Acute cardiac admissions after natural disasters 
Insight from the Christchurch earthquakes

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Acute Cardiac Admissions After Natural Disasters

*Insight from the Christchurch Earthquakes*

Dr. Christina Wei-Hsin Chan

MB CHB, FRACP
Abstract

Introduction

It is known that acute cardiovascular events can be triggered by external factors among susceptible individuals. Previous studies have shown an increased risk of acute cardiac events following psychosocial and environmental triggers such as warfare, national sporting events and natural disasters. Earthquakes are well documented to cause cardiac complications. This topic is perhaps the hardest to study due to the unpredictable nature of the disaster. Often, severe destruction of the infrastructure and medical facilities hinders stringent study methodology. Christchurch, New Zealand, was struck by 2 major earthquakes at 4:36am on 4 September 2010, magnitude 7.1 and at 12:51pm on 22 February 2011, magnitude 6.3. Both events caused widespread destruction. Christchurch Hospital, the region’s only acute care hospital, was fortunate to have escaped major damage. It remained functional following both earthquakes. We sought to examine thoroughly the effects of the 2 earthquakes on acute cardiac presentations and their sequelae. We hypothesised that there would be an increase in overall chest pain admission, a surge of acute myocardial infarction and stress cardiomyopathy cases and that major earthquakes of different intensity, occurring at different times of the day would result in different cardiovascular presentation patterns.

Methods

Patients admitted under Cardiology in Christchurch Hospital 3 weeks prior to and 5 weeks following both earthquakes were analysed, with corresponding control periods in September 2009 and February 2010. Patients were categorised based on diagnosis: ST elevation myocardial infarction, Non ST elevation myocardial infarction, stress cardiomyopathy, unstable angina, stable angina, non-cardiac chest pain, arrhythmia and
other. A sub-group analysis as well as a follow up study at 12 months was done for patients who presented with stress cardiomyopathy following the February 2011 earthquake.

Results

In the first 2 weeks following the early morning September earthquake, there was a significant increase in overall cardiovascular admissions (mean 75 admissions per week during the control periods, 120 admissions in week 1 and 100 admissions in week 2, p=0.003), ST elevation myocardial infarction (mean 5 cases per week during the control periods, 9 cases in week 1 and 11 cases in week 2, p=0.016), and non-cardiac chest pain (mean 29 cases per week during the control periods, 46 cases in week 1 and 36 cases in week 2, p=0.022). This pattern was not seen after the early afternoon February earthquake. Instead, there was a very large number of stress cardiomyopathy admissions with 21 cases (95% CI 2.6-6.4) in 4 days compared to only 6 stress cardiomyopathy cases after the first earthquake (95% CI 0.44 – 2.62; p<0.05). At 12 months, a follow-up study of the 21 patients with stress cardiomyopathy triggered by the second earthquake showed 100% survival rate with the majority free from cardiovascular, other medical or psychological sequelae.

Conclusion

The early morning September 2010 earthquake triggered a large increase in ST elevation myocardial infarction and a few stress cardiomyopathy cases. The early afternoon February earthquake, although smaller in Richter scale, was far more destructive compared to the first event given its shallow depth and closeness to the city centre. It caused significantly more stress cardiomyopathy in an already vulnerable population that may have been sensitised by the first earthquake. Two major earthquakes of different intensity, occurring at
different times differed in their effect on acute cardiac events. Patients who had stress cardiomyopathy as the result of earthquakes had excellent prognosis in the intermediate follow-up period.
Work Performed Personally

The study protocols were designed and Ethics Committee approval was sought personally for both the main study reported in Chapter 4 and 5, and the subgroup follow-up study described in Chapter 6. I was solely responsible for the acquisition of data in both studies. I personally obtained consent from and conducted telephone and psychometric questionnaire interviews in 21 patients 12 months following their presentations with stress cardiomyopathy after the 2011 earthquake. All ensuing data was collated, graphed and analysed personally with advice and assistance from a biostatistician, Associate Professor Chris Frampton. The research outcomes have been analysed and interpreted personally and have been presented for peer review as listed in the Publications Section (please see below). As first author, I was responsible for drafting the articles and revising them critically for important intellectual content and final approval of the version to be published.

The studies described in this thesis were undertaken at Christchurch Hospital whilst holding a post as a Senior Cardiology Registrar (2010 – 2011) and Research and Echocardiography fellow (2012) with the supervision of Professor Richard Troughton, Associate Professor John Elliott and Dr Paul Bridgman.
Acknowledgements

I am indebted to my supervisors Professor Richard Troughton, Associate Professor John Elliott and Dr Paul Bridgman for their expert guidance in formulating and writing this thesis. I would like to acknowledge financial support from the Christchurch Cardiology Trust Fund and Heart Foundation NZ who provided me with the Overseas Training and Research Fellowship that enabled me to undertake this research.

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I wish to acknowledge the staffs of Christchurch Cardiology Department for their hard work during the earthquakes. The doctors, nurses, technicians and administration staff worked tirelessly to ensure our patients received the best of care at such difficult times. I would like to thank my patients who gave their time generously and participated in the study.

Finally, and most importantly I wish to thank my husband, Gary for his patience and support. You took over household duties, proof read this thesis and have never complained. Thank you for having total belief in me, as always.
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<tr>
<td>ACE Inhibitor</td>
<td>Angiotensin converting enzyme inhibitor</td>
</tr>
<tr>
<td>ACS</td>
<td>Acute coronary syndrome</td>
</tr>
<tr>
<td>AF</td>
<td>Atrial fibrillation</td>
</tr>
<tr>
<td>AMI</td>
<td>Acute myocardial infarction</td>
</tr>
<tr>
<td>ARB</td>
<td>Angiotensin receptor blocker</td>
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<tr>
<td>β blocker</td>
<td>Beta blocker</td>
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<tr>
<td>BNP</td>
<td>Brain natriuretic peptide</td>
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<tr>
<td>CAD</td>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>CCU</td>
<td>Coronary care unit</td>
</tr>
<tr>
<td>CHF</td>
<td>Congestive heart failure</td>
</tr>
<tr>
<td>CK-MB</td>
<td>Creatinine kinase – MB</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>HADS</td>
<td>Hospital Anxiety and Depression Scale</td>
</tr>
<tr>
<td>HAQ</td>
<td>Health Anxiety Questionnaire</td>
</tr>
<tr>
<td>IES-R</td>
<td>Impact of Event Scale – Revised</td>
</tr>
<tr>
<td>IHD</td>
<td>Ischaemic heart disease</td>
</tr>
<tr>
<td>NSTE-MI</td>
<td>Non ST elevation myocardial infarction</td>
</tr>
<tr>
<td>PE</td>
<td>Pulmonary embolism</td>
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<tr>
<td>PTSD</td>
<td>Post traumatic stress disorder</td>
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<tr>
<td>SCD</td>
<td>Sudden cardiac death</td>
</tr>
<tr>
<td>SCM</td>
<td>Stress cardiomyopathy</td>
</tr>
<tr>
<td>STEMI</td>
<td>ST elevation myocardial infarction</td>
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<tr>
<td>SVT</td>
<td>Supraventricular tachycardia</td>
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Publications Related to this Thesis

Journal articles


Abstracts and Presentations

C Chan, P Bridgman, R Troughton, J Elliott. 21 Cases of Stress Cardiomyopathy Following the Christchurch, New Zealand 2011 Earthquake – Self Reported Health Outcome at 1 Year (Abstract).

- The Cardiac Society of Australia and New Zealand Annual Scientific Meeting, Auckland, June, 2012 (oral presentation).
- The Cardiac Society of Australia and New Zealand Annual Scientific Meeting, Brisbane, August, 2012 (poster).

- The Cardiac Society of Australia and New Zealand Annual Scientific Meeting, Hawke’s Bay, June, 2011 (oral presentation).
- The Cardiac Society of Australia and New Zealand Annual Scientific Meeting, Perth, August, 2011 (poster).
- The Internal Medicine of Australia and New Zealand Annual Scientific Meeting, Hanmer Springs, April, 2012 (oral presentation).

J Elliott, C Chan, M Daly, W Chan, R Saireddy, K Milburn, R Troughton, P Bridgman. When the Earth Quakes, the Heart Breaks: Stress Cardiomyopathy After a 6.3 Earthquake (Abstract).

- The Cardiac Society of Australia and New Zealand Annual Scientific Meeting, Hawke’s Bay, June, 2011 (oral presentation).


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Chapter One – Introduction

1.1 Background

Every year, approximately 15,000 earthquakes occur in New Zealand. Fortunately, the majority of the earthquakes are too small or too deep to cause any damage or disruption. New Zealand is a part of the Pacific Ring of Fire, where 90% of the world’s earthquakes take place. The Ring of Fire is a 40,000 kilometre horseshoe shaped seismically active belt with more than 400 volcanoes and a series of oceanic trenches circling the Pacific Basin. New Zealand sits in the southern Rim of fire on the junction between the Pacific and Australian tectonic plates. The islands of New Zealand were formed millions of years ago when the two plates were pushed together. The plates continue to move against each other slowly, causing energy build up and earthquakes occur when energy is released through the upper layer of the plates. Fault lines are areas where the plates slide under or over each other with tremendous stress to cause fractures of rock and soil. There are at least eight major fault lines in the North Island, including the well-known Wellington fault. Together, with smaller related faults, they form the seismically active North Island fault system. In the South Island, there are several major parallel faults, known as the Marlborough Fault System. They join together further south to form the Alpine fault.
Since the early European settlements in New Zealand in the 1840’s, several major earthquakes have been recorded. The Wairarapa earthquake occurred in 1855, magnitude 8.2, was the most severe event to have occurred since colonization. It caused widespread damage in Wellington, Wanganui and Kaikoura. Nine people were killed. In 1931, a magnitude 7.8 earthquake struck Hawkes Bay. Due to the relatively shallow epicenter depth of 20 kilometres, it was extremely destructive. It caused the largest loss of life of any quake in New Zealand history with 256 fatalities and thousands were injured. Many were killed as
the city turned into rubble when unreinforced brick buildings collapsed. This tragedy acted as a catalyst for introducing building guidelines and also the Earthquake Commission in New Zealand. Since then, a few more major earthquakes have struck the country, including the 2009 magnitude 7.8 Dusky Sound earthquake, which was the nation’s largest in nearly 80 years, but which caused little damage on the mainland.

New Zealand faces a very real ongoing threat of large earthquakes that could cause damage to metropolitan centres. Great effort has been given to predicting where the next major event will occur, in the hope of reducing associated destruction and mortality. The city of Wellington has always been considered at high risk of seismic activity as it sits on a major active fault line with active parallel fault lines nearby. The probabilistic seismic hazard model formulated by Stirling et al in 1998 showed that there is a 10% probability of an event with peak ground accelerations of > 0.4g occurring in Wellington within 50 years. In contrast, no major earthquakes were expected to occur in Auckland, Christchurch or Dunedin in the same time frame. In 1991, Elder et al reported that moderate to large earthquakes (magnitude 6 to 7.5) could be expected in the Canterbury Plains foothills and North Canterbury area and less frequent moderate earthquakes under the Canterbury Plains and Christchurch itself. They predicted that a modified Mercalli IX intensity earthquake (Table 1) was likely to occur every 300 years and a X intensity earthquake would have a return period in excess of 6000 years.
<table>
<thead>
<tr>
<th>Modified Mercalli Intensity Scale</th>
<th>Impact of the earthquake</th>
</tr>
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<tbody>
<tr>
<td>MM I</td>
<td>Imperceptible</td>
</tr>
<tr>
<td>MM II</td>
<td>Scarcely felt</td>
</tr>
<tr>
<td>MM III</td>
<td>Weak</td>
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<td>MM IV</td>
<td>Light</td>
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<td>MM V</td>
<td>Moderate</td>
</tr>
<tr>
<td>MM VI</td>
<td>Strong</td>
</tr>
<tr>
<td>MM VII</td>
<td>Damaging</td>
</tr>
<tr>
<td>MM VIII</td>
<td>Heavily damaging</td>
</tr>
<tr>
<td>MM IX</td>
<td>Destructive</td>
</tr>
<tr>
<td>MM X</td>
<td>Very destructive</td>
</tr>
<tr>
<td>MM XI</td>
<td>Devastating</td>
</tr>
<tr>
<td>MM XII</td>
<td>Completely devastating</td>
</tr>
</tbody>
</table>

Table 1 - Simplified New Zealand Modified Mercalli Intensity Scale (Geonet NZ)

1.1.1 September 2010 Darfield earthquake

On 4 September, 2010 at 4:46am, an unknown fault line which had not been active for the past 16,000 years ruptured under the Canterbury Plain, causing a magnitude 7.1 earthquake. The epicenter was located in Greendale, 40 km west of the Central Business District of Christchurch. It was 10 kilometres deep and generated a vertical 1.25 G force.
The maximum intensity on the Modified Mercalli scale was 9 near the epicenter. The city suffered significant damage to its infrastructure and buildings. Liquefaction, a phenomenon whereby a saturated soil substantially loses strength and behaves like liquid in response to stress such as violent shaking due to earthquakes, posed a serious problem for many areas of the city, especially the eastern suburbs. Financial loss was estimated to be as high as $4 billion NZ dollars. A state of emergency was declared. Fortunately, there were no direct fatalities. This was largely attributed to the timing of the event, as most people were asleep in bed and the streets were empty.

