellitus without complications	0.95	0.91, 0.99	<0.01
Shock	1.42	1.28, 1.58	<0.01
<b>Substance use</b>			
Current smoker	1.05	1.02, 1.08	<0.01
Alcohol abuse	0.70	0.64, 0.78	<0.01
Drug abuse	0.89	0.75, 1.06	0.20
<b>Private health insurance</b>			
No (ref)	1.00		<0.01
Yes	1.27	1.24, 1.31	
<b>Socioeconomic status*</b>			
1st quintile- least disadvantaged (ref)	1.00		0.05
2nd quintile	1.01	0.96, 1.07	
3rd quintile	1.01	0.95, 1.07	
4th quintile	1.03	0.97, 1.10	
5th quintile - most disadvantaged	0.95	0.89, 1.01	
<b>Remoteness of residence†</b>			
Major city (ref)	1.00		0.06
Inner regional	1.06	1.02, 1.11	

(Continued)

**Table 3. Continued**

	AHR	95% CI	P Value
Outer regional	1.02	0.95, 1.10	
Remote/very remote	1.05	0.88, 1.25	

AHR indicates adjusted hazard ratio; AMI type, acute myocardial infarction type; CI, confidence interval; COPD, chronic obstructive pulmonary disease; NSTEMI, non-ST-elevated myocardial infarction; Ref, referent group in the analysis; and STEMI, ST-elevated myocardial infarction.

\*Socio-Economic Indices for Areas (SEIFA) Index of Relative Socio-Economic Disadvantage population quintiles based on statistical local area of residence.

†Accessibility/Remoteness Index of Australia (ARIA+) based on statistical local area of residence.

lower risk groups.<sup>32</sup> Updated research is needed on whether revascularization confers an overall benefit for those with a high comorbidity burden, given recent improvements in surgical techniques.<sup>33</sup> Our finding that those with shock had a higher likelihood of receiving a revascularization procedure than those without may be attributable to the SHOCK trial<sup>34</sup> showing evidence for the benefit of revascularization for this high-risk patient group.

In our study, much of the remaining disparity in revascularization rates was accounted for when substance use and private health insurance were added to the model, leaving a nonsignificant 4% (–7% to 13%) disparity. Because of the universal health system in Australia, one would not necessarily expect differences in revascularization rates by health insurance status, however higher rates of revascularization procedures particularly for privately insured patients in private hospitals has been shown previously in Australia.<sup>35</sup> The reasons for this are complex. Those with private health insurance may be more likely to get discretionary procedures and may be overtreated. Also, in the Australian context, private health insurance may be a proxy for individual SES. The reduction in racial disparities once private health insurance was accounted for in the current study differs from results on racial disparities in the USA, where racial disparities persisted after controlling for insurance status.<sup>8</sup>

Other studies in Australia have found disparities in revascularization rates for Aboriginal compared to non-Aboriginal patients of between 7% and 40%.<sup>4,12,13,36</sup> It is difficult to directly compare these findings with ours, because of differences in methods, study populations, and the level of adjustment in models. Overall, it appears that Aboriginal people receive fewer revascularization procedures than age-adjusted non-Aboriginal people, but once factors such as area of residence, hospital of admission, comorbidity burden, or private health insurance are taken into account, the disparity reduces.

Similar to our study, another Australian study has shown higher rates of CABG procedures among Aboriginal compared with non-Aboriginal patients.<sup>36</sup> Explanations for this might include the following: more extensive coronary artery disease and diabetes mellitus in Aboriginal patients, for which CABG may be the clinically preferred therapy<sup>37</sup> or clinician concern about rates of stent thrombosis (a rare but dangerous complication of PCI) for Aboriginal patients. Clinicians may be concerned about compliance with antiplatelet therapy,<sup>38</sup> particularly if the patient is returning to a rural or remote

**Table 4. Hazard Ratios for Hospital Covariates Added to the Adjusted\* Multilevel Model One at a Time**

	AHR	95% CI	P Value
<b>Model 9</b> Remoteness of hospital†			
Major city (ref)	1.00		<0.01
Inner regional	0.56	0.44, 0.70	
Outer regional	0.51	0.42, 0.64	
Remote/very remote	0.70	0.50, 0.97	
<b>Model 10</b> Average acute admissions per year			
<1200	0.43	0.33, 0.56	<0.01
1200–3899	0.43	0.34, 0.55	
3900–7084	0.52	0.38, 0.71	
7085–18 399	0.71	0.56, 0.90	
18 400 + (ref)	1.00		
<b>Model 11</b> Catheterization laboratory			
No	0.46	0.35, 0.60	<0.01
Yes, not 24/7	0.60	0.44, 0.80	
Yes, 24/7 (ref)	1.00		

24/7 indicates 24 h a day, 7 days a week; AHR, adjusted hazard ratio; CI, confidence interval; and Ref, referent group in the analysis.

\*Adjusted for Aboriginal status, sex, age group, year, acute myocardial infarction (AMI) type, comorbid conditions, substance use, private health insurance, socioeconomic status, remoteness, and whether the hospital transfers  $\geq 10\%$  of their AMI patients interstate.

†Accessibility/Remoteness Index of Australia (ARIA+) based on postcode of hospital.

community where follow-up is less certain; however we could find no research on differential rates of antiplatelet therapy compliance or rates of stent thrombosis for Aboriginal and non-Aboriginal patients.

We repeated the revascularization analysis using the time to first angiography, which showed very similar results confirming that the disparities in revascularization rates were not attributable to differences in angiography results but rather that Aboriginal people with AMI were not getting the same rate of angiography or revascularization as non-Aboriginal people.

After adjusting for all individual covariates and transfer of patients interstate, hospitals varied markedly in the 30-day revascularization rates, with a median 63% higher rate of a revascularization for patients first admitted to hospitals with a higher rates of revascularization. This level of influence of admitting hospital is on par with the influence of individual characteristics such as age, sex, AMI type, and some comorbidities, and was stronger than the hospital-level impact on 30-day mortality after AMI admission where a median odds ratio of 1.34 was found.<sup>39</sup> This reflects the direct influence of the practices of a hospital and its clinicians on procedure rates.

In the current study, half of the hospital-level variation in revascularization rates after AMI was explained by hospital size, presence, and level of on-site cardiac facilities and remoteness of the hospital. However, these measured hospital-level factors might have been correlated with other unmeasured factors such as the time taken for the patient to get to hospital after AMI onset.<sup>40</sup> Communication and

coordination between those hospitals capable of performing revascularization and those not, electrocardiograms in ambulances and activation of catheterization laboratories, have been shown to improve time to revascularization<sup>41,42</sup> and are part of new models of care being rolled out in Australia.<sup>43</sup> It will be important to monitor the impact of these new models of care to ensure that they contribute to a reduction in the overall state-wide disparity in revascularization rates for Aboriginal people.

Increasing revascularization rates is only part of the story in reducing the gap in mortality from AMI for Aboriginal Australians. International studies have estimated that 50% or more of the decrease in AMI mortality in Western countries since the 1980s has been a result of a reduction in event rates.<sup>1,2</sup> Primary and secondary prevention are key factors to not only reducing the incidence of AMI for Aboriginal people in Australia but also decreasing the levels of comorbidity or better managing chronic conditions that may contribute to lower rates of revascularization.