Figure 2 - The fault line that caused September 2010 Darfield earthquake (GNS Science)

1.1.2 February 2011 Christchurch earthquake

Six months and thousands of mild to moderate aftershocks later, Christchurch was again struck by a very powerful earthquake at 12:51 pm on 22 February 2011. Although smaller on the Richter scale than the first one, the epicentre of this magnitude 6.3 earthquake
(modified Mercalli intensity IX felt in the city region) was only 5 kilometres deep and 10 kilometres southeast of the city centre. It generated a vertical 2·2G force, the highest peak ground acceleration ever recorded in the world\textsuperscript{12}. As many as 185 people died with many more injured and left homeless. The iconic Christchurch Cathedral was destroyed. More than one third of the buildings in the central business district, including 2 multistory buildings were destroyed. It was considered one of the nation’s worst natural disasters since the 1931 Napier earthquake.

![Figure 3 - Location of February 2011 Christchurch earthquake (Geonet)](image)

1.2 Christchurch Hospital

The initial health care focus after major earthquakes, of course, was on assessment and treatment of acute casualties such as trauma and crush injuries. Christchurch Hospital is the largest tertiary hospital in the South Island of New Zealand with 600 to 650 beds. It serves the wider region of Canterbury, population 466,000\textsuperscript{13}. It remained fully functional
after the September 2010 earthquake but sustained some structural damage during the February 2011 event. The facility lost power immediately after the initial major shock. Although there were diesel-fueled generators to provide electricity for essential services such as Emergency Department, Radiology and Intensive Care Unit, incessant aftershocks disrupted their function intermittently. With great difficulty, the Emergency Department treated a large number of patients presented with a varying degree of musculoskeletal injuries after the February earthquake. A total of 6659 people were injured and 142 were admitted to Christchurch Hospital. Surgery was required for 82 patients and several needed amputation of limbs. Medical wards located on the fourth and fifth floor of the Riverside hospital building had to be evacuated due to loss of power and flooding from roof reservoirs. Many patients had to be carried or dragged down the darkened stairwell on mattresses by staff as lifts were not working. They were placed on other wards or transferred out to the Princess Margaret Hospital, a rehabilitation hospital 6 kilometres away.

1.3 Cardiovascular complications due to stressful events

For people who survive an initial catastrophic impact and are fortunate enough to escape traumatic injuries, there is an increased risk of medical complications occurring in subsequent days and weeks. Major stressful events are well known to increase the incidence of acute cardiac events. After the 11 September 2001 terrorist attacks, significantly more patients presented with acute myocardial infarction (AMI) to the hospitals in Brooklyn and New Jersey. Also, cardiovascular complications more than doubled during the FIFA World Cup games of 2006 hosted in Germany.

Earthquake induced cardiovascular complications have been studied and documented elsewhere. There was a significant increase in AMI following the 1994 Northridge (Los
Angeles) earthquake in California\textsuperscript{20}, the 1995 Hanshin-Awaji (Kobe) earthquake in Japan\textsuperscript{21}, and the 1999 Ji-Ji earthquake in Taiwan\textsuperscript{22}. There was also increased risk of short and long-term cardiac related death after earthquakes, following earthquakes in Athens\textsuperscript{23} and Niigata-Chuetsu\textsuperscript{24}. Earthquakes are amongst the most catastrophic natural disasters to cause adverse cardiovascular events. To make matters worse, mass destruction of buildings and infrastructure can often disrupt the delivery of health care at a time when it is most needed.

1.4 Christchurch Cardiology Department

Christchurch Hospital is the only acute admitting hospital in the city. Christchurch Cardiology Department is the only acute cardiac service provider in the wider region of Canterbury. Fortunately, the Department remained fully functional after both major earthquakes. The service consists of 10 cardiologists, 2 cardiac catheterisation laboratories, 1 Coronary Care Unit (CCU), an echocardiography department and 54 beds. For interventional cardiology and pacemaker implantations, it services a large population of 551,000 in Canterbury, South Canterbury and West Coast\textsuperscript{13}. For implantable defibrillators and complex electrophysiology studies, it serves all of the South Island. On average, 300 to 380 patients are admitted under the cardiology service per month. Immediately following the September 2010 earthquake, the cardiology admitting staff noticed a large increase in acute non-traumatic cardiac chest pain presentations. A plan to study the effect of such an event on acute cardiac admission pattern was quickly formulated and exercised.

1.5 Aims of the study

Earthquakes are usually unheralded events. Current knowledge of the impact of earthquakes on acute cardiovascular events is based on a small number of studies and is thus limited. All of the previous studies were based on populations exposed to a single major
earthquake at a specific time. Little is known about whether the timing of earthquakes makes a difference in triggering acute cardiac events. The focus of previous studies was mainly AMI and sudden cardiac death (SCD) following earthquakes. Very little data exists on stress cardiomyopathy (SCM) triggered by earthquakes. Most of the previous studies required collaboration of multiple centres for data collection. The study reported in this thesis aimed to address some of the unanswered questions. This study aimed to document the pattern of cardiovascular – and in particular chest pain – admissions following a unique sequence of multiple large earthquakes. In particular, it carefully identified the pattern of SCM presentations. A follow up study was also conducted at 12 months after the February earthquake, documenting the medium term cardiac and psychological sequelae in this unique group of people.

We had four clear hypotheses –

1. There would be an increase in overall chest pain admissions in the immediate period following an earthquake compared to time matched periods in earlier years.

2. There would be a surge of AMI and SCM cases.

3. Major earthquakes which differed in strength and depth, struck at different locations and at different times of the day would result in different patterns of cardiovascular presentations.

4. People with earthquake induced SCM would recover well at 12 months following the event.

The overarching aim of this study was to provide an understanding of the epidemiology of non-traumatic chest pain presentation following the Christchurch earthquakes that will enable formulation of a disaster cardiovascular event strategy for our health region in the future.
1.6 **Outline of chapters**

Chapter One provides the background of this thesis and the development of the research questions. Chapter Two discusses literature on cardiovascular disease, including statistics and general facts. It explores physical, physiological and psychological triggers of cardiac events and provides examples from a wide range of studies. It also presents relevant studies worldwide showing the impact of earthquakes on cardiovascular events. Chapter Three introduces SCM, an acute coronary syndrome (ACS) primarily triggered by emotional or physical stress. It is highly relevant to the study as there were many cases of SCM after the second earthquake. The methodology of this research, data collection, and the methods chosen for data analysis are presented in Chapter Four. Chapter Five presents study findings, using descriptive statistics and graphs to display results. Chapter Six focuses on the subgroup of patients who presented with SCM after the February 2011 earthquake and discusses their longitudinal health outcomes. Chapter Seven discusses and interprets the significance of our findings, relating the results to relevant literatures. This chapter also addresses the limitation of this study, discusses potential clinical implications and makes suggestions for future research. Finally, Chapter Eight summarizes the major findings of our research.
Chapter Two – Literature Review: Physiological, Physical and Emotional Precipitants of Acute Myocardial Infarction

2.1 Introduction

‘Coronary heart disease is now the leading cause of death worldwide; it is on the rise and has become a true pandemic that respects no borders’ – WHO 2009. In New Zealand, ischaemic heart disease (IHD) (19.7%) along with malignancy (29.8%) and cerebrovascular disease (9.2%) are the leading causes of mortality. The national health population based 2006/2007 New Zealand health survey showed that 1 in 20 adults had been diagnosed with IHD, which equates to 161,000 people. A nationwide audit showed 1007 patients with a suspected or definite ACS were admitted to 39 New Zealand hospitals over the 14-day period form 14 May to 27 May 2012. In 2011, the American Heart Association updated the statistics on heart disease to show that more than 2200 Americans die of cardiovascular disease per day, an average of 1 death every 39 seconds and an American experiences a coronary event every 25 seconds. The heavy disease burden cost the US government $286.8 billion dollars in 2008.

The pathogenesis and progression of coronary artery disease (CAD) is associated with a multitude of risk factors. The non-modifiable risk factors that predispose individuals to disease include gender, family history and ethnicity. Other well accepted conventional risk factors are cigarette smoking, diabetes, hypertension and hyperlipidaemia. An analysis of 14 international randomised control trials showed that at least 1 of the conventional risk factors was present in 84.6% of women and 80.6% of men who presented with coronary disease. In 2004, a large scale case-control study of AMI in 52 countries, involving approximately
30,000 participants showed that smoking, abnormal lipid, hypertension, diabetes, abdominal
obesity and psychosocial factors accounts for most of the risk of myocardial infarction
worldwide. The same study also demonstrated that regular consumption of alcohol, fruit and
vegetables, regular exercise seemed to modify the risk of AMI. Over the past few decades,
health organizations and practitioners worldwide have worked tirelessly to raise public
awareness and to promote modification of cardiovascular risk factors. Capewell et al
reported a fall in coronary heart disease mortality rate by 23.6% in Auckland between 1982
and 1993. They attributed 50% of this fall in mortality to reductions of major risks such as
smoking cessation, better cholesterol and blood pressure control. A more recent report
published by the New Zealand National Heart Foundation in 2004 showed a decline in
coronary heart disease age-standardized death rates by 61% in men and by 56% in women
from 1970 to 2000.

Coronary atherosclerosis begins and progresses silently for decades before the acute
clinical event. It can present in a benign manner as stable angina or a catastrophic acute
event. The acute event usually involves formation of thrombus at the site of a ruptured or
eroded atherosclerotic plaque. The clinical manifestation can be variable, including
unstable angina (UA), non ST elevation myocardial infarction (NSTEMI), ST elevation
myocardial infarction (STEMI) and SCD due to ventricular arrhythmia as the result of
ischaemia. Over the past few decades, there have been different views on the cause of
conversion of chronic stable coronary disease to an acute unstable event. The concept of
possible triggers for AMI was introduced as early as 1910. A trigger is defined as a
stimulus or activity that causes physiological changes leading directly to the onset of acute
cardiac events. For the past 20 years, many studies have been done to identify potential
triggers of acute coronary events and to define the proportion of onsets that may be
attributable to such triggers. Ultimately, the goal is to reduce the overall risk of acute cardiac events by formulating strategies to protect against the short term pathophysiological effects of triggering in concurrence with long-term medical therapy for risk modification. Commonly accepted triggers that have been proposed to cause acute cardiac events can be classified into three categories - physiological, physical and emotional.

2.2 Search strategy

The search strategy for relevant literature commenced with searching databases – Ovid Medline, PubMed and Cochrane Review as well as a review of the bibliographies of reports from the above search results.

The keywords used in the search were related to acute cardiac events and triggers. The search used a combination of the following MeSH and words: acute myocardial infarction, myocardial infarction, AMI, MI, Q wave infarction, non-Q wave infarction, unstable angina, acute coronary syndrome, sudden cardiac death, ventricular arrhythmia, stress cardiomyopathy, Takotsubo cardiomyopathy, broken heart syndrome, trigger, physiological triggers, circadian variation, diurnal variation, physical triggers, physical exertion, physical activity, emotional triggers, emotional stress, mental stress, psychosocial factors, job stress, stock market, natural disasters, unnatural disasters, earthquakes, terrorism, war, football games and risk prevention.

Searches were limited to medical publications written in English between 1970 to present. The period since 1970 was chosen as the concept that endogenous and exogenous triggers might exist for acute coronary event started to emerge in the late 1970s.
2.3 Physiological triggers

2.3.1 Circadian variation of acute myocardial infarction

The concept of triggers was stimulated by observation of a circadian variation in acute cardiovascular events. Muller et al performed a landmark study between 1978 and 1983 to investigate the role of triggers in AMI. They developed a large database for the Multicentre Investigation of Limitation of Infarct Size (MILIS) study to evaluate the effect of propranolol or hyaluronidase for AMI. They found that in 847 randomised patients who had AMI, there was a significant increase in self-reported onset of pain between 6am and noon. The weakness of relying on patients’ subjective reports was dissipated by the objective measure of plasma creatinine kinase-MB (CK-MB) enzyme. There was a significant elevation of CK-MB between 5am and 2pm, with a second peak between 7pm to 9pm, which correlated to the peak incidence detected with pain related onset. The ISAM (Intravenous Streptokinase in Acute Myocardial Infarction) Study involving 1741 patients and the analysis of the TIMI II study involving 3339 patients also confirmed the existence of morning peak of AMI. The ISAM study showed that myocardial infarction was 3.8 times more likely to occur between 8am and 9am than between 12am and 1am. Two further studies demonstrated similar circadian pattern of AMI. The Second Intravenous Streptokinase and Infarct Survival (ISIS-2) study and a study done by Behar et al both showed predominant morning peak of AMI between 6am and noon. Subgroup analysis showed a similar pattern in patient groups categorized with respect to geographic distributions in the ISIS-2 study, age and gender in both studies. The subgroups of patients who failed to demonstrate circadian variation of AMI included diabetic patients (ISIS-2), patients who were taking beta blockers (β blockers) and aspirin. There seems to be conflicting results regarding non-Q wave infarction. Behar et al found a similar diurnal pattern in both non-Q wave MI and Q wave MI. In contrast, two larger studies failed to find an increased morning incidence of non-Q wave MI.
The TRIMM pilot study (Triggers and Mechanisms of Myocardial Infarction Study) in Germany further examined the relationship of AMI and time after awakening in the morning. The initial findings showed a significantly higher frequency of AMI from 6 to 9 am. After adjusting for wake times, the relative risk of AMI increased even more so from 1.8 to 2.4 during the first 3 hours after awakening. Goldberg et al reported a study involving the CCU of 4 teaching hospitals in Massachusetts. After excluding patients in whom symptoms have caused awakening, there was a 2.5 fold increase in AMI in the first hour after awakening from sleep. The authors concluded that an increase in mental and physical stress associated with the transition from sleep to arousal may be responsible for the increased risk of onset of MI after awakening and arising.

2.3.2 Circadian variation of sudden cardiac death

SCD was also found to exhibit a circadian variation with increased incidence in the morning. In 1987, Muller et al analysed mortality records from the Massachusetts population and found there was a primary peak in SCD from 10am to 11am. A major limitation of this study is that it is based solely on the information obtained from the death certificates. Willich et al performed another analysis of the time of day of SCD in the Framingham Heart Study population. There were 264 definite SCD (11% of total death among 5209 patients). They found the hourly risk of such death to be 70% higher from 7am to 9am than the average risk during the rest of the day. Although Willich’s analysis was more detailed, they were only able to ascertain the precise timing of death in 59% of the cases. Arntz et al performed a more sophisticated study of circadian variation in SCD by analyzing the automatic external defibrillator recordings in out of hospital arrest patients. They observed that in 703 patients, there was a marked increase in SCD in the morning from 6am to noon with a second peak in
Interestingly, patients whose initial rhythm was ventricular fibrillation exhibited marked circadian variation whereas people who had asystole or pulseless bradyarrhythmia were evenly distributed over the day. After evaluating and analyzing the mortality records from 4 cities and towns in Massachusetts in August 1989, Willich and colleagues again found an increased SCD rate during the initial 3 hours after awakening (RR 2.6, 95% CI 1.6 to 4.2) compared with other times of the day.

2.3.3 Endogenous factors

A combination of endogenous physiological factors are likely to contribute to the morning increase of AMI and SCD including haemodynamic factors, vascular resistance and haemostasis. Blood pressure and heart rate are known to display a circadian pattern with an early morning surge on waking, reaching peak mid-morning, then progressively falling throughout the day. During sleep, blood pressure is about 10 to 20% lower than the mean day time recordings. Miller-Craig et al studied and verified this phenomenon in the 1970s using brachial artery cannulation and electrocardiogram (ECG) to obtain continuous recordings of blood pressure and heart rate in patients. Since 24-hour ambulatory blood pressure monitoring has become readily available, the diurnal variation of blood pressure has been well documented. The mechanism responsible for these changes includes sympathetic nervous system and renin-angiotensin-aldosterone system activation. A study by Quyyumi et al suggested that ischaemic threshold is lower in the morning while vascular resistance is higher. Increased vascular tone in the presence of severe atherosclerotic coronary disease may impair coronary flow significantly to cause ischaemia. High morning levels of catecholamines and cortisol in combination with increased blood pressure, heart rate and vascular resistance could certainly promote rupture of vulnerable plaques leading to coronary thrombosis. To make matters worse, several small studies
have also shown a propensity to increased coagulability in the morning. Tofler et al showed that in 15 healthy subjects there was increased platelet aggregability during the hours 6:00-9:00 in the morning. However, this was not observed when the subjects remained supine and inactive. A further study found that morning increases in platelet aggregation were not accompanied by increased platelet activation. The investigators suggested that it was primarily due to increase in platelet count, haematocrit, catecholamine level as the result of assuming an upright position after waking. Andreotti et al observed in 6 healthy young people that at 6am, their plasma tissue type plasminogen activator was at the lowest level while their plasminogen activator inhibitor increased markedly. Such imbalance in the haemostatic equilibrium could stimulate thrombosis in the newly ruptured plaque. In an editorial from the British Heart Journal, Mulcahy et al pointed out that the time soon after awakening is particularly dangerous for patients with coronary disease due to the physiological changes mentioned above. However, they also acknowledged that the potential cardiovascular benefits of not getting up at all are outweighed by a reduced quality of life and the complications of prolonged bed rest.

2.3.4 Risk modification

The importance of recognizing the existence of a circadian variation for acute cardiac events and the potential physiological triggers is that emphasis can then be placed on pharmacological protection during the morning period. In the MILIS study, Muller’s group showed that patients taking β blocker did not display significant circadian rhythm for AMI compared to those who were not on treatment. However due to the small number of patients on β blocker, the statistical power of this subgroup analysis was limited. Later on, the ISAM study demonstrated that amongst 1741 study subjects, the only subgroup of 209 patients who did not have a significant morning increase in AMI were already established on
β blocker treatment. A similar finding was verified by a large study by Hansen’s group in Sweden. Mulcahy et al showed that while Nifedipine did not alter the circadian pattern of ischaemic events, atenolol abolished the morning peak. Ridker et al showed in the Physician’s Health Study, a randomised double-blind control involving 22,000 male physicians that alternate dosing of aspirin effectively blunted the morning increase and reduced overall AMI cases.

2.4 Physical triggers

2.4.1 Physical activities triggering acute myocardial infarction

Regular physical exercise has been shown to reduce the overall risk of myocardial infarction, but vigorous physical activity can also lead to acute ischaemic coronary events. The stimulation of the sympathetic nervous system leading to a surge in heart rate and blood pressure can create a mismatch in myocardium oxygen supply and demand in patients with underlying CAD. There is also evidence that platelet activation increases after strenuous exercise in patients with CAD and in sedentary individuals. In the MILIS study, 23% of patients who suffered AMI reported heavy (9%) or moderate (14%) physical activities as possible triggers. In the TIMI II study, 18.7% of patients reported to have had AMI during exercise. Compared to patients who had an infarct at rest, this group was found to have fewer coronary arteries with a significant (≥60%) stenosis on coronary angiography, although they were more likely to have an infarct-related artery that was occluded. An autopsy series found that men who died of SCD during exercise were more likely to have acute plaque rupture than those who died at rest in the setting of severe CAD. A major weakness of the MILIS and TIMI II studies is that they lack appropriate control data. To address this issue, Maclure’s group developed the method of case-crossover design where each patient served as his or her own control. They tested this method in the Myocardial Infarction Onset Study.
(Onset Study) by comparing patients’ physical activity in the 1 to 2 hours before AMI to their usual level of physical exertion in the past year and to their actual physical activity in the same time period 24 hours prior to AMI. They also had a healthy matched control subject for each patient. Their study showed that 54 patients out of 1228 (4.4%) reported heavy physical exertion ($\geq 6$ metabolic equivalents) within the hour of AMI. The relative risk of such physical activity triggering AMI was 5.6 compared to less strenuous exertion or none. The study also demonstrated that the relative risk of AMI progressively decreased as patients’ habitual exercise level increased. The TRIMM study showed that 7.1% of the 1194 patients were engaged in heavy physical exertion at the onset of AMI with a relative risk of 2.1. Similar to the Onset study, they also concluded that strenuous physical exertion increased the risk of AMI. However, the relative risks reduced from 6.9 among those who exercised fewer than 4 times a week to 1.3 for those who exercised above this level.

2.4.2 Physical activities triggering sudden cardiac death

Heavy physical exertion has been implicated for triggering SCD through the process of cardiac ischaemia in subjects with known CAD. Increases in sympathetic nervous activity may also lead to propensity for ventricular arrhythmia. Thompson et al conducted a population-based study in Rhode Island, USA, investigating the incidence of SCD in men while jogging from 1975 to 1980. There were 11 deaths due to CAD. The age adjusted relative risk was 7 compared with the death rate from CAD during more sedentary activities. Another population-based study from Seattle and King County found that in men without an apparent history of CAD and with a low level of habitual activity; the relative risk of SCD was significantly raised at 56 (95% CI 23 to 131) during exercise. The relative risk reduced dramatically to 5 (95% CI, 2 to 14) in men who had the highest level of habitual activity. In a prospective, nested case-cross over design within the Physician’s Health Study
by Albert et al, there were 122 SCD among the 21,481 male physicians who had no self-reported history of CAD over a follow up period of 12 years. Seventeen (13.9%) deaths occurred during and 6 (4.9%) occurred 30 minutes after vigorous exercise such as jogging or racquet sports. They demonstrated that the relative risk of SCD during and up to 30 min after vigorous exercise was 16.9 (95% CI 10.5 to 27.0). Again, men who exercised regularly had a much lower relative risk of SCD compared to their sedentary counterparts. It needs to be emphasized that although there is a transient increase in relative risk of SCD associated with physical exertion, the absolute risk is low. Thompson’s study showed that the incidence rate was estimated to be 1 death per 15,240 joggers per year. The Seattle and King County population study estimated the incidence rate of SCD during vigorous activity to be 1 death per 20,000 per year. The Physician’s Health Study found the absolute risk of SCD during vigorous exertion to be 1 per 1.5 million episodes of exertion. Overall, there is good evidence to support habitual exercise as it diminishes the risk of SCD during vigorous exertion.

2.4.3 Sexual activity

Sexual intercourse is a recognized but uncommon trigger for AMI. In a small series of 88 men with known CAD monitored with ambulatory ECG, 31% had ischaemic changes during sexual activities. Only 22% were symptomatic and the majority had silent ischaemia. In the Onset study, Muller interviewed more than 1770 patients a week after MI. He reported that 48% of the patients were sexually active in the year prior to MI and only 3% of this group reported sexual activity in the 2-hour period before MI, with a relative risk of 2.5 (95% CI 1.7 to 3.7). In patients with prior history MI, the relative risk was similar (2.9, 95% CI 1.3 to 6.5). In the Stockholm Heart Epidemiology Programme (SHEEP), only 1.3% of 699 patients reported sexual activity in the 2-hour period prior to AMI, with a relative risk.
of 2.1 (CI, 0.7–6.5) ⁸². The authors of both studies concluded that although the relative risk of MI immediately after sexual activity is strong, the absolute risk is extremely low – ‘1 chance in a million for a healthy individual’ ⁸³. Muller’s group also demonstrated such risk can be further reduced by regular physical exercise.

2.5 Emotional triggers - Individual experiences

Adverse cardiovascular outcomes have been associated with chronic stress such as job strain ⁸⁴-⁸⁷, marital stress ⁸⁸, ⁸⁹ and other psychosocial factors ³¹. Chronic stress increases cardiovascular risk over time. Acute emotional stress has also been suggested to cause acute cardiac events ⁹⁰. Emotional upset was identified as the trigger for AMI in 18.4% of 412 patients in the MILIS study. It was the most common trigger for AMI. The next most common trigger was moderate physical exertion ⁷¹. In the TRIMM pilot study, 52% of 224 patients reported emotional stress or upset as possible acute triggers for their MI ⁴⁷. In contrast, only 1.4% of 1114 patients enrolled in the Secondary Prevention Reinfarction Israeli Nifedipine study reported unusual mental stress at the time of symptom onset ⁴³. The varied results could be explained by the methodology of these studies, where interviews were conducted to enquire about AMI triggers. Again, they lacked suitable control groups for comparison. Several studies adopted the case-cross over method to eliminate selection and individual reporting biases. Gullette et al looked at 58 patients with known CAD who were monitored with ambulatory ECG for 48 hours and were asked to record their feelings in a diary. Cardiac ischaemia was defined as ST depression of 1mm or more compared to baseline for more than 1 minute. They found that relative risk of myocardial ischaemia adjusted for physical activity and time of the day was 2.2 for tension (95% CI 1.1 to 4.5) and 2.2 for frustration (95% CI 1.1-4.3) whereas there was no significant increase risk of MI for
In the Onset study, 1623 patients completed the onset anger scale for each of the 26 hours prior to AMI, which was then compared to their frequency and level of anger in the previous year. The onset anger scale identified 39 patients with episodes of anger in the 2 hours before the onset of AMI. The relative risk in comparison to their usual level of anger was 2.3 (95% CI 1.7 to 3.2) and 4.0 (95% CI 1.9 to 9.4) to a pair-matched control period 24 hours earlier. The SHEEP study demonstrated that in patients without premonitory ischaemic symptoms, the absolute risk was 1.2% and the relative risk of AMI was 15.7 (95% CI 7.6 to 32.4) in the hour following an episode of intense anger. Episodes of anger have been shown to increase the likelihood of a ventricular arrhythmia requiring shock (odds ratio 1.8, 95% CI 1.04 to 3.16) in patients with Implantable Cardioverter Defibrillators. The SHEEP study demonstrated that a sudden increase in work related mental stress could increase risks of acute cardiac events. They found 8% of the 1381 participants who suffered AMI had a work related event 24 hours prior to their infarction. People who had a ‘high pressure deadline at work’ had a 6-fold increase in risk of AMI (OR 6.0, 95% CI 1.8 to 20.4). The Onset study also found that AMI rate is elevated 21-fold within 24 hours of learning of the death of a significant person.