The strengths of this study were in the comprehensive population coverage of the admitted patient data, as well as the linkage that allowed us to track patients from one hospital to another and censor those who died. However, there were limitations to using administrative data. The data were not collected for research purposes and thus were missing information on some clinical indications such as extent of coronary artery disease. That said, we adjusted for the presence of comorbidities and risk factors associated with revascularization in our models. Also, we were unable to identify which patients were given thrombolysis, and as a result, may not have needed a revascularization procedure. However, systematic hospital-level differences in the likelihood of administering thrombolysis as a result of size and remoteness would have been accounted for by the random hospital effect in the multilevel models that compared treatment rates within hospital. Additionally, the administrative data were missing information about patient preference, refusal, or physician attitudes or recommendations. The administrative data were for NSW hospitals only, and therefore, if someone was transferred to another hospital outside of NSW for their procedure they were lost to follow-up. We accounted for this when quantifying the impact of hospital of admission on variation in procedure rates and also confirmed that there was no impact of this cross-border flow on the adjusted Aboriginal to non-Aboriginal hazard ratio.

## Conclusions

Our study shows that the overall disparity in revascularization rates for Aboriginal compared with non-Aboriginal Australians was associated with lower revascularization rates for all patients admitted to smaller regional and rural hospitals and, among Aboriginal patients, a higher burden of chronic conditions such as diabetes mellitus, chronic obstructive pulmonary disease, and renal failure and lower levels of private health insurance. These findings can potentially be generalized to minority populations worldwide that suffer the dual disadvantage of low SES, and residence in rural and remote areas with limited access to specialist services.

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## Disclosures

None.

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### CLINICAL PERSPECTIVE

Ischaemic heart disease is a leading contributor to the health gap experienced by Aboriginal Australians. Despite Australia's universal health care system, Aboriginal people have lower rates of revascularization after acute myocardial infarction (AMI). However, because a greater proportion of Aboriginal people live in rural areas, they are more likely than other Australians to be admitted to smaller, regional hospitals without the facilities to perform revascularization. This study modelled Aboriginal and non-Aboriginal revascularization rates after AMI from July 2001 to December 2008, using administrative hospital data. To better understand the reasons for the population-level disparity in revascularization rates, we sequentially adjusted for demographic characteristics, hospital of admission, and individual risk factors. We found that among patients of the same age, sex, year of admission and AMI type, Aboriginal patients had an overall 37% lower rate of revascularization after AMI compared with non-Aboriginal patients, but an 18% lower rate of revascularization compared with non-Aboriginal patients admitted to the same hospital. The disparity was further reduced after adjusting for the presence of comorbidities such as diabetes mellitus, chronic obstructive pulmonary disease and renal failure, as well as smoking, drug and alcohol use and private health insurance, leaving a nonsignificant 4% disparity. In summary, we found the overall disparity in revascularization rates for Aboriginal compared with non-Aboriginal Australians was associated with lower revascularization rates for all patients admitted to smaller regional and rural hospitals and, among Aboriginal patients, higher levels of chronic conditions and risk behaviors, and lower levels of private health insurance.

## 9. Discussion

### 9.1. Background and aims

Aboriginal health disadvantage has been reported extensively[9, 12, 13] and is a result of a complex causal pathway including historical displacement and dispossession, intergenerational disadvantage, poverty, education, stress, racism, and poor health behaviours. Ischaemic heart disease (IHD) alone accounts for 14% of the gap in burden of disease between Aboriginal and non-Aboriginal people.[12] Acute myocardial infarction (AMI), the acute form of IHD, can be investigated using routinely collected hospital and deaths data. This thesis aimed to identify factors that influence the higher rates of AMI events and mortality for Aboriginal people in NSW, Australia, and to disentangle the influences of individual and contextual factors, using multilevel modelling, to identify which interventions can best reduce the overall burden of AMI (and therefore heart disease). This, in turn, could have a significant impact on reducing the overall burden of disease for Aboriginal people in Australia.

The analyses were undertaken using linked, whole-of-population hospital and deaths data for the state of NSW, which has the largest population of Aboriginal people of all the States and Territories of Australia.[2] While the linked hospital and deaths data have been used for monitoring the health and well-being of people in NSW,[135] there were concerns about the recording of Aboriginal status in both the hospital and the deaths data.[33, 136, 137] As such, the first aim of the thesis was to explore the recording of Aboriginal status in the linked NSW hospital and deaths data and to determine whether the data were suitable for monitoring AMI events and outcomes for Aboriginal people in NSW. Once this was established, the thesis aimed to investigate the disparities in AMI event rates, and mortality and procedure rates after admission with AMI, and to determine whether any disparities persisted after taking into account the contextual influences of area of residence and hospital of admission. Specifically, this thesis aimed to answer the following questions:

1. How well is Aboriginal status recorded in the routinely collected hospital data in NSW and does this vary by hospital? Can algorithms improve the reporting of Aboriginal status, and what is the impact of these algorithms on reported health disparities?
2. Is there a disparity in rates of AMI between Aboriginal and non-Aboriginal people in NSW and, if so, does it persist when taking into account area of residence? What is the influence of area of residence on AMI event rates and the Aboriginal to non-Aboriginal disparity?
3. Is there a disparity in short- and longer-term mortality after admission with AMI when taking into account the hospital of admission? What is the influence of hospital of admission on short- and long-term mortality?
4. Is there a disparity in the provision of revascularisation surgery after admission with AMI? If so, does it persist when taking into account the hospital of admission? What is the influence of hospital of admission and individual risk factors on revascularisation rates after admission?

## 9.2. Summary of main findings

### 9.2.1. Using linked routinely collected hospital and deaths data to report Aboriginal health outcomes

My analysis in Chapter 5 identified that there were inconsistencies in the way Aboriginal status was recorded for the same person across his or her admission history, which, while highlighting the under-recording of Aboriginal status, also pointed to the improvements that could be achieved through data linkage. My analysis was the first, to my knowledge, to use MLM to determine the relative contributions of factors relating to the admission, the hospital and the person to under-recording of Aboriginal status.

My analysis showed that 60% of the variation in recording of Aboriginal status was due to the hospital of admission. Specifically, there was poorer recording in private and major city hospitals. I found that only 20% of the variation was at the individual level. This may have been an underestimate, as the analysis was not able to identify Aboriginal people who were not recorded as such, or chose not to self-identify, at all of their hospital admissions.

In my analysis, I developed and compared a number of enhancement algorithms that combined the available information on Aboriginal status across records. All algorithms increased the number of admissions reported as Aboriginal, but the size of the increase varied for the algorithms tested. The choice of algorithm had an impact on the number of people reported as Aboriginal, and as such had a clear impact on admission ratios, as these were calculated from the number of admissions over the static population figure. However, it also had an impact on the reported Aboriginal to non-Aboriginal mortality rate ratios. Less strict algorithms, those that identified a larger number of people as Aboriginal, resulted in higher admission rate ratios but generally lower mortality rate ratios, particularly for cardiovascular disease. This could have been due to the less strict algorithms including a proportion of non-Aboriginal people who had been erroneously recorded as Aboriginal on one admission and had better health outcomes than Aboriginal people, or it could have been due to an increase in Aboriginal people with better health outcomes being included in the reporting group. Without an external validation sample, it is not possible to determine this.