2.5.1 Pathophysiology

Similar to the triggering effects of morning hours and physical exertion, emotional stress is recognized as a cause of a wide range of pathophysiological changes leading to coronary plaque rupture. Several studies involving mental stress tests on either healthy subjects or patients with CAD may provide insight into such mechanisms. Andrews et al found that during mental stress testing of 15 patients with stable angina, there was a significant increase in plasma epinephrine and norepinephrine levels, and autonomic arousal as measured by changes in skin conductance. Strike et al studied 34 men who suffered
ACS on average 15 months earlier on and asked them to perform challenging color-word interference and public speaking tasks. An interview done soon after their acute events showed 14 men had experienced acute negative emotion within 2 hours prior to AMI (the emotional trigger group). Both the emotional trigger group and the non-trigger group had similar elevation of blood pressure and heart rate during mental stress testing. However, the emotional trigger group had delayed recovery of systolic pressure and cardiac output, as well as significant increases in leucocyte-, monocyte- and neutrophil-platelet aggregation compared with the non-trigger group. Literature reviews also suggest epinephrine stimulates factor VIII clotting activity, von Willebrand factor antigen, tissue-type plasminogen activator and platelets. In healthy subjects, haemostasis equilibrium is balanced as acute mental stress enhances both coagulation and fibrinolysis whereas in patients with CAD, procoagulant responses may outweigh anticoagulant mechanisms thus promoting a hypercoagulable state. Acute mental stress has been suggested to cause endothelial dysfunction and impaired arterial vasomotor responses. A study by Yeung et al showed that mental stress testing during cardiac catheterization caused vasoconstriction in atherosclerotic coronary arteries and vasodilation in normal coronary arteries. Another study demonstrated that anger recall during coronary angiography also caused vasoconstriction in diseased coronary arteries but not in normal arteries. In summary, these studies showed that emotional and mental stresses have the potential to cause acute cardiac events through a cascade of adverse physiological process.

2.5.2 Risk modification

It is impossible to avoid emotional or mental stress in daily living. For at risk patients, several pharmacological agents have been suggested to attenuate the risk of AMI. β blockers can protect against myocardial ischaemia and SCD as they reduce heart rate and
decrease oxygen demand of myocardium. They can also reduce the mechanical and haemodynamic stress on vulnerable plaques, thus preventing or delaying rupture 103. Although the statistical power was limited in subgroup analysis, the studies of emotional stress triggering have shown trends suggesting that β blockers reduced risk of acute cardiac events 71, 92, 93. Mittleman’s group also showed that regular use of Aspirin appeared to be protective against emotional triggering of AMI 92.

2.6 Emotional triggers – Population-based studies

Emotional triggering of acute cardiac events is difficult to study. As demonstrated previously, the majority of the studies were done by collecting information from individuals after the onset of AMI. Such methodology is susceptible to retrospective reporting bias and memory decay. Patients may overestimate the triggers in the period prior to the acute events and underestimate similar exposure in the past 75. Patients may form their own beliefs about the cause of their infarction 104. It is also hard to quantify the level of emotional stress such as anger as it varies widely with individuals. The alternative is to perform a population-based study when a large group of people has been exposed to a common stimulus strong enough to trigger acute cardiac events. Studies have been performed to identify AMI and SCD event rate after sporting events, terrorist attacks, war and natural disasters.

2.6.1 Sporting events

Watching sporting events can cause emotional and mental stress in team supporters. Football is the most commonly studied sport in regards to the triggering of AMI and SCD but the findings remain controversial. Between 1994 and 1999, there was a significant increase in mortality due to AMI and stroke in males by 30% when the local professional team lost at home in the Newcastle and North Tyneside, Sunderland, Tees, and Leeds Health Authority areas of England 105. Witte et al reported that on the day the Dutch football team was
eliminated from the European football championship in 1996, mortality from CAD and stroke significantly increased in Dutch men (RR 1.51, 95% CI 1.08 to 2.09)\textsuperscript{106}. During the 1998 FIFA World Cup, an increase of out of hospital cardiac arrests among the male population of the French speaking provinces of Switzerland was observed\textsuperscript{107}. These studies did not demonstrate a significant increase in cardiovascular mortality in females. A study done by Caroll’s group showed that there was a significant 25% increase in AMI admissions to English hospitals in the 2 days after England lost to Argentina in a penalty shoot-out in the 1998 World Cup\textsuperscript{108}. The admission ratios for myocardial infarction were slightly higher in men (1.27, 95% CI 1.08 to 1.49) than women (1.16 95% CI 0.85 to 1.59). A prospective study in Germany during the 2006 FIFA World Cup involving 4279 patients showed there was an increase in the incidence of cardiac emergencies (incidence ratio 2.66, 95% CI 2.33 to 3.04), STEMI (2.49, 95% CI, 1.47 to 4.23) and cardiac arrhythmia causing major symptoms (3.07, 95% CI, 2.32 to 4.06) on the days the German team played a match\textsuperscript{19}. The highest average incidence of events was observed during the first 2 hours after the beginning of each match, supporting the triggering theory. Wilbert-Lampen et al also observed that an increased cardiac event rate was associated with the German team losing as well as winning. In contrast, there was a significantly lower mortality rate from AMI in French men on the day when France won the 1998 World Cup final\textsuperscript{109}. However not all studies have demonstrated an increase in cardiac events when watching sport. Toubiana et al replicated Witte’s study\textsuperscript{106} and failed to demonstrate an increase in all cause mortality or mortality from AMI in the French population\textsuperscript{110}. Similarly, an analysis done by Brunekreef’s group testing Witte’s hypothesis did not show increased total or cardiovascular mortality associated with five major football games played between 1988 and 1994 by the Dutch national team\textsuperscript{111}. 
2.6.2 Terrorism and war

The attacks on the World Trade Centre on September 11, 2001 were the most devastating acts of terror ever experienced in the United States. Several studies tested the hypothesis that such extreme emotional stress would trigger AMI and SCD. However, the results are mixed. Feng et al analyzed admissions to CCU at New York Methodist Hospital 4 miles from the World Trade Centre 60 days prior to and after the September 11 attacks. They found a significant increase in cardiac admissions post the attacks compared to pre September 11 (p=0.008), particularly AMI (15.5% vs 11.2%) and tachyarrhythmia (19.9% vs 13.6%). This pattern of admission was not observed in the same time period in 2000. Similarly, another retrospective study showed that there was a significant 49% increase in AMI cases (p=0.01) collectively from 16 emergency departments within a 50 miles radius of the World Trade Centre 60 days after the catastrophe. This group did not find an increase in tachyarrhythmia cases. In Worcester, Massachusetts, Goldberg and colleagues found a significant increase in AMI risk on September 11 and 12, 2001. In contrast, Chi et al conducted a survey involving 8 hospitals in New York City and failed to find an acute increase in cardiac related hospitalisation rate after the event. An analysis of death certificate data in New York City for the time period around September 11 from 1997 to 2001 did not demonstrate an excess in mortality from cardiac or cerebrovascular disease.

There were very few studies examining the effects of war on acute cardiac events. This is hardly surprising given that data collection may be extremely difficult in such chaotic times. During the initial phase of the Gulf war in 1991, Meisel et al described a significant increase in AMI, especially anterior STEMI in a tertiary hospital 24km outside of Tel Aviv. Out of hospital SCD was also markedly increased. They observed that the peak incidence of AMI closely coincided with the beginning of the war and with the first 2 missile
attacks on Israel by Iraq. Admission rates of acute cardiac events then returned to baseline with subsequent attacks. Another nationwide survey confirmed Meisel’s finding and showed a marked 58% increase in mortality in Israel on the day of the first missile strike, mostly attributed to SCD and cardiovascular disease. After the war started in Croatia in September 1991, two studies yielded different results when trying to determine the impact of war on cardiovascular events. Bergovec et al found a higher frequency of AMI and AMI mortality during the war period in the city of Zagreb, where air-raid alarms were frequent. However, another study done in Split, a coastal town in Croatia that endured air raid alarms and attacks from land and sea, did not show an increase in AMI or SCD from September to November 1991.

2.6.3 Earthquakes

Amongst all the natural disasters, earthquakes are the most frequently studied events in relation to their potential to trigger adverse cardiac outcomes. However, results have been variable. The earliest study was done in 1981 after a major earthquake in Athens. Trichopoulos et al examined death certificates and found an increase in cardiac mortality due to underlying atherosclerotic coronary disease from an average of 2.6 cases to 5.4 cases during the 5 days after the earthquake. The group yielded similar results after studying the 1978 Thessaloniki earthquake in Greece using the same methodology. The investigators did not examine the effects of earthquakes on non-fatal cardiac events. In 1989, a magnitude 5.6 earthquake struck Newcastle, New South Wales, Australia. There was a small increase in fatal AMI with a total of 6 cases within 4 days (p=0.016), which was unusually high compared to the control period.

The Northridge earthquake is one of the most thoroughly studied earthquakes. This magnitude 6.7 earthquake affected more than 15 million people in Los Angeles, Southern
California in 1994. A questionnaire survey involving 72 CCUs in the region showed that there was a 35% increase (from 149 to 201 patients) in total AMI admissions in the week following the event compared to the preceding week. Analysis of the mortality records from the Department of Coroner of Los Angeles County demonstrated a marked increase in SCD from a daily average of 4.6 cases in the previous week to 24 cases on the day of the Northridge earthquake. Deaths due to IHD and atherosclerotic coronary disease were also markedly elevated (from a daily average of 73 cases pre earthquake to 125 cases on the day of event) while there was no obvious increase in death from other cardiac causes.

Japan is a country that is especially prone to earthquakes and has generated many studies examining the impact of earthquakes on cardiac diseases. The Hanshin-Awaji earthquake killed more than 6000 people and left 250,000 homeless in 1995. Suzuki et al found a 3.5 fold increase in AMI cases presenting to Awaji Island’s only hospital during the 4 weeks following the event compared to the control periods. In their study, patients presented with AMI after the earthquake had significantly higher post traumatic stress disorder (PTSD) reaction index score, especially in women. The group concluded that earthquake induced emotional stress could trigger AMI. Another group observed an increase in AMI mortality in 16 municipalities (which covered most of the area affected by the Hanshin-Awaji earthquake) for up to 8 weeks after the event. A study involving 42 elderly people who lived near the epicenter suggested earthquake induced stress could cause a transient increase in blood pressure, blood viscosity, D-dimer and prolonged endothelial cell stimulation, thus contributing to acute cardiac events. The 2004 Niigata –Chuetsu earthquake was also found to be associated with an increase in SCD and ACS but the effects were less striking compared to previous studies. The recent devastating magnitude 9.0 Great East Japan earthquake in 2011 triggered a powerful tsunami and caused meltdowns of
the nuclear plants in Fukushima. More than 15,000 people were killed with thousands missing and injured. Aoki et al examined the ambulance records made by doctors in the Miyagi Prefecture (the centre of the disaster area) for 4 weeks before and 16 weeks after the event\textsuperscript{126}. In comparison to the control periods in 2008 to 2010, they found a significant increase in the weekly occurrence of ACS, cardiopulmonary arrest, heart failure, stroke and pneumonia. While ACS and cardiopulmonary arrest rate decreased within 2 to 3 weeks after the earthquake, heart failure and pneumonia showed a prolonged increase for more than 6 weeks.

In the 1991 Ji-Ji earthquake, a magnitude 7.3 event struck Taiwan, killing 2321 people and injured more than 10,000. A study showed a significant increase in AMI admissions in the 6 counties close to the epicenter with 99 cases in the 6 weeks following the event compared with 65 cases in the same period of the previous year (p=0.009)\textsuperscript{22}. Interestingly, they found the risk of AMI was comparatively higher in the counties with higher Richter scale measurements.

Not all studies were positive when examining the relationship between earthquakes and acute cardiac events. In 1989, the magnitude 7.0 Loma Prieta earthquake struck the San Francisco Bay area and lasted approximately 20 seconds. There were at least 63 deaths. Although it was comparable in magnitude to the Northridge earthquake (magnitude 6.7, 57 deaths), there was no statistically significant increase in AMI admissions on the day of the Loma Prieta earthquake\textsuperscript{127}. Brown hypothesized that the main difference to be the timing of the event. Northridge earthquake occurred at 4.31 am and had the added risk of early morning awakening triggering AMI whereas Loma Prieta happened at 5.04 pm when most people were awake.
2.7 Summary

In reviewing the literature, it seems that in many cases the conversion of stable CAD to acute or life threatening events is not a random event. There is evidence that acute stressors can trigger acute cardiac events. A variety of internal and external factors may trigger acute cardiac events. The physiological aftermath of morning awakening, vigorous physical exercise, mental and emotional stress appear to have a transient deleterious impact on cardiac status. Studies examining acute cardiac event triggers have often been limited by study design (retrospective studies, self-reports), patient selection and recall bias, lack of appropriate control subjects and heterogeneous triggering events. Nevertheless, methods such as case-cross over design and studying a population exposed to common stressful triggers like earthquakes may overcome some of the obstacles.