From this study, I chose a preferred algorithm for the reporting of Aboriginal people for the remainder of the analyses. This algorithm increased the number of people reported as Aboriginal compared with using only the Aboriginal status recorded on the index admission. It also minimised potential bias by using the recording of Aboriginal status from the most recent hospitalisation, rather than from a proportion of admissions. The latter would have given those with more admissions (and possibly more health issues) more opportunities to be recorded as Aboriginal. Sensitivity analyses were also included in the remaining papers in order to communicate the uncertainties in the reporting of rates and disparities for Aboriginal people using the routine data.

### 9.2.2. Disparities in rates of AMI events

Chapter 6 used hospital and deaths data to identify AMI events for 25 to 84 year olds from 2002 to 2008 in NSW. Within the 25 to 84 year olds in the analysis, the average age at first



AMI was 56 for Aboriginal people and 68 for non-Aboriginal people. When accounting for age, sex and year of event, Aboriginal people had higher age-adjusted rates of AMI than non-Aboriginal people, which was not surprising given previous research. However, my analysis went a step further by accounting for clustering by area of residence and therefore properly accounting for contextual influences that could have explained all or some of the previously reported disparities. The MLM analysis took into account the fact that a higher proportion of Aboriginal people live in rural and remote areas and socially disadvantaged areas, where AMI rates are generally higher than in other areas.[138] This was the finding in my study too: AMI rates were higher outside major cities and increased with increasing area disadvantage.

Even when accounting for area of residence, and essentially comparing Aboriginal and non-Aboriginal people within areas, rates of AMI events in Aboriginal people were still more than two times those in non-Aboriginal people of the same age, sex and year of event. Therefore, the disparities in AMI rates for Aboriginal people cannot be attributed to general disparities in health experienced by those in more remote or socially disadvantaged areas. I was not able to account for individual comorbidity burden or rates of smoking, which are likely contributors to the increased AMI event rate, in this population-level analysis.

The relative disparity in rates was particularly high in younger age groups (25-44 year olds), with almost five times the rate of AMIs for Aboriginal people in the 25-34 year age group. The relative disparity was also higher among women, even though the rate of AMI events overall was lower for women than men. However, my analysis showed that Aboriginal women in NSW had about the same AMI event rate as non-Aboriginal men.

There was significant variation in AMI event rates by area; for any population group defined by age, sex, year and Aboriginal status from two randomly chosen areas, the rate of AMI events in one area was on average 31% higher than in the other area, with just over a third of this area-level variability explained by area-level disadvantage. There was also significant variation in the Aboriginal to non-Aboriginal disparity by area, although almost all areas showed a directionally or significantly higher rate of AMI events for Aboriginal people compared with non-Aboriginal people. The Aboriginal to non-Aboriginal disparity was higher outside major city areas, and increased with increasing area-level socioeconomic disadvantage.

Using multilevel modelling to look at rate ratios by small geographic areas, my analysis highlighted a number of SLAs that should be targeted as a priority, as they exhibited both higher than average rates of AMI for Aboriginal people and high Aboriginal to non-Aboriginal disparity in rates. These 'high rate, high disparity' SLAs were mainly in inner regional and outer regional areas of northern NSW.

### 9.2.3. Mortality rates after AMI

Chapter 7 compared mortality after admission for AMI between Aboriginal and non-Aboriginal patients. My research found no difference in 30-day mortality after AMI admission for Aboriginal and non-Aboriginal people of the same age and sex attending the same hospital. However, after adjusting for hospital of admission, age, sex and year of

admission, Aboriginal patients were more likely than non-Aboriginal patients in the same hospital to die within one year of admission.

This increasing mortality disparity with increasing follow-up time has been shown in other studies in Australia.[139] In my research, the higher longer-term mortality was partly associated with the higher comorbidity burden among Aboriginal people, and the disparity moved towards the null after adjusting for comorbidities. This highlights the importance of not just targeting AMI, but also the prevalence of other comorbid conditions among Aboriginal people.

My research was the first in Australia to quantify the impact of hospital of admission on mortality after AMI, and showed that differences between hospitals impacted on mortality outcomes for both Aboriginal and non-Aboriginal patients. For patients with the same individual characteristics, such as age, sex, and comorbidities, there was an average 34% increase in the odds of dying within 30 days by attending a hospital with worse mortality outcomes compared with a better performing hospital. Patients admitted to smaller hospitals, and those in outer regional and remote areas, had a higher risk of mortality, while patients admitted to larger, urban hospitals and hospitals with on-site angiography facilities had a reduced risk of dying, within 30 and 365 days of admission.

#### 9.2.4. Revascularisation rates after AMI

Chapter 8 compared rates of angiography and revascularisation within 30 days of admission for AMI between Aboriginal and non-Aboriginal patients. After adjusting for age, sex, year of admission and AMI type, Aboriginal people had less than two-thirds the likelihood of receiving a revascularisation procedure than non-Aboriginal people in the 30 days after being admitted with an AMI. This level of disparity has been previously reported in Australia.[14] However, using sequential adjustment, my analysis 'unpacked' this overall disparity in NSW to first understand the influence of hospital of admission, and then the influence of confounding variables. The sequential adjustment found that the overall disparity was partly related to the type of hospital to which Aboriginal people were being first admitted, as dictated by their area of residence; however, even when comparing people within hospitals, Aboriginal people remained significantly less likely than non-Aboriginal people of the same age, sex, year and AMI type, to have angiography and revascularisation procedures.

The disparity reduced after accounting for the higher comorbidity burden among Aboriginal people, such as the higher rates of diabetes and renal failure, as these conditions can impact on the provision of angiography and revascularisation.

The disparity was further explained after adjusting for smoking, and alcohol and drug abuse, and whether or not the person had private health insurance, which are all possible proxies for individual SES. In fact, after accounting for all of these factors, there was no longer a significant disparity in rates of revascularisation. However, this does not mean that there is no disparity that requires attention. The fact is that Aboriginal people are more likely to live in regional and remote areas, and are more likely to have complicating comorbidities, means that they are less likely to receive revascularisation procedures. These factors, which are associated with the lower rates of revascularisation procedures,

must be addressed to increase the overall rate of revascularisation procedures for Aboriginal people.

Once individual factors were accounted for (as well as the transfer of patients across State borders), there was still a marked difference in procedure rates between hospitals. The variation between hospitals equated to a median hazard ratio of 1.63, meaning that a patient with AMI had, on average, a 63% greater likelihood of having revascularisation within 30 days when first admitted to a hospital with a greater propensity to revascularise, compared with a patient with identical characteristics who was first admitted to a hospital with a lower revascularisation rate. Patients admitted to non-major city hospitals, smaller hospitals or hospitals without catheterisation laboratories were significantly less likely to receive revascularisation within 30 days.