With the knowledge that potential triggers exist to cause acute coronary events, preventative measures may be adopted for at risk patients. Aspirin and β blockers have been shown to abolish the morning peak of AMI. β blockers are effective in attenuating AMI risk in the setting of emotional stress. Regular habitual physical exercise has been proven to reduce vigorous exercise induced AMI and SCD risk. Unfortunately, sudden catastrophic events like acts of terrorism and earthquakes often strike without warning. It is thus impossible to prevent the associated acute cardiac sequelae. However, knowledge of the pattern of cardiac presentations that follow triggering events will enable appropriate management plans and efficient resource allocation and will minimize subsequent cardiac mortality and morbidity.
Chapter Three – Literature Review: Stress Cardiomyopathy

3.1 Introduction

SCM is a fascinating cardiac condition that was first reported in Japan\textsuperscript{128-130}. It mimics AMI on initial presentation with ischaemic symptoms, ECG changes and elevated myocardial injury markers, and often follows acute emotional or physical stress. However, patients are often found to have normal coronary arteries or non-obstructive coronary disease on coronary angiography. The syndrome is characterized by transient left ventricular mid-wall and apical akinesis with basal segment hyperkinesis on ventriculogram or transthoracic echocardiography. This unique appearance earned it names such as apical ballooning syndrome and takotsubo cardiomyopathy (tako-tsubo is Japanese for octopus pot which is a round bottomed and narrow necked vessel)\textsuperscript{131}. It accounts for 1 to 2\% of all cases of suspected AMI\textsuperscript{132-134}. Over the past decade, there has been an increase in frequency of publications on SCM as it has gained broad attention in the field of cardiology over the world. However, given the rarity of SCM, the majority of the publications are individual case reports or small case series.

3.2 Demographic characteristics

There is striking gender discrepancy with more women presenting with SCM than men. A review of 28 case series including a total of 563 patients by Pilgrim et al showed 90\% of patients with SCM were post menopausal women with mean age from 62 to 76 years\textsuperscript{135}. Other case series demonstrated similar findings\textsuperscript{136, 137}. Men account for less than 10\% of SCM presentations\textsuperscript{138}. 
3.3 **Presenting symptoms and triggers**

At the onset of SCM, the most common presenting complaints are chest pain and dyspnea. There have been a few case reports of syncope \(^{139, 140, 141}\), cardiogenic shock \(^{131, 142, 143}\), and ventricular fibrillation \(^{142, 143}\) at initial presentation.

It is well documented that emotional or physical stress often precedes SCM presentations. Emotional triggering events range from public speaking, surprise birthday party, heated arguments, financial loss, and death of a family member to earthquakes. The most common physical triggers of SCM are exacerbation of systemic illness and surgical procedures. In one of the largest SCM case series, Sharkey et al found that in 136 consecutive patients with SCM, 121 (89%) had experienced a significant stressful event immediately preceding the presentation \(^{141}\). Emotional stress accounted for 47% of cases and physical triggers accounted for 42%. While some studies have shown emotional stress to be solely responsible for triggering SCM \(^{142, 144}\), others documented physical stressors to have caused as many as 70% of cases \(^{145, 146}\). A case series of earthquake induced SCM is presented in section 3.10.

3.4 **Clinical features**

3.4.1 **Electrocardiographic changes**

The most common ECG changes in SCM are ST segment elevation in the initial phase followed by deep T wave inversion, predominantly in the precordial leads \(^{135, 136}\). Pathological Q wave exists in 30% of cases. QT interval prolongation has been documented in many case series \(^{133, 142, 143, 145-147}\). Some investigators suggested a few specific ECG findings could help distinguish SCM from anterior STEMI. Ogura et al reported in a case
series of 13 patients that the lack of reciprocal ST segment depression, the absence of
pathological Q waves and that higher ST elevation voltage in leads V4 – V6 than V1 – V3
was highly sensitive and specific for diagnosing SCM. Jim et al compared 8 SCM
patients with 27 patients who suffered from anterior STEMI, and proposed that the absence
of ST-segment depression or ST segment elevation in inferior leads, especially if the ST
segment in lead II is higher or equal to that of lead III, was highly suggestive of SCM.
Given these were small studies, there are still no validated criteria for diagnosing SCM based
on ECG solely.

3.4.2 Cardiac biomarkers

In Pilgrim’s review, 13 case series reported an elevation of Troponin I or T in 85% of
patients, 4 studies reported an elevation of creatine kinase in 53% of cases and 5 studies
found 38% of SCM cases had an increase in creatine kinase MB. The degree of cardiac
enzyme elevation is often modest compared to AMI. Unlike AMI with evident rise
and fall of myocardial injury markers, SCM patients tend to have peak cardiac enzyme level
at the time of presentation. Plasma brain natriuretic peptide (BNP) has also been observed
to increase during the acute phase of SCM. One study reported BNP level to be a good
indicator of the severity of left ventricular basal segment hyperkinesis. A high level was not
associated with poor prognosis in SCM, unlike in other cardiac disorders.

3.4.3 Coronary angiography

Coronary angiography often reveals normal coronary arteries or non-obstructive
coronary disease when patients present acutely with SCM. However, obstructive
coronary disease does not necessarily preclude the diagnosis of SCM when there is a left
ventricular regional wall motion abnormality extending beyond the distribution of any single
coronary artery.
3.4.4 Left ventricular function

Left ventricular function is often assessed by echocardiography or ventriculogram. The most common abnormality in SCM cases is transient akinesis of left ventricular apical or mid-ventricular segments with a hyperkinetic basal region. Sharkey’s case series of 130 SCM showed 75% had the typical apical ballooning pattern. Pilgrim’s review of case series documented reduced mean left ventricular ejection fraction ranging from 20 to 49.4% on admission and recovered to 59 to 76% over a period of 18 days on average (mean time range to recovery 7–37 days). Most patients would have complete resolution of the presenting regional wall motion abnormality. Other variants of SCM also exist such as mid-ventricular ballooning with basal and apical hyperkinesis and left ventricular basal ballooning, also known as the ‘inverted Takotsubo’ pattern. Right ventricular involvement is estimated in 30% of SCM cases and these patients tend to be more severe cases with greater tendency to develop heart failure.

3.5 Diagnostic criteria

The diagnosis of SCM should be considered as a differential diagnosis in patients presenting with AMI, especially in postmenopausal women. However, there is no general consensus on the diagnostic criteria for SCM. In 2008, Prasad et al proposed criteria that have become known as the modified Mayo criteria. They are commonly used in publications in the field. The modified Mayo criteria comprise: (1) Transient hypokinesis, akinesis, or dyskinesis of the left ventricular mid segments with or without apical involvement; the regional wall motion abnormalities extend beyond a single epicardial vascular distribution; a stressful trigger is often, but not always present. (2) Absence of obstructive coronary disease or angiographic evidence of acute plaque rupture (the authors noted it is possible that a patient with obstructive coronary atherosclerosis may also develop...
SCM).  (3) New electrocardiographic abnormalities (either ST-segment elevation and/or T-wave inversion) or modest elevation in cardiac troponin.  (4) Absence of pheochromocytoma or myocarditis. These criteria therefore require early echocardiography and coronary angiography studies as well as follow-up echocardiograms. These investigations were not routine pre-discharge until recent years and may explain why SCM is a recent diagnosis.

3.6 Prognosis and complications

The prognosis of SCM is generally favorable with less than 2% of in-hospital mortality rate. A variety of complications have been described during the initial acute phase of SCM. Pulmonary oedema and left ventricular failure is most common, occurring in up to 46% of patients in case series. Dynamic left ventricular outflow tract obstruction may occur due to basal segment hyperkinesis and systolic anterior motion of mitral leaflet. A study reported 18% of patients had a significantly increased intraventricular pressure gradient during the acute phase which quickly resolved in the sub-acute phase. Pilgrim et al observed cardiogenic shock in 10% of patients in their review of case series. Other rare complications such as life threatening arrhythmia, left ventricular free wall rupture and intramural thrombus formation have been reported. Given the appropriate supportive care during the acute phase, patients are expected to have complete recovery of left ventricular systolic function and regional wall motion abnormality within days to weeks.

3.7 Recurrence and survival

The recurrence rate of SCM ranges from 3% to 11%. There are mixed reports on the long-term survival of SCM patients. Sharkey et al observed a reduced survival in 136 SCM patients compared to that expected for an age- and sex-matched general population.
They reported 17 deaths (15%) from 4 months to 4.7 years from SCM onset, predominantly due to malignancy. Elesber et al also had 17 deaths in the follow up of 100 SCM patients in 4 to 8 years. They concluded that there was no difference in survival or in cardiovascular survival to an age- and gender matched population. Parodi et al reported that SCM patients had better survival and freedom from major cardiac events at 6 months than patients with CAD.

3.8 Treatment

The optimal management for SCM has not been established. Given the presentation often mimics acute myocardial ischaemia due to obstructive coronary disease, initial treatment often includes anti-platelet agents until emergency coronary angiography rules out coronary disease. Prompt diagnosis of associated complications and delivering appropriate supportive care is most important. Hypotension is common and can be caused by acute pump failure or dynamic left ventricular outflow tract obstruction due to basal segment hyperkinesis and systolic anterior motion of mitral leaflet. While intravenous inotropic agents may be beneficial for acute pump failure, it is contraindicated for dynamic outflow obstruction. Cautious trial of intravenous fluid and β blockers may be helpful in this situation provided there is no significant heart failure. Peripheral vasoconstrictors such as phenylephrine may be considered if β blockers and fluid administration are contraindicated or ineffective. Mechanical support such as intra aortic balloon pumping has been used for blood pressure support. Diuretic therapy is often needed for heart failure symptoms. Anticoagulation should be considered if intraventricular thrombus is suspected. For sub-acute and long-term management of SCM, several groups, including the Mayo clinic, recommend empirical treatment with β blockers and angiotensin converting enzyme inhibitor.
(ACE inhibitor) or angiotensin receptor blocker (ARB)\textsuperscript{138,153}. Once left ventricular function has recovered, ACE inhibitors or ARB may be ceased.

### 3.9 Pathophysiology

The pathophysiology of SCM remains unclear. Most studies suggest a neurohormonal effect of excess catecholamine production and exaggerated sympathetic nervous stimulation. Wittstein et al found SCM patients to have significantly higher epinephrine and norepinephrine level compared to patients who suffered AMI\textsuperscript{142}. Abraham et al described 9 cases of SCM manifestation immediately post intravenous administration of epinephrine or dobutamine\textsuperscript{168}. Ueyama’s group showed pre-treatment with adrenal blockage in rats successfully prevented emotional stress induced reversible apical ballooning\textsuperscript{169}. Several groups used 123 I-metaiodobenzyl-guanidine imaging in SCM patients to assess cardiac sympathetic activity. Akashi’s group suggested cardiac sympathetic hyperactivity and neurogenic myocardial stunning as the causative mechanism in 8 SCM patients on the basis of heart–mediastinum ratios and higher radioisotope washout rates in the initial stage compared with follow-up scans 3 months later\textsuperscript{134}. Burgdorf and colleagues concluded that SCM could be caused by a functional alteration in myocardial presynaptic sympathetic neurotransmission\textsuperscript{170}.

Microvascular dysfunction has been associated with SCM. The Mayo clinic demonstrated abnormal myocardial perfusion in 29 out of 42 patients by performing coronary angiography and analyzing Thrombolysis In Myocardial Infarction myocardial perfusion grade\textsuperscript{171}. Transthoracic echocardiography\textsuperscript{172-174}, nuclear scan\textsuperscript{149,175} and intra-coronary Doppler\textsuperscript{176,177} have also been utilized to demonstrate microvascular dysfunction in SCM patients. These studies were limited by small patient samples given the rarity of the
syndrome. It is still unclear whether microvascular dysfunction causes SCM or whether it
could be a secondary response to sudden increases in mechanical wall stress. Multi-vessel
coronary artery spasm and myocarditis have been speculated as possible causes of SCM but
are not strongly supported by the literature.

The greater propensity for SCM in postmenopausal women remains a mystery. A
deficiency in oestrogen has been postulated given the higher incidence of SCM in
postmenopausal women, however, little data exists to clarify this issue. Ueyama et al showed
a significant reduction in left ventricular contraction with apical ballooning in ovariectomized
female rats exposed to stress by immobilisation. They also demonstrated oestrogen
supplementation attenuated cardiac responses to similar stress. They hypothesized that
oestrogen attenuated the stress-induced sympato-adrenal outflow from the brain to the heart
and upregulates various cardioprotective substances such as atrial natriuretic peptide and
Heart Shock Protein 70. Obviously, more investigations are warranted to establish such
relationships.