### 9.3. Implications for policy and practice

#### 9.3.1. Recording and reporting of Aboriginal status

The analysis in Chapter 5 highlighted the need for system change at the hospital level to improve the recording of Aboriginal status in hospital data; greater consistency within and across hospitals would result in significant gains in accuracy of recording. There is little existing research into how to improve recording, but interventions designed to improve the training of new and ongoing staff are likely to be important, as deficits in this area have been linked with poor recording of Aboriginal status.[114, 140] Good practice in training of incoming staff, and consistent, reinforced training of existing staff, have also been suggested as contributing factors for two hospitals mentioned as best practice examples for the collection of data on Aboriginal status.[114] In order to target poorer performing hospitals, the introduction of evidence-based training modules must be followed by ongoing monitoring and quality improvement. Australian States and Territories have signed the National Indigenous Reform Agreement and, as part of this, have committed to quality improvement projects for capturing Aboriginal status in health data.[141] Specifically, jurisdictions have committed to projects related to adopting the national standard Indigenous status question (please refer to section 3.1.2); to improving procedures for collecting this information in health data through staff training on how and why to ask the question, and the importance of asking the question; and to raising awareness among Aboriginal and Torres Strait Islander people about the importance of identifying as such when accessing services.

However, it will take time for any improvements to filter through to the datasets used for research purposes. Therefore, linkage of routinely collected datasets is important for enhancing current and historical reporting of Aboriginal people. The NSW Ministry of Health is working on an indicator that combines information on the recording of Aboriginal status in all the linked datasets included in the Centre for Health Record Linkage Master Linkage Key;[34] however, individual researchers must take the time to determine how the use of particular datasets in an enhancement algorithm might introduce bias for their specific research outcome. This is particularly important if the outcome of interest is sourced from a different dataset to the population, and if this outcome dataset is used to

enhance reporting of Aboriginal status, as this can introduce differential misclassification bias.

### 9.3.2. Early intervention for heart disease among Aboriginal people

The analyses in Chapters 6, 7 and 8, particularly the event rates analysis in Chapter 6, highlighted the importance of early intervention to address the early onset of heart disease in Aboriginal people. The greatest disparities in AMI event rates were in those under 44 years of age, and the largest number of events for Aboriginal people were in the 45-54 year age group. Thus, these younger age groups must be a focus of interventions to reduce the incidence of AMI and the disparity in rates. In fact, preventive interventions should be targeting mothers, babies and children in order to halt the early onset of chronic disease in Aboriginal people. The WHO states that investment in the early years of childhood has the greatest potential to reduce the gap in health outcomes for disadvantaged people.[22]

To target this early onset of heart disease, as well as the influence of area-level disadvantage on AMI rates, it will be necessary to focus on macro and contextual causes. Primordial prevention is the stage of prevention that deals with the social determinants of health and attempts to avoid the types of social, economic and cultural patterns and disparities that contribute to elevated risk of disease.[142] Interventions must encompass poverty, education, employment, racism, impacts of dispossession, and disempowerment for Aboriginal people. Examples of primordial preventive interventions include using welfare policy to reduce inequalities in SES, and empowering Aboriginal people through policies of self-determination. A study comparing welfare policies in OEDC countries found that increased generosity in family policies supporting dual-income families was associated with a decrease in infant mortality, while increasing generosity in pensions providing basic security was linked to lower excess mortality in old-age.[143] Community control of health and health services has been shown in Canada to have a real impact on health outcomes. In Canada, First Nations communities with lower cultural continuity and control were found to have higher rates of youth suicide.[144] Access to primary health care on-reserve and local autonomy were found to be related to lower rates of potentially preventable hospitalisations for First Nations communities in Manitoba, Canada.[145] In Australia, lower than expected morbidity and mortality in a decentralised community in the NT was thought to be due to primary care outreach, physical activity as part of lifestyle, and connectedness to culture, family, and land, as well as opportunities for self-determination.[146]

Overall socioeconomic disadvantage among Aboriginal people must also be targeted, in particular as my findings showed increasing disparities in AMI rates with increasing area-level socioeconomic disadvantage. This increasing disadvantage may point to a higher sensitivity among Aboriginal people to the factors associated with lower SES, such as poverty and lower education levels, which increase the risk of AMI. Another possibility is that there were unmeasured factors specific to Aboriginal people and correlating with area SES (e.g. stress, experience of racism and early life predisposition to cardiovascular disease) that increased the risk of AMI for Aboriginal people living in the more disadvantaged areas.

Targeting smoking rates among Aboriginal people is crucial for reducing the early onset of heart disease. Smoking is one of the most important risk factors for AMI worldwide,[147] and Aboriginal people are two times more likely than non-Aboriginal people to be current daily smokers.[56] Reducing smoking in younger Aboriginal people will have big impacts in later years and prevent heart disease development, but smoking cessation can also have short-term benefits for older people who already have coronary heart disease.[148]

There are few published RCTs investigating smoking cessation interventions among Aboriginal and Torres Strait Islander people. One recent trial found an increase in smoking cessation in the intervention group (11%) versus the control group (5%) for a locally tailored, intensive, multidimensional smoking cessation program delivered in an Aboriginal Community Controlled Health Service setting; however, this difference was not statistically significant.[149] Similarly, an RCT of intensive smoking cessation among pregnant Aboriginal and Torres Strait Islander women found a directional effect in favour of the intervention, but again this was not statistically significant.[150] A community-level trial found modest effects in intervention communities, but there was a high variation between intervention and control communities and no clear impact.[151] Targeting whole communities and community norms, not just individuals, is important when trying to reduce smoking. For example, Aboriginal women mentioned smoking as a 'normal' and accepted behaviour in one study.[152] Interventions must deal with this community norm in order to maximise the impact of an intervention on an individual. And, importantly, interventions must take into account the external stressors and social determinants that have led to smoking, and the factors that reduce the ability of an individual to change their behaviour.[153]

Mainstream smoking interventions have been investigated to see what impact they have on Aboriginal people. Research in South Australia has shown that Aboriginal people contacted the Quitline (a telephone service providing support to those who wish to quit smoking) at comparable rates to non-Aboriginal people, but they were less likely to report quitting at three months.[154] Research into mass-media advertisements indicated that those with first-person narratives about the health effects of smoking were rated highly by Aboriginal people, even though they were not Aboriginal-specific advertisements.[155]

Macro-level interventions, like tobacco taxes, have been shown to be a powerful smoking cessation tool in developed and developing countries.[156, 157] Research in Australia has shown short-term decreases in smoking rates after an excise increase,[158] however, the impact of taxation and price increases on smoking rates in remote Aboriginal communities is not clear.[159] Price increases may have more of an impact on the rate of initiation of smoking, rather than on the rate of quitting, and must be part of a suite of interventions to reduce the short- and long-term harms of tobacco.

Another government intervention to assist Aboriginal people to stop smoking commenced in December 2008. Two courses of nicotine patches per year have been provided to all Aboriginal and Torres Strait Islanders through the Pharmaceuticals Benefits Scheme (PBS), initially at a subsidised cost, and since July 2010, free for healthcare card holders registered with their accredited health provider as part of the Practice Incentives Program Indigenous Health Incentive, and at a concessional rate if they were non-card holders.[160, 161]

Analysis of the PBS has estimated that between December 2008 and February 2011 about 3200 prescriptions of the patches were specifically for Aboriginal and Torres Strait Islanders; this was estimated to be about 2.9% of the eligible population of smokers aged 15 years and over in non-remote areas.[162] I was not able to find any population-level evaluation of this policy on quit-rates among Aboriginal people so this is an area where further research is needed.

### 9.3.3. Prevention and management of chronic diseases

The findings from Chapters 7 and 8 highlight the importance of prevention and management interventions to target the comorbid chronic conditions that have causal associations with AMI. These conditions can also complicate treatment of AMI and impact on survival after AMI. Higher rates of type 2 diabetes and renal disease in Aboriginal people contribute to AMI event rates, and are also associated with higher mortality rates and lower rates of surgery after AMI.

An audit of preventive activities for well adults in Indigenous health centres across Australia found a high variability in the provision of guideline-recommended regular services, such as documenting blood pressure, proteinuria and abnormal blood glucose levels, and providing lifestyle modification interventions.[163] This baseline audit was part of the Audit and Best Practice for Chronic Disease (ABCD) Extension project, a continuous quality improvement intervention, which reported improvements of 10% or more in the delivery of services to prevent chronic diseases in 64% of the health services providing data for three rounds of data collection during 2005-2009.[164] The ABCD Extension project was one of the continuous quality improvement interventions that informed the Healthy for Life program, an Australian Commonwealth Government initiative funding 100 health-care sites in Australia from 2007 onwards.[165] The Healthy for Life program included a focus on early detection of chronic disease among Aboriginal and Torres Strait Islander people, and resulted in some success for short-term process outcomes, such as a 30% increase in adult health checks, and an 18% increase in the testing of haemoglobin A1c and blood pressure among those with Type 2 diabetes; however, there was no change in blood pressure testing for those with coronary heart disease.[165] Whether these management changes result in long-term health outcome improvements is yet to be determined.

Smaller, single-site interventions for chronic disease management have shown some improvements in longer-term outcomes. In the Torres Strait, a trial and subsequent follow-up showed that the use of registers, recall and reminder systems, and basic diabetes care plans, supported by a specialist outreach service, improved diabetes care processes, control of blood pressure and reduced admissions to hospital for diabetes complications.[166] Another intervention at the community level involved a subsidised fruit and vegetable program in rural Australia, which resulted in improvements in fruit and vegetable consumption biomarkers in Aboriginal children, although not self-reported levels of consumption.[167] A trial is currently underway in 20 communities to assess the effectiveness of price discounts on fruit and vegetables, with or without additional nutrition education.[168]

At the secondary prevention level, better symptom control and management for Aboriginal people is needed to prevent worsening of chronic conditions. This might be achieved through improved adherence to medication. A trial is currently underway within the Kanyini study to determine the effectiveness of a polypill, a pill that includes fixed doses of combinations of treatments to simplify the taking of these medications to improve adherence.[169]

#### 9.3.4. Cardiac procedures

While the findings of Chapter 8 showed that those with comorbidities, such as diabetes and renal failure, were less likely to receive revascularisation procedures, a question remains as to whether the presence of these comorbidities should reduce the rate of revascularisation. While those people with comorbidities may have poorer outcomes than those without these comorbidities, they may have better outcomes with than without the procedure. A recent UK study among those admitted with Non-ST Elevated Acute Coronary Syndrome (NSTEMI), found no evidence of a modification of survival benefit after revascularisation by renal function; however, despite international guidelines recommending early invasive strategies for those with renal impairment, there was a stepwise decline in odds of angiography with worsening renal function.[66] In a related example, people admitted with cardiogenic shock had an overall higher mortality than those without, and before a dedicated RCT (the SHOCK trial[170]) investigating the survival benefit of early revascularisation, those with shock tended to receive fewer revascularisation procedures than those without. The SHOCK trial showed survival benefits at six months for patients receiving early revascularisation versus those with shock who did not.[170] This research appears to have been well accepted clinically, as people recorded as having shock in my analysis had an increased likelihood of receiving a procedure.

Improving access and treatment for all residents of regional and remote areas should improve procedure rates and mortality rates in these areas, as there was high variation in procedure rates by hospital (Chapter 8) and also variability in short- and long-term mortality (Chapter 7). Transfers to large hospitals away from family and support networks can be very stressful for Aboriginal people living in remote areas; however, an action research study concluded that relatively small interventions, such as having dedicated liaison officers in the health system, could improve outcomes for Aboriginal patients.[171] The National Heart Foundation has proposed a framework for overcoming disparities for Aboriginal people in the management of acute coronary syndromes, with coordination of the treatment pathway for Aboriginal people as a primary objective.[39] Any improvements or interventions in regional and rural areas must have Aboriginal community involvement and support, and would need to be 'culturally safe' for Aboriginal people in order to have the most impact on improving their AMI outcomes.[172] A qualitative study of Aboriginal cardiac patients describes current barriers to accessing treatment, including communication issues, experiences or stories of racism, previous experiences, mistrust, fear, competing priorities, lack of cultural awareness and lack of Aboriginal Liaison Officers, as well as poor health literacy.[50] All of these inter-related factors must be addressed to improve outcomes after AMI.

The current balance between public and private health care in Australia may also be contributing to disparities in access to cardiac procedures for Aboriginal people. Chapter 8 showed far lower rates of private health insurance for Aboriginal people compared with non-Aboriginal people in NSW, and having private health insurance was associated with a higher rate of revascularisation. Since the introduction of a 30% rebate for private health insurance premiums in 1999, the Australian Government has been directing an increasing proportion of federal government expenditure on health towards private hospital insurance, with the aim of encouraging the use of private services and decreasing the pressure on public hospitals.[173, 174] However, whether this policy has in fact substantially increased the take-up of private health insurance is not clear;[174] greater impact may have come from the 'lifetime health cover' policy penalising those taking up private health insurance after the age of 30, with private health insurance premiums increasing for every year without insurance.[174] The risk of the current rebate is that it directs substantial funds to wealthier Australians who could afford private health insurance anyway, and this may disadvantage Aboriginal people, as they are less likely to have private health insurance and receive the benefits of private health care.

### 9.3.5. Cardiac rehabilitation

The higher mortality among Aboriginal patients in the first year after admission for AMI, as described in Chapter 7, also highlights the importance of improved post-AMI care, including appropriate medication and lifestyle interventions. There appears to be a need to decrease barriers to attending cardiac rehabilitation for Aboriginal people to prevent readmissions and mortality. Research suggests that communication between different health services within and between communities needs to be improved.[175] The design of rehabilitation programs must also be culturally appropriate. Cardiac rehabilitation programs within Aboriginal Community Controlled organisations have had success, with improvements to cardiovascular health measures and management.[176, 177]

## 9.4. Implications for further research

My findings also highlight some priority areas for further research:

- Further clinical trials into smoking cessation for Aboriginal people are needed to find interventions with a clear impact.
- Evaluations of existing measures, such as subsidies for nicotine replacement therapy, are needed to determine whether these measures are having the desired impact, and if not, what the possible reasons are.
- More research is needed to determine whether mainstream smoking cessation services and messages are having an adequate impact on Aboriginal people, or whether targeted services and messages are needed.
- Research investigating the impact of mainstream tobacco tax policies on smoking rates and smoking-attributable hospitalisations for Aboriginal versus non-Aboriginal people would highlight any differential impacts, and again possibly indicate the need for more targeted interventions.