3.10 Stress cardiomyopathy and earthquakes

Major earthquakes cause significant emotional and physical stress. Thus, it is not
surprising that they can trigger SCM. However, there are very few reports on earthquake
related SCM cases. This may be due to the fact that the majority of the earthquake related
cardiovascular studies were done prior to SCM being recognized widely as an acute cardiac
condition. Also, unlike the modern era, coronary angiography and echocardiography were
not as readily available to allow for the accurate diagnosis of SCM. When diagnosis was
made based on patient’s clinical features and rudimentary investigation such as
electrocardiography findings, SCM could easily have been mistaken for AMI.
After the 1995 Great Hanshin earthquake in Japan, Yamabe et al reported 6 patients with deep T wave inversion on ECG after presenting with either chest pain or dyspnea. These were elderly patients (mean age 70 ± 8 years) and 5 were females. Coronary angiography revealed normal or minimal coronary disease in 3 patients. Cardiac imaging with $^{123}$I-metaiodobenzyl-guanidine demonstrated significant total or regional defects involving the anterior wall and the apex with markedly increased wash out rate. These findings were similar to those studies done on confirmed cases of SCM patients years later. Although Yamabe’s group did not directly associate the phenomenon observed with SCM, it is highly likely to be the case. The only other earthquake that has been associated with SCM in the literature was the 2004 Niigata –Chuetsu earthquake. Watanabe et al reported 25 cases of SCM in the 4 weeks following the event. Sato et al found that SCM occurred predominantly in elderly women on the day of the earthquake who lived near the epicenter.

### 3.11 Stress cardiomyopathy and other natural disasters

The relationship between natural disasters other than earthquakes and SCM is even less well described in the literature. Butterly et al reported 2 cases of SCM after the 2011 Queensland floods in Australia. Both patients were post-menopausal women without angiographic evidence of coronary disease and presented with the typical apical ballooning pattern of left ventricular dysfunction. Recently at the American College of Cardiology’s 63rd Annual Scientific Session, Pant et al presented their findings of SCM case clustering in the United States in 2011. They found Vermont and Missouri had the maximum number of SCM cases. They speculated that Tropical storm Irene (Vermont) and Joplin tornado (Missouri) which occurred in 2011 were potential triggers for increased SCM presentations.
3.12 Summary

SCM is a rare but potentially fatal condition. It is a great mimicker of AMI with typical ischaemic symptoms, ECG changes and abnormal myocardial injury markers. Given the management of SCM is different to AMI, prompt diagnosis of this condition is crucial and requires timely performance of coronary angiography and echocardiography. Most of the publications involve case reports and small case series where SCM are triggered by heterogeneous stressors. There is only 1 published case series of 25 patients developing SCM after been exposed to a common stressor – the 2004 Niigata earthquake. Although the exact mechanism is still unknown, there is no denying that emotional stress can cause severe myocardial dysfunction in SCM.
Chapter Four – Methodology

4.1 Introduction

A large-scale retrospective audit was undertaken within 4 weeks after the September 2010 earthquake and February 2011 earthquake to clarify their impacts on acute cardiology events. This chapter outlines the research methodology utilized for the study including study periods, study population, data collection and statistical analysis.

4.2 Ethical approval

The Southern Health and Disability Ethics Committee was consulted for consideration of expedited ethical approval for the main study. They advised ethical approval was not required because this study did not require direct patient contact and would not identify individuals. For the follow-up subgroup study of the 21 SCM patients, ethical approval was obtained subsequently (see Chapter Six for details).

4.3 Study design and study periods

The main study was designed as a retrospective audit with time matched control periods from preceding years with the aim to address the first three hypotheses outlined in Chapter One. A study period of 3 weeks prior to and 5 weeks following each earthquake was chosen after review of relevant literature. Previous studies have demonstrated that the effects of earthquake on acute cardiac presentations may vary from days up to a few weeks after the event. The 5 week post-earthquake period was chosen to ensure we had a more than adequate follow-up period after each event. The 3 week pre-earthquake period was chosen as a sufficient comparator period. The study period for the 4 September 2010 earthquake was
from 14 August to 8 October 2010 and for the 22 February 2011 earthquake, 1 February to the 28 March 2011. The corresponding time period from the previous year served as control - 15 August to 9 October 2009 for the September earthquake and 2 February to 29 March 2010 for the February earthquake.

4.4 Study population

The study population consisted of patients who presented acutely to the Cardiology Department either via the Emergency Department or referred by their General Practitioners in the time period specified above, and who were residents of the earthquake zone (Christchurch city, Waimakariri and Selwyn district). These patients were identified by using the electronic patient management system at Christchurch Hospital. Patients transferred from other Hospitals outside of Christchurch (including Timaru, Greymouth and Ashburton) or who were admitted electively were excluded from the study.

4.5 Data collection

Systematic review of the clinical files, electronic discharge summaries, coronary angiograms and echocardiograms were completed for each patient. Data collected included basic patient characteristics, date of admission and discharge, and investigations performed. Cardiac diagnoses were defined according to accepted validated criteria.

4.5.1 ST elevation myocardial infarction and Non ST elevation myocardial infarction

STEMI was defined as chest pain associated with at least 2 millimetres of ST segment elevation in 2 precordial leads or 1 millimetre in 2 other contiguous leads on ECG. NSTEMI was defined as chest pain associated without ST segment elevation. Other ECG changes such as ST segment depression may or may not be present. For both STEMI and
NSTEMI cases, a rise and fall in serial troponin I level with peak level >0.03µg/l and culprit lesion(s) identifiable on coronary angiography were required.

4.5.2 Unstable angina and stable angina

Unstable angina was defined as ischaemic symptoms at rest or with little physical exertion, with or without dynamic ECG changes, and with serial troponin I of <0.03µg/l. Stable angina was defined as ischaemic symptoms onset only with physical activities, without dynamic ECG changes and with serial troponin I of <0.03µg/l. For newly presented patients, the diagnosis is made following either positive stress tests or coronary angiography to confirm CAD. In those who have known CAD on previous coronary angiography, further stress test or repeat imaging was not necessary to make the diagnosis.

4.5.3 Non-cardiac chest pain

Non-cardiac chest pain (NCCP) was defined as chest pain presentation without associated ECG changes and with serial troponin I <0.03µg/l at least 12 hours after the onset of symptoms. Other significant causes of chest pain had to be excluded to the satisfaction of the attending Cardiologist. Where exercise ECG, exercise echocardiograms or dobutamine stress echocardiograms were undertaken, the results were negative. In cases where coronary angiography was performed, significant obstructive CAD had to be excluded for the patient to be classified as having NCCP.

4.5.4 Cardiac arrhythmia

Cardiac arrhythmia presentations were classified into heart block (second degree or complete), ventricular arrhythmia, atrial fibrillation (AF), atrial flutter or supraventricular tachycardia (SVT). Cardiac arrest was defined as arrhythmia (ventricular or asystole) that required electrical cardioversion or CPR to support circulation. All diagnoses of arrhythmia were confirmed by review of the ECGs.
4.5.5 Stress cardiomyopathy

SCM was defined as all patients who were admitted with chest pain and who satisfied the modified Mayo criteria: evolving ECG changes (ST elevation, ST depression or T wave inversion), a troponin I rise >0.03µg/l, a recognised transient echocardiographic regional wall motion abnormality (apical ballooning pattern, mid wall variant or basal segment variant), and no culprit lesion on coronary angiography.

4.5.6 Other cardiac presentations

Patients classified as having heart failure had symptoms and signs in keeping with the diagnosis, plus one of the following – radiographic changes of fluid overload, elevated BNP above the diagnostic cut point for our laboratory of 80pmol/L, or ventricular dysfunction on Echocardiogram. A diagnosis of pericarditis was made if patient had typical symptoms and saddle shaped ST elevation on ECG, with normal serial troponin I (<0.03µg/l), with or without pericardial effusion on echocardiogram and prodromal illness. Significant valvular heart disease was diagnosed when patients have severe valvular lesion on echocardiography and associated symptoms. The diagnosis of pulmonary embolism (PE) was made radiologically either by CT pulmonary angiography or ventilation perfusion scanning.

4.6 Statistical analysis

Statistical analysis was performed under the supervision of Associate Professor Christopher Frampton, a biostatistician at the University of Otago, Christchurch. The demographic and presentation features of the control and study groups were compared using chi-square tests and t-tests as appropriate. The number of total cardiac admissions and the occurrences of each specific cardiac diagnosis before and after both earthquakes (Aug - Oct 2010 & Feb - Mar 2011) were compared to the respective control periods in the previous
years (Aug – Oct 2009 & Feb – Mar 2010). A Poisson regression model which included terms for the pre and post-earthquake periods, the earthquake and control periods, and the interaction of these two factors was fitted to the admission data. The interaction term which directly compares the changes (before to after) between the control and earthquake periods was the focus of the analyses. A two-tailed p-value <0.05 was taken to indicate statistical significance.

The above method was not suitable to assess the change in SCM rate given its rare occurrence. Instead, the Poisson 95% confidence interval for the events prior to and following each earthquake was calculated.

4.7 Medium term follow up study of 21 cases of stress cardiomyopathy following the February 2011 earthquake

Within 4 days of the February 2011 earthquake, 21 people presented to Christchurch Hospital with SCM. A detailed subgroup analysis was launched, carefully documenting patient’s basic characteristics, clinical features of disease presentation, investigations, treatment and short-term clinical outcomes.

A medium term follow up study was conducted at 12 months post event to assess cardiovascular health and psychological outcomes of this group of patients. Telephone interviews and psychometric questionnaires were conducted to collect crucial data for further analysis (for details of the study see Chapter Six).
Chapter Five – Results

5.1 Introduction

The earthquakes have provided a unique opportunity to examine the short-term effects of 2 earthquakes on a range of acute cardiac presentations. This chapter summarizes the impacts of the September 2010 and the February 2011 earthquakes on overall acute cardiology admissions, ACS, cardiac arrhythmia, SCM and other cardiac presentations. Baseline patient characteristics of the study and the control groups will be summarized.

5.2 Basic patient characteristics

In total, 2480 patients were included in the study. The baseline patient characteristics collected include age, gender, history of IHD, hypertension, diabetes, dyslipidaemia, congestive heart failure (CHF), AF/atrial flutter, cerebral vascular events, smoking and psychiatric illness. The results are summarized in Table 2. There was no significant difference in baseline patient characteristics between each study group and its control, or between each study group.

<table>
<thead>
<tr>
<th></th>
<th>2009 Sep Control</th>
<th>2010 Sep EQ</th>
<th>2010 Feb Control</th>
<th>2011 Feb EQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>607</td>
<td>678</td>
<td>579</td>
<td>616</td>
</tr>
<tr>
<td>Age</td>
<td>62.9 (+/-14.0)</td>
<td>64.1 (+/-13.0)</td>
<td>63.3 (+/-13.1)</td>
<td>64.3 (+/-12.7)</td>
</tr>
<tr>
<td>Male</td>
<td>358 (59.0%)</td>
<td>347 (51.2%)</td>
<td>277 (40.8%)</td>
<td>244 (42.1%)</td>
</tr>
<tr>
<td>IHD</td>
<td>224 (36.9%)</td>
<td>277 (40.8%)</td>
<td>244 (42.1%)</td>
<td>270 (43.9%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>259 (42.7%)</td>
<td>337 (49.7%)</td>
<td>264 (45.6%)</td>
<td>276 (44.9%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>91 (15.1%)</td>
<td>112 (16.6%)</td>
<td>94 (16.2%)</td>
<td>106 (17.2%)</td>
</tr>
<tr>
<td>Dyslipidaemia</td>
<td>208 (34.4%)</td>
<td>220 (35.8%)</td>
<td>220 (35.8%)</td>
<td>220 (35.8%)</td>
</tr>
<tr>
<td>CHF</td>
<td>88 (14.5%)</td>
<td>110 (16.2%)</td>
<td>80 (13.9%)</td>
<td>68 (11.0%)</td>
</tr>
<tr>
<td>AF/A.Flutter</td>
<td>106 (17.6%)</td>
<td>114 (16.9%)</td>
<td>98 (17.0%)</td>
<td>101 (16.4%)</td>
</tr>
<tr>
<td>CVA</td>
<td>64 (10.6%)</td>
<td>74 (10.9%)</td>
<td>57 (9.8%)</td>
<td>56 (9.1%)</td>
</tr>
<tr>
<td>Smoking</td>
<td>88 (14.5%)</td>
<td>83 (12.2%)</td>
<td>82 (14.2%)</td>
<td>84 (13.6%)</td>
</tr>
<tr>
<td>Psych illness</td>
<td>122 (20.1%)</td>
<td>129 (19.1%)</td>
<td>124 (21.5%)</td>
<td>134 (21.9%)</td>
</tr>
</tbody>
</table>

Table 2 - Basic patient characteristics
5.3 Acute cardiology admissions

Soon after commencing the study, we could identify a significant increase in admission rate in the first 2 weeks following the events. From the third week onwards, the admission rate then returned to baseline. This provides a rationale for focusing on and analysing all the specific outcomes out to 2 weeks only. On average, 75 patients were admitted acutely each week during the control periods. In the week immediately following the 4 September 2010 event, there were 120 acute admissions. In the second week, there were 100 admissions. In the week following the 22 February 2011 event, there was a similar increase with 116 patients, but the admission rate then returned to baseline in the second week. Statistical analysis using the Poisson regression model showed that the increase in total cardiology admissions in the 2 weeks following the first earthquake was significant (p=0.003). There was a trend to an increase in admission rate 1 week after the February 2011 (p=0.051). The pattern of acute cardiology admissions in the weeks before and after the 2 earthquakes is shown in figure 4.