- As mentioned in Section 9.3.4 above, a recent observational study found no evidence that renal function modified survival benefit for those admitted with NSTEMI/ACS[66]. Perhaps a clinical trial is needed to determine whether early revascularisation provides a clear survival benefit for those with renal impairment, or other complicating comorbidities. A positive result could lead to wide acceptance among clinicians and a subsequent change in practice.
- More detailed clinical audit data on management of AMI should be collected and interrogated to investigate the appropriateness of treatment decisions for Aboriginal versus non-Aboriginal patients.
- Further investigation is needed on how best to improve access to high quality cardiac treatment and care for residents of regional and remote areas, and for Aboriginal people in particular; and questions remain as to whether this should be achieved by transferring patients more quickly to major city hospitals or by increasing services in less densely populated areas.
- Audits of the continuity of care after leaving hospital, and the quality of cardiac rehabilitation care, as well as specific information about medication adherence among Aboriginal people, are needed. This information could determine which improvements would have the greatest impact on the longer-term poor outcomes for Aboriginal people.

## 9.5. Dissemination and policy impact

I have presented results from this thesis at a number of conferences and meetings including the Australasian Epidemiological Association conference in Sydney 2010, the Coalition for Research to Improve Aboriginal Health Conference in Sydney in 2011, the Health Services and Policy Research Conference in Adelaide in 2011, the World Congress of Epidemiology in Edinburgh in 2011, the International Data Linkage Conference in Perth in 2012, and the Population Health Congress in Adelaide in 2012. Furthermore, my findings have been presented by others in the project team to wide audiences - firstly in a plenary session at the Population Health Congress in Adelaide in 2012, in a presentation at the UK Society for Social Medicine Conference in 2013, and more recently in a plenary session at the World Congress of Epidemiology in Anchorage in 2014.

The results from Chapter 8 were presented at the NSW Ministry of Health to the Chief Health Officer and representatives from the Centre for Aboriginal Health and the Centre for Epidemiology and Evidence. The study was also cited in a draft paper titled 'Better Cardiac Care for Aboriginal and Torres Strait Islander People 2014' for the 'Better Cardiac Care Forum', a joint Australian State and Territory government initiative, as well as in the Australian Commission on Safety and Quality in Health Care 'Vital Signs' report.[40] The Chapter 7 study was cited in the 2012 Aboriginal and Torres Strait Islander Health Performance Framework [41] and in a consensus statement from the National Heart Foundation of Australia on overcoming disparities in management of acute coronary syndromes,[39] and both studies were cited in the recently released 2014 Aboriginal and Torres Strait Islander Health Performance Framework.[42] I also provided comments to the

AIHW on their publication, “Report on the use of linked data relating to Aboriginal and Torres Strait Islander people”.

## 9.6. Strengths and limitations

The main strengths of this thesis include the use of whole-of-population linked data for NSW, the State with the largest Aboriginal population in Australia. This allowed me to look at small-area variation in AMI rates, and account for clustering of events within geographic areas and admissions within hospitals. Additionally, my application of multilevel modelling techniques allowed me to produce “shrunken” small-area estimates, which, compared with crude or standardised rates, are not as prone to random fluctuations. However, the linked data brought with them some limitations. The data were observational in nature, and as such, could have been subject to unmeasured confounding. It is difficult in any multivariable analysis of observational data to adjust adequately for confounding and to tease out independent effects. In hierarchical or multilevel data, there are additional potential sources of confounding: cross-level and within-level confounding.[178] Multilevel modelling is the appropriate mechanism for analysing this data, whose hierarchical structure is determined by the organisation and delivery of healthcare, and it is only through the application of multilevel modelling that cross-level confounding can be controlled for (through the inclusion of appropriate individual-level variables). Also, there were strong relationships between many of the variables in the models, such as the hospital-level variables, and their independent effects should be interpreted with caution.

Additionally, data were only available from July 2000 onwards, so I was not able to remove all prevalent cases of AMI using a substantial clearance period (i.e. a period at the beginning of the dataset that is discarded to minimise the number of prevalent cases that appear to be index cases due to the data subset). For the event rates analysis in Chapter 6, I used a minimum of an 18-month clearance period to maximise the amount of data available for analysis, and conducted a sensitivity analysis to investigate the impact of longer clearance periods on the Aboriginal to non-Aboriginal AMI rate ratios. This indicated that the RRs attenuated slightly with longer clearance periods, suggesting that using an 18-month clearance may have overestimated the disparity. A similar sensitivity analysis for the mortality after admission analysis (which had a minimum one-year clearance period) showed no difference in the mortality ratios with increasing clearance periods up to four years.

The possible overestimation of the disparity in the event rates is likely to be minimal in comparison with the potential for underestimation associated with the known under-recording of Aboriginal status in hospital[33] and deaths[113, 136] data, particularly in more urban areas. I used the ‘most recent’ algorithm from Chapter 5 to enhance reporting of Aboriginal status in the analyses in Chapters 6 to 8. For the event rates analysis, the ‘ever identified’ algorithm produced a far higher Aboriginal to non-Aboriginal rate ratio than the ‘most recent’ algorithm, suggesting that the estimates of the disparity using the ‘most recent’ algorithm were indeed conservative. Differences in recording of Aboriginal status by area may have increased the geographic variability in Aboriginal AMI event rates; however, the enhancement algorithm differentially increased numbers of events reported

as Aboriginal in major cities, redressing at least in part the differential under-recording in urban areas.

For the analyses of mortality and surgery after admission for AMI, I was limited by the routinely collected data in terms of measures that could be used for risk adjustment. There were limited measures of severity of disease and no recording of the time between the AMI event and getting to hospital. For risk adjustment I used rules developed for use with routine data such as the Ontario AMI Mortality Risk Prediction Rule[128] and the Charlson Comorbidity Index[112, 132], and performed additional analysis in order to ensure that there was good mortality prediction when adjusting for these conditions. Furthermore, I was limited by the number of deaths in the study period, particularly for the smaller Aboriginal population, and as such, may have lacked power to find a significant difference between Aboriginal and non-Aboriginal people in the 30-day mortality rate.

The mortality and revascularisation analyses may have some residual confounding due to adjusting for age in categories. This approach is suitable for most analyses, and produces readily interpretable coefficients. However, more precise age adjustment may have been warranted given the very big difference in the age distribution between Aboriginal and non-Aboriginal people, and the strong association of age with both mortality and receipt of revascularisation procedure. An alternative approach that might improve age adjustment in future analyses would be to test the use of age as a continuous variable and find the best functional form using fractional polynomials.

Finally, the probabilistic linkage may have resulted in some false-positive links as well as missed links within the hospital data, and between the hospital and deaths data, but quality assurance measures at the Centre for Health Record Linkage ensure that these are kept to a minimum. At the time of extraction of the current study data, the false-positive rate was estimated to be 4/1,000 records (0.4%) and the false-negative rate was estimated to be <5/1,000 records (< 0.5%).

## 9.7. Conclusions

The influence of the hospital of admission on the likelihood of recording of Aboriginal status highlights the importance of continuing efforts to improve the collection of data on Aboriginal status in hospitals, particularly in major city and private hospitals. In the meantime, data linkage is useful for increasing the reporting of Aboriginal status in current data. However, when combining the multiple records of Aboriginal status, there is a possibility of introducing bias. As such, it is important to perform sensitivity analyses with various reporting methods to understand how the outcomes are affected by different algorithms.

In this thesis, I used an algorithm, chosen to increase reporting and minimise bias, to show that Aboriginal people were two times as likely to have an AMI event as non-Aboriginal people. This occurred even when the variation in AMI rates by area of residence were taken into account, with disparities being greatest for Aboriginal women and those in younger age groups. Significant variation in overall AMI rates by area was partly explained by area-level disadvantage, with certain priority areas identified for targeted preventive interventions. Improving access to larger hospitals, or those with specialist treatment

facilities, could improve surgical rates and outcomes after AMI for all residents of rural and regional areas, both Aboriginal and non-Aboriginal. However, closing the gap in burden of heart disease between Aboriginal and non-Aboriginal people will require major efforts in primordial, primary and secondary prevention to reduce the early onset of heart disease among Aboriginal people, as well as their earlier onset of important comorbid conditions, such as diabetes and renal disease. Any interventions must acknowledge the wider historical and contextual causes of the current Aboriginal health disadvantage and, to have a significant impact, must deal with macro, contextual and individual levels of influence.

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## APPENDICES

Appendix A. List of conference presentations

Appendix B. Related papers

Appendix C. Data cleaning and data editing steps

## Appendix A. List of Conference Presentations

Randall D, Jorm L, Lujic S, Leyland A. Targeting interventions to improve disparities in incidence of acute myocardial infarction among Aboriginal Australians using multilevel modelling of linked data. International Data Linkage Conference, Perth, 2012.

Randall D, Jorm L, Lujic S, O'Loughlin A, Leyland A. Rates of coronary procedures for Aboriginal and non-Aboriginal patients admitted with acute myocardial infarction. 7th Health Services & Policy Research Conference, Adelaide 2011.

Randall D, Jorm L, Leyland A, Lujic S, Churches T, Haines M, Eades S, O'Loughlin A. Variation in outcomes for Aboriginal and non-Aboriginal people after admission for acute myocardial infarction. 3rd CRIAH Aboriginal Health Research Conference, Sydney 2011.

Randall D, Jorm L, Lujic S, Banks E, Leyland A, Churches T, Eades S. Algorithms to improve Aboriginal identification in the NSW Admitted Patient Data Collection. 3rd CRIAH Aboriginal Health Research Conference, Sydney 2011.

Randall D, Jorm L, Leyland A, Lujic S, Churches T, Haines M, Eades S, O'Loughlin A. Variation in outcomes for Aboriginal and non-Aboriginal people after admission for acute myocardial infarction. Australasian Epidemiological Association Annual Conference, Sydney, 2010.

## Appendix B. Related Papers

Harrold TC, Randall DA, Falster MO, Lujic S, Jorm LR. The contribution of geography to disparities in preventable hospitalisations between Indigenous and non-Indigenous Australians. PLoS ONE 2014;9.

Randall DA, Reinten T, Maher L, Lujic S, Stewart J, Keay L, Leyland AH, Jorm LR. Disparities in cataract surgery between Aboriginal and non-Aboriginal people in New South Wales, Australia. Clinical and Experimental Ophthalmology (in press).

Falster K, Randall D, Banks E, Eades S, Gunasekera H, Reath J, Jorm L. Inequalities in ventilation tube insertion procedures between Aboriginal and non-Aboriginal children in New South Wales, Australia: A data linkage study. BMJ Open 2013;3.

Falster MO, Randall DA, Lujic S, Ivers R, Leyland AH, Jorm LR. Disentangling the impacts of geography and Aboriginality on serious road transport injuries in New South Wales. Accident Analysis and Prevention 2013;54, 32-38.

## Appendix C. Data Cleaning and Editing Steps

Table C1. Data cleaning issues and remedy.

Data cleaning issue	Description	Number of records	Remedy
<b>APDC</b>			
<b>Exact duplicate separations</b>	There were a number of duplicate hospital admissions with different hospital record IDs (apdc_recid), but linked within the same PPN and containing the same information on all variables.	13000	One record out of a duplicate pair removed from the dataset.
<b>Almost duplicate separations</b>	Duplicate admission date, admission time and separation date, but with different information in at least one field.	11854 (0.06%)	Flagged in the dataset.
<b>Admission date not in plausible range</b>	Some admission dates were not in a plausible range, ie outside of the range 1999 to 2008, and leading to implausible lengths of stay.	49827 (0.3%)	Flagged in the dataset.
<b>Admission date after separation date</b>	For some separations, the admission date was after the separation date, leading to negative lengths of stay.	159 (0.001%)	Flagged in the dataset.
<b>Date of birth is not in plausible range</b>	Some dates of birth were not in a plausible range from 1890 to 2008.	735 (0.004%)	Flagged in the dataset and not included on the new date of birth variable (see below)
<b>Inconsistent date of birth</b>	For some people linked under the one PPH, there were inconsistent dates of birth.		Created new date of birth variable (dob2) that applies one date of birth consistently to all PPNs, the date of birth that either (1) matches the birth record, (2) is the most common date of birth, or (3) is the earliest recorded one.
	Inconsistent dates of birth, but no date that was more common than another. The dates were not greater than 10 years apart or different on day, month or year.	30708 (0.16%)	The earliest recorded dob was chosen as the date of birth in the new dob2 variable, and the records flagged in the dataset.
	Some people had multiple dates of birth recorded where the difference was greater than 10 years or the dates of birth were different on day, month and year, so seemingly two different people.	22676 (0.12%)	Flagged in the dataset and dob not in new dob2 variable.
	Two dates of birth for the one person but both matching a 'born in hospital' record, so seemingly two different people.	72 (0.0004%)	Flagged in the dataset and dob not in new dob2 variable.
	Date of birth not consistent with admission date, eg date of birth after admission date or after separation date.	54 (0.0003%)	Flagged in the dataset and dob not in new dob2 variable.
<b>Inconsistent sex</b>	For some people linked under the one PPH, there were inconsistencies with the sex field.		
	Inconsistent sex, but one more frequent than the other	98177 (0.53%)	Created new sex variable (sex2) with the most common sex consistently applied to all records for the one PPN.
	Inconsistent sex, but no sex that was more common than another.	5702 (0.03%)	Flagged in the dataset and not included in the new sex variable (see above).