![Figure 4 - Total acute cardiology admissions](image-url)
5.4 ST elevation myocardial infarction

In the first 2 weeks after the September 2010 earthquake (EQ week and 1 week after), there was a significant increase in STEMI presentations with 9 and 11 cases respectively (p=0.016) (figure 5) compared with the 2009 control period and the 3 weeks prior to the September earthquake. The STEMI rate then decreased sharply in the third week to 1 case only. In contrast, there was no significant increase in STEMI cases after the February 2011 earthquake (first week following earthquake, p=0.405).

![Figure 5 - STEMI presentations](image)

5.5 Non-cardiac chest pain

There was an increase in non-cardiac chest pain presentations in the 2 weeks after the September 2010 earthquake with 46 cases in the first week and 36 cases in the following week. This was statistically significant compared with the 2009 control period and the 3 weeks prior to the September earthquake (p=0.022) (figure 6).
Non ST elevation myocardial infarction, unstable angina and stable angina presentations

At a glance, there seemed to be a marked increase in other chest pain presentations (NSTEMI in the week following 2010 event, unstable angina in the second week following both earthquakes and stable angina in the week following both events). However, statistical analysis showed these to be non-significant. There was no significant increase in the presentations of NSTEMI (2010 earthquake, p=0.139) (figure 7), unstable angina (2010 earthquake, p=0.12; 2011 earthquake, p=0.597) (figure 8) or stable angina (2010 earthquake, p=0.255; 2011 earthquake, p=0.858) (figure 9).
Figure 7 - NSTEMI presentations

Figure 8 - Unstable angina presentations
Figure 9 - Stable angina presentations

5.7 Cardiac arrhythmia

There were no statistically significant changes in acute cardiac arrhythmia presentations in the first 2 weeks following both earthquakes (figure 10).
Again, there seemed to be a marked increase in AF and atrial flutter presentations after the first earthquake. However, given the high baseline presentation rate in the preceding weeks and the corresponding control period, this was not statistically significant ($p=0.243$) (figure 11).
5.8 Stress cardiomyopathy

There were no reported cases of SCM in the 2009 and 2010 control periods. After the September earthquake there were 6 cases. There was a dramatic increase with 21 SCM presentations within 4 days of the February 2011 earthquake. The 95% confidence intervals on the rate over 5 weeks are 0 to 1.27 for the control period and 0.44 to 2.62 and 2.6 to 6.4 respectively for each earthquake. This showed a significant increase for the February 2011 earthquake (p<0.05) (figure 12).

![Figure 11 - AF and atrial flutter presentations](image-url)
5.9 Other cardiac presentations

Neither earthquake affected presentation rates for CHF (figure 13), pericarditis (figure 14), PE (figure 15), or significant valvular heart disease (figure 16).
Figure 13 - CHF presentations

Figure 14 - Pericarditis presentations
Figure 15 – PE presentations

Figure 16 - Significant valvular disease presentations
5.10 Summary

Acute cardiac presentations were significantly affected by both earthquakes but in different ways. Following the September 2010 earthquake, there was a significant increase in STEMI and non-cardiac chest pain presentations and a lesser increase in SCM. Six months later, the second earthquake triggered 3 times as many SCM cases within 4 days, without a spike in AMI. The other striking finding was that the effects of the earthquakes on acute cardiac presentations were most apparent in the first 2 weeks following events. After that, the changes in acute cardiac admission dissipated. Neither earthquake affected the admission rate of NSTEMI, unstable angina, stable angina, cardiac arrhythmia, CHF, PE, pericarditis or significant valvular heart disease.
Chapter Six – Characterization and Medium Term Follow-Up of 21 Cases of Stress Cardiomyopathy Following the February 2011 Earthquake

6.1 Introduction

Within a few days of the February 2011 earthquake, 21 patients presented to Christchurch Hospital with SCM. The Christchurch Cardiology Department admits approximately 6 patients with SCM per year. After the September 2010 earthquake, there were 6 cases of SCM. The surge of SCM cases after the February earthquake generated a vast amount of interest. This chapter details the initial presentation of SCM triggered by the magnitude 6.3 earthquake, including clinical features, investigations, treatments and short-term clinical outcomes. Sections 6.3 to 6.6 summarize the findings of a follow up study conducted at 12 months after the event. This study aimed to determine the longer-term outcomes of patients’ cardiac and health status, as well as their psychological well-being.

6.2 Patient presentations after the February 2011 earthquake

6.2.1 Timing of presentations

On the day of the 22 February earthquake, 4 patients presented acutely to the admitting cardiology team with SCM. The admission rate peaked at 9 cases on 23 February. On 24 and 25 February 2011, 6 and 2 patients were admitted with SCM respectively (figure 17).
In total, 62 cardiac patients were admitted acutely in the first 96 hours following the February earthquake. The 21 cases of SCM comprised one third of the overall admissions (figure 18).
6.2.2 Basic patient characteristics

All 21 SCM patients were postmenopausal females with median age of 68 years (52 to 85 years). Only 1 woman had a history of IHD with stenting to her right coronary artery and circumflex artery in September 2010. She presented shortly after the September earthquake with the typical apical balloon pattern of SCM. Her regional wall motion abnormality on echocardiography study extended beyond the area supplied by her diseased coronary arteries. Another woman also had a history of SCM. She had presented in August 2009 with apical ballooning. As a whole, the group had few conventional cardiovascular risk factors such as hypertension (23.8%), diabetes (0%), dyslipidaemia (38%) or smoking (23.8%). There was also very low rate of atrial arrhythmia (9.5%), cerebrovascular disease (4.8%) and psychiatric illness (9.5%). The findings are summarized in table 3.

<table>
<thead>
<tr>
<th>Total cases = 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Females</td>
</tr>
<tr>
<td>NZ European</td>
</tr>
<tr>
<td>IHD</td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Diabetes</td>
</tr>
<tr>
<td>Dyslipidaemia</td>
</tr>
<tr>
<td>AF / Atrial flutter</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
</tr>
<tr>
<td>Current or ex-smoker</td>
</tr>
<tr>
<td>Previous SCM</td>
</tr>
<tr>
<td>Psychiatric illness</td>
</tr>
</tbody>
</table>

Table 3 - Basic characteristics of the 21 SCM patients
6.2.3 Clinical features

All patients had chest pain on admission. A patient presented with chest and flank pain concurrently. One woman also had palpitations and another woman had dyspnea. Everyone identified the powerful earthquake to be the stressor responsible for triggering symptoms except for the woman who had chest and flank pain. She reported the combination of flank pain and the earthquake caused her chest pain. She was found to have renal calculi as well as SCM.

6.2.4 Myocardial injury marker

All patients had troponin I measured upon presentation. The median troponin I level was 1.6 µg/l (0.02 to 9.2 µg/l). Troponin I level was repeated in 14 patients during admission, ranging from a few hours to 2 days later. The median repeat troponin level was 2.7 µg/l (0.34 to 7.8 µg/l). Four women discharged from hospital on the same day did not have a repeat test. However, 3 patients who did not have serial troponin I had at least 24 hours of hospital admission. It was unclear in this group why troponin I was not repeated.

6.2.5 Electrocardiography studies

All 21 patients had an ECG on admission. The most common changes seen were ST elevation (57.1%) - anterior in 11 patients and laterally in 1 patient. T wave inversion was found in 6 patients (28.6%). Two patients had ST segment depression (9.5%) and 1 woman (4.8%) did not have significant ST changes on admission initially, but developed deep T wave inversion later on. The majority of patients had serial ECGs during hospital stay except for 2 women who were discharged on the same day. Discharge ECGs were done at a median time of 24 hours (3 to 60 hours). More than half of the SCM patients developed deep T wave inversion (13 patients). Median QTc interval prolongation was prolonged at
discharge (493ms range 355ms to 592ms) compared to QTc on admission (437ms range 356ms to 604ms). Only 3 patients had Q waves.

6.2.6 Echocardiography

All patients had echocardiography studies within 24 hours of initial presentation. The typical pattern of mid wall and apical hypokinesis or akinesis was documented in 19 women (90.5%). The other 2 women had the mid wall variant of SCM with sparing of the apex (9.5%). The median left ventricular ejection fraction was 39% (30% to 53%). The patient who presented with the typical takotsubo form of SCM after the September earthquake had a different regional wall motion abnormality on this occasion. She had the mid wall variant of SCM.

6.2.7 Coronary angiography

Coronary angiography was performed in 20 women. The patient with previous history of SCM in August 2009 had a completely normal study then, therefore the test was not repeated. The woman who had previous right coronary artery and circumflex artery stenting was found to have patent stents with no new disease. One patient was found to have severe circumflex disease that required treatment. Her left ventricular regional wall motion abnormality extended beyond the diseased single coronary vascular bed and involved the whole of apex and mid wall region. The rest of the group had either normal coronary arteries (9 patients) or mild atheroma only (9 patients).

6.2.8 Length of stay and complications

The average length of hospital admission was 37 hours, ranging from 3 hours to 120 hours. Fortunately, none of the patients had serious complications during hospital stay. Two women developed mild left ventricular failure in hospital and another patient was readmitted to hospital after discharge with left ventricular failure. Their symptoms resolved with oral
Frusemide treatment. A patient was hypotensive initially but did not require inotropic support or intra-aortic balloon pump insertion. There were no deaths in this SCM group during the study period.

6.2.9 Follow-up and left ventricular function

The follow up rate post discharge was good with 19 patients attending Cardiology Outpatient clinic review (90.5%). One patient moved to the North Island prior to her follow up appointment and another did not attend. The median time to clinic follow up was 56 days (35 to 394 days). Echocardiography studies were repeated a few days prior to or on the day of the clinic appointments. All 19 patients had normal left ventricular systolic function with a median left ventricular ejection fraction of 67% (57% to 74%). Only 2 patients had residual mild apical hypokinesis whereas everyone else had no left ventricular regional wall motion abnormality.

6.2.10 Medications

Data on medication treatment prior to SCM onset, during admission and after clinic follow-up were collected (table 4).
Prior to the February 2011 earthquake, this group of patients were on few medications. After the onset of SCM, Aspirin and ACE inhibitor (or ARB) treatment more than doubled during hospital admission. Nineteen of the 21 patients were on a β blocker. There was no significant increase in Clopidogrel, long acting nitrate, calcium channel blocker or anxiolytic medication usage. At clinic follow up, many patients were told to stop taking β blocker and Aspirin and fewer patients continued taking ACE inhibitor or ARB compared to during admission. Such a decision is most likely based on the fact that left ventricular function had returned to normal in all patients.

Table 4 - Medication treatment prior to SCM onset, during admission and post cardiology clinic follow up

<table>
<thead>
<tr>
<th></th>
<th>Prior to SCM onset N = 21</th>
<th>During admission N = 21</th>
<th>Post clinic follow up N = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspirin</td>
<td>7 (33.3%)</td>
<td>16 (76.2%)</td>
<td>7 (36.8%)</td>
</tr>
<tr>
<td>Clopidogrel</td>
<td>1 (4.8%)</td>
<td>2 (9.5%)</td>
<td>1 (5.3%)</td>
</tr>
<tr>
<td>β blocker</td>
<td>3 (14.2%)</td>
<td>19 (90.5%)</td>
<td>6 (31.6%)</td>
</tr>
<tr>
<td>ACEI/ARB</td>
<td>4 (19%)</td>
<td>9 (42.9%)</td>
<td>6 (31.6%)</td>
</tr>
<tr>
<td>Statin</td>
<td>6 (28.6%)</td>
<td>7 (33.3%)</td>
<td>6 (31.6%)</td>
</tr>
<tr>
<td>Long acting nitrate</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (5.3%)</td>
</tr>
<tr>
<td>Calcium channel blocker</td>
<td>1 (4.8%)</td>
<td>1 (4.8%)</td>
<td>1 (5.3%)</td>
</tr>
<tr>
<td>Anxiolytics</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
6.3 Follow up study at 12 months

It is clear from the literature that the prognosis for SCM is excellent with prompt recovery of left ventricular function and low recurrence rate. However, the majority of the case series comprise of patients who were exposed to a single stressful event. Very little is known about the health outcome of SCM patients when they are exposed constantly to similar triggering stressors such as regular major aftershocks. Watanabe’s group reported a case series of 25 SCM following the 2004 Niigata earthquake in Japan but they did not have follow up data on these patients. For this reason, a follow up study was conducted on all 21 earthquake induced SCM patients 12 months after the February 2011 event.