## Appendix C. Data Cleaning and Editing Steps

Data cleaning issue	Description	Number of records	Remedy
<b>RBDM and ABS</b>			
<b>Duplicate records in RBDM dataset</b>	There were a number of duplicate death records with different IDs (rbdm_recid), but linked within the same PPN and containing the same information on all variables.	88700	One of duplicate pair removed from the dataset.
<b>Duplicate records in the ABS dataset</b>	There were a number of duplicate death records with different IDs (abs_recid), but linked within the same PPN and containing the same information on all variables.	1068	One of duplicate pair removed from the dataset.
	There were a small number of duplicate records where one (or both) records had missing date of birth information.	16	These were printed and examined, and the one record without the dob information was removed in most cases.
<b>Multiple death records</b>	After removing duplicates there were still multiple death records that were linked with the one PPN.		Used many-to-many join so that all possible combinations were retained, and then created a hierarchy to determine which death record was the best match with the APDC record. Higher ranking match was chosen if there was more than one. The hierarchy was:
	ABS – different record ids but same date of death	534	1. Separation mode on the hospital admission = 'died' and date of death is the same day (plus or minus 1) = rank 1
	ABS – different record ids and different date of death	124	2. If the date of birth is the same on the hospital and deaths data = rank 2
	RBDM – different record ids but same date of death	228	3. If the day and month of DOB are the same on the hospital and deaths data = rank 3
	RBDM – different record ids and different date of death	764	4. If the day and month of DOB are swapped but year is the same = rank 4
			5. If day and year of DOB are the same on the hospital and deaths data = rank 5
			6. If month and year of DOB are the same on the hospital and deaths data = rank 5
			7. If DOB is missing on hospital record but the RBDM and ABS dates of birth are the same = 6
			8. If SLA on the ABS mortality data matches SLA on the hospital data = rank 7
			9. If Aboriginal status on the ABS mortality data matches Aboriginal status on the hospital data = rank 8
			10. Other possibilities = rank 98
			11. Separation date is more than 3 days after supposed date of death = rank 99

## Appendix C. Data Cleaning and Editing Steps

Data cleaning issue	Description	Number of records	Remedy
<b>ABS and RBDM dates of death different</b>	Even after choosing the best matching death records for the APDC, there were still a small number of ABS-RBDM matches where the date of death was recorded differently on each dataset. For most of the cases, the dates of death were only different by one day.	1596  (1444 diff by 1 day)	For those with different dates of death, the following criteria was used to choose a date of death: <ol style="list-style-type: none"> <li>1. If one was before the final separation date and one was on or after the separation date, the one on or after was chosen.</li> <li>2. If one matched exactly the separation date, and separation mode was 'died in hospital' then this date of death was chosen.</li> <li>3. If one was within 3 days of the separation date, and separation mode was 'died in hospital' then this was chosen.</li> <li>4. Otherwise the highest date was chosen.</li> </ol>
<b>Linked APDC, RBDM and ABS</b>			
<b>Inconsistent date of death</b>	Date of death is before the date of separation (and sometimes before the date of admission)	4136 (0.02%)	Flagged in the dataset
<b>Separation mode is death but no linked death record</b>	There were some records where the separation mode was coded as 'died in hospital' but there was no linked death record. A small number of these were not the last separation for that PPN, so must have been incorrect data in the APDC.	4411 (0.02%) 182	A new date of death variable, date_dth2, was created that included all the linked deaths and also those where the separation mode was 'died in hospital' and this was the last separation. This variable was used for sensitivity analyses to see if including the additional deaths made any difference.

## Appendix C. Data Cleaning and Editing Steps

Table C2. Major data editing steps.

Edit	Description
<b>Link separations into episodes</b>	<p>Separate admissions (or separations) were linked into episodes that count transfers and type-changes as being part of the same episode (or stay). First, nested separations were identified. Nested separations are those where someone has been transferred to another hospital for a short period of time, for a procedure for example, and then transferred back without being discharged from the first hospital.</p> <p>Assumptions for creating episodes:</p> <ul style="list-style-type: none"> <li>• A new separation was considered part of a continuing episode if the separation above had one of the transfer codes as the separation mode, or the new separation recorded that the person was transferred from the previous hospital in the 'trnsfrom' variable as long as the admission date was either the same date as the separation date of the separation above, or 1 day later (to capture overnight transfers).</li> <li>• All nested separations were considered to fall within the same episode of the separation that started before and ended after the nested transfer.</li> </ul> <p>Note: those separations that had an admission date and discharge date the same day as the previous separation date were not considered part of the episode, as it was not clear whether they were a nested separation on the final day of the overall stay, or a new admission and separation, due to separation date and time not being available.</p>
<b>Create episodeset variable</b>	The episodeset variable incremented only when a new separation was also a new episode.
<b>Copy the separation date for the last separation in the episode to all separations in the episode</b>	A 'finsep' variable was created that was the date of separation for the final episode in a stay, and this was copied across all the separations that formed one episode.
<b>Recalculate length of stay</b>	The total length of stay ('totlos') was calculated using the admission date for the first separation in an episode and the separation date for the final separation in an episode.
<b>Calculate Aboriginal enumeration variables</b>	<p>The following variables were created combining the Aboriginal status from each record in different ways to get a consistent report of Aboriginal status for each person in the dataset.</p> <ul style="list-style-type: none"> <li>- Status 1 = 100% of separations with Aboriginal status recorded</li> <li>- Status 2 = at least one separation with Aboriginal status recorded</li> <li>- Status 3 = 50% or more separations with Aboriginal status recorded</li> <li>- Status 4 = 75% or more of separations with Aboriginal status recorded</li> <li>- Status 5 = 50% or more public hospital separations with Aboriginal status recorded (or 50% or more of private separations if only have private separations)</li> <li>- Status 6 = 75% or more of public hospital separations with Aboriginal status recorded (or 75% or more of private separations if only have private separations)</li> <li>- Status 7 = most recent public hospital separation has Aboriginal status recorded (or last private separation if only have private separations)</li> <li>- Status 8 = 100% of public hospital separations with Aboriginal status recorded (or 100% private, if only have private separations)</li> <li>- Status 9 = at least one public hospital separation recorded as Aboriginal (or at least one private if only have private separations)</li> <li>- Status 10 = recorded as Aboriginal in at least two hospitals, if have gone to more than one hospital, otherwise recorded as Aboriginal at least once in the one hospital</li> </ul>



## Appendix C. Data Cleaning and Editing Steps

Edit	Description
<b>Calculate Aboriginal enumeration variables</b> <i>(continued)</i>	<ul style="list-style-type: none"> <li>- Status 11 = at least one separation with Aboriginal status recorded, but never recorded as non-Aboriginal</li> <li>- Status 12 = most recent admission (public or private) recorded as Aboriginal</li> <li>- Status 13 = 50% or more public hospital separations (not including type-change separations) with Aboriginal status recorded (or 50% or more of private separations if only have private separations)</li> <li>- Status 14 = 100% of public hospital separations (not including type-change separations) with Aboriginal status recorded (or 100% of private separations if only have private separations)</li> <li>- Status 15 = 'weight of evidence' algorithm from NSW Health report[34], where at least two separations (not including type-change separations) have to be recorded as Aboriginal, if person has three or more separations, or at least one if only has one or two separations.</li> </ul>
<b>Create acute hospitalisation summary variable</b>	<p>Using data from 2001 to 2007 (full calendar years), the number of acute admissions per year for each hospital was calculated. A mean number per year was also calculated by dividing by the number of years where there was at least one acute admission in the dataset. The mean per year for each hospital was grouped at the 50<sup>th</sup>, 75<sup>th</sup>, 85<sup>th</sup> and 90<sup>th</sup> centiles.</p>