6.4 Methods

6.4.1 Telephone interviews

Telephone interviews were conducted between in March 2012, between 12 and 13 months after the February 2011 earthquake. A structured questionnaire was used to assess patients’ self-reported cardiac and general health status (Appendix A). Patients answered questions enquiring about their cardiac symptoms, especially in relation to major aftershocks, hospital admissions, other non-cardiac medical conditions and treatment. Other data collected include exercise habit, place of residence and medications.

6.4.2 Psychometric questionnaires

After the initial telephone interview, 3 validated psychometric questionnaires were posted out for consenting patients to complete. The Health Anxiety Questionnaire (HAQ), the Hospital Anxiety and Depression Scale (HADS) and the Impact of Event Scale - Revised (IES-R) were used to assess the psychological well-being of this cohort of patients. The HAQ was developed to identify individuals with high levels of concern about their health.
The 21 item scale quantifies four factors: worry and health preoccupation, fear of illness and death, reassurance-seeking behavior and the extent to which symptoms interfere with a person's life (Appendix B). Total scores of 0–8 have been classified as representing low, 9–13 as medium, and 14 and above as high health anxiety\(^\text{185}\). The HADS has been shown to accurately diagnose generalized anxiety disorders and major depressive episodes in an out-patient setting\(^\text{186}\) (Appendix C). Anxiety disorders and depression are defined by the use of a score \(\geq 8\) as cut-off. The IES-R was developed to reflect the Diagnostic and Statistical Manual of Mental Disorders IV criteria of PTSD in 1997\(^\text{187}\). It aims to assess levels of intrusion, avoidance and hyperarousal. Patients who score \(\geq 33\) may have PTSD (Appendix D).

In anticipation of abnormal results from the psychometric questionnaires, a Senior Clinical Psychologist working for the Canterbury District Health Board was consulted. She agreed to provide clinical assistance if patients required further assessment indicated by the outcome of their tests.

### 6.4.3 Ethical approval

Expedited ethical approval was obtained from the Southern Health and Disability Ethics Committee. Patient confidentiality and anonymity was preserved, as this study does not disclose their names, address or hospital identification numbers. The collected raw data are kept in a secure place and only the researcher has access to the database.

### 6.5 Telephone interview results

#### 6.5.1 Survival and place of residence

All 21 patients were successfully interviewed. Two patients left Christchurch shortly after the February earthquake. One had taken residence in the North Island and other had
returned to live in Christchurch 13 months after the event. The remaining 19 patients stayed in Christchurch. Out the 19 patients, only 1 woman moved house as the earthquake had destroyed her home.

6.5.2 Recurring symptoms

Initially, 6 women (27%) still had chest pain after discharge. Five patients reported that they have experienced a few episodes of chest pain with aftershocks. One patient experienced chest pain on exertion. She had normal coronary arteries on coronary angiography in February. Fortunately, their symptoms all settled by May 2011.

6.5.3 Hospital admissions

In the 12 month follow up period, there were a total of 6 hospital admissions - 5 patients (23.8%) were admitted to hospital and 1 of them had 2 admissions. There were 3 cardiac related admissions in March 2011, not long after the initial SCM presentation. One patient re-presented 1 day after discharge with heart failure symptoms. She stayed in hospital for another 24 hours and received treatment for heart failure. Another patient presented to Timaru Hospital 9 days after she was discharged from Christchurch Hospital with chest pain. Her ECG changes were similar to her discharge ECG. She had a minor high sensitivity troponin T elevation (hs TNT = 49, normal range 0 to 13). She was not in heart failure and chest X-ray showed clear lung fields. She was managed conservatively and was discharged on the same day. Another patient presented 28 days after initial discharge with AF requiring rate control treatment.

There were 3 non-cardiac related admissions that occurred later on. A patient with a history of chronic obstructive airway disease was admitted to Waikato Hospital in July with exacerbation of airway disease. Another patient had multiple compression fractures in
December, requiring rehabilitation. The patient who presented in March with AF had renal colic due to calculi. She was admitted under the Urology team in November.

6.5.4 Other health issues

Seven patients (33%) reported ongoing active medical problems. Musculoskeletal disorder was the commonest concern with 5 patients suffering from conditions such as compression fracture, fracture of wrist, osteoporosis, sciatica, rheumatoid arthritis and osteoarthritis. A patient was diagnosed with hyperthyroidism and borderline type II diabetes mellitus. Another patient suffers from chronic obstructive airway disease. The majority of patients remained healthy with no ongoing medical issues.

6.5.5 Exercise

Once life started to resume normality, some patients tried to return to their usual exercise regime. Thirteen patients (62%) exercised regularly at least twice a week. Walking was the most popular choice of exercise (6 patients) along with swimming (1 patient), Pilate (1 patient), yoga (1 patient), bowling (1 patient). Three patients do a combination of 2 forms of exercise listed above regularly. Approximately half of the group reported worse exercise tolerance (11 patients) while 8 experienced the same level and 2 patients actually had better level of exercise tolerance.

6.5.6 Medications

More patients were taking a β blocker (mainly Metoprolol) compared to when they were discharged from clinic (47.6% vs. 31.6%). There was also an increase in the usage of ACE inhibitor/ARB (42.9% vs. 31.6%) and calcium channel blocker (14.3% vs. 5.3%). Hypertension was the most common reason for adding these medications to patients’ existing treatment.
Table 5 - Medication treatment at 12 months follow up after the February 2011 earthquake.

<table>
<thead>
<tr>
<th>Medication</th>
<th>Prior to SCM N = 21</th>
<th>During admission N = 21</th>
<th>Post clinic follow up N = 19</th>
<th>* At 12 months N = 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspirin</td>
<td>7 (33.3%)</td>
<td>16 (76.2%)</td>
<td>7 (36.8%)</td>
<td>7 (33.3%)</td>
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<tr>
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<td>6 (28.6%)</td>
</tr>
<tr>
<td>Long acting nitrate</td>
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<td>0 (0%)</td>
<td>1 (5.3%)</td>
<td>1 (4.8%)</td>
</tr>
<tr>
<td>Calcium channel blocker</td>
<td>1 (4.8%)</td>
<td>1 (4.8%)</td>
<td>1 (5.3%)</td>
<td>3 (14.3%)</td>
</tr>
<tr>
<td>Anxiolytics</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

6.6 Psychometric questionnaire results

6.6.1 The Health Anxiety Questionnaire

Seventeen patients completed the HAQ (80.9%) and the median score was normal at 8 (1 to 13). Overall, 9 patients had normal health anxiety level (score 0 to 8) and 8 patients had medium level of health anxiety (score 9 to 13). No one had high level of health anxiety according to the test.

6.6.2 The Hospital Anxiety and Depression Scale

Eighteen patients (85.7%) completed the HADS. The median score for anxiety and depression was 5.5 (1 to 13) and 2.5 (0 to 10) respectively, which were both normal. The test indicated that only 5 patients had borderline anxiety and 1 had borderline depression. The rest of the group did not have abnormal level of anxiety or depression.
6.6.3 The Impact of Event Scale – Revised

Sixteen patients (76.2%) completed the IES-R questionnaires. The median score was normal at 12 (2 to 45). Four patients may have borderline PTSD as they have a score greater than 33.

6.7 Recurrence of stress cardiomyopathy

There was no recurrence of SCM during the 12 months follow up period. However, 2 months after the completion of the follow up study, 1 woman from this cohort of SCM presented to Christchurch Hospital again with chest pain. This 68-year-old woman initially presented on the 23rd of February 2011 with earthquake induced SCM. She had the typical apical ballooning pattern of regional wall motion abnormality with reduced left ventricular ejection fraction of 30%. She only had mild atheromatous coronary disease on coronary angiogram. She was discharged from hospital the next day on Aspirin and Metoprolol. Her repeat echocardiography study 57 days later showed complete recovery of left ventricular function (ejection fraction 69%) with no regional wall motion abnormality. Therefore she was instructed to stop taking Metoprolol.

At 12 months, she was doing extremely well, having returned to work and regular exercise with no limitations. Other than mild hypertension, she did not have other medical issues. Her general practitioner commenced her on Cilazapril and Simvastatin. Her psychometric questionnaires showed that she had medium level of health anxiety and borderline abnormal anxiety level. She was not depressed nor did she have PTSD.

In May 2012, she had sudden onset chest pain while she was walking. She denied a stressful preceding event. There had not been major aftershocks on the day either. On
admission, she was found to have a peak troponin I level (3.1µg/l) and ST segment elevation laterally on ECG. Her echocardiography study showed a large area of left ventricular apical and mid wall akinesis with basal segment hyperkinesis, similar to her previous study in February after the earthquake. Her left ventricular ejection fraction was markedly reduced at 20%. Given she only had very minor coronary disease on previous coronary angiogram, it was therefore not repeated. Thyroid function test and plasma metanephrine level were both normal. She was mildly hypotensive during admission but did not require inotropic support or intra-aortic balloon pump insertion. She was again commenced on Metoprolol. She was discharged 3 days later.

She was followed up in clinic 1 months later. At that stage, her left ventricular function has again normalised (ejection fraction 66%) with normal regional wall motion. She did not tolerate Metoprolol therefore it was switched to Carvediolol. She was told that she should stay on lifelong therapy of ACE inhibitor and β blocker.

6.8 Summary

The 22 February 2011 earthquake triggered 21 cases of SCM within 4 days of the event. All 21 patients were postmenopausal women with few cardiovascular risk factors. The majority had anterior ST segment elevation on ECG, QTc prolongation, modest elevation of troponin I, typical apical ballooning of the left ventricle and insignificant coronary disease. The short-term clinical outcome was excellent, with no mortality or significant mortality. The mean length of stay was 37 hours. The follow up study was launched at 12 months in order to gain better understanding of longer-term outcome of earthquake induced SCM patients, as it has not been previously studied. Again, patient outcome was favorable with 100% survival and only 1 case of recurrence at 15 months. Most
patients remained healthy both physically and psychologically despite been exposed to incessant aftershocks since February 2011.
Chapter Seven – Discussion

7.1 Introduction

This chapter discusses current findings of the comparative study of the 2 major Christchurch earthquakes and the findings of the study of the 21 SCM cases after the February 2011 earthquake. It also reviews the 2 published papers on SCM emanating from the earthquakes in Christchurch.

7.2 Time course of acute cardiac presentations

One of the most striking findings of the first study in this thesis is that the bulk of earthquake related acute cardiac admissions occurred within 2 weeks of events. There was a significant increase in overall acute cardiology admissions in the first 2 weeks following the September 2010 earthquake (120 cases in week 1, 100 cases in week 2, p=0.003) and a trend of increased admissions in the first week after the February 2011 earthquake (116 cases, p=0.051). The September 2010 earthquake triggered a large number of STEMI presentations in the first 2 weeks following event (N=20, p=0.016). This is in accordance with the findings of previous earthquake research. The Newcastle earthquake had higher than usual AMI cases within first 4 days of event \(^{120}\). Both the Northridge and the Niigata earthquakes were associated with a marked increase in AMI 1 week following the event \(^{20,125}\). The Ji-Ji earthquake study found the largest number of AMI occurred in the first 3 weeks of event onset \(^{22}\). The most recent Great East Japan earthquake saw a rapid increase and decrease in ACS within 2 to 3 weeks of the major earthquake \(^{126}\). The February 2011 earthquake triggered a significant 21 cases SCM presentations with the first 4 days. Similarly, the only other case series in literature showed that there was also a surge in SCM immediately following the Niigata earthquake, with 16 cases in the first week \(^{125}\). The difference between
the 2 earthquakes is that the SCM admissions continued with 5 cases then 4 cases in the 2nd and 3rd week respectively after the Niigata earthquake, whereas there SCM presentations ceased after the first week in Christchurch.

Interestingly, AMI presentations reduced sharply to 1 and 2 cases in the 3rd and 4th week following the September 2010 earthquake. This could well be due to a “harvesting” effect as the stress of earthquake result in vulnerable coronary plaques to rupture and temporarily shift forward disease presentations\textsuperscript{188,189}. The subsequent, compensatory reduction in AMI raises the possibility that the earthquake had affected especially those who had unstable disease at higher risk for an acute event in the short term anyway.

Population movement after earthquakes is another important factor when studying the time course of acute cardiac presentations. Nissen et al analysed cellphone calls made by Christchurch users over the first six months of 2010 and 2011\textsuperscript{190}. They found that approximately 15\% (55,000) of the usual Christchurch residents were likely to have left the city in the week after the February earthquake. This could result in loss of complete data capture and potential underestimation of true disease prevalence. We were aware of a woman who left Christchurch immediately after the 2010 earthquake despite having developed chest pain. She presented to Auckland Hospital shortly afterwards with SCM.

7.3 Differences in acute cardiac presentations between the two earthquakes

Another significant finding of this study is that the 2 earthquakes differed in their effects on acute cardiac admission pattern. The 2 major earthquakes struck Christchurch within 6 months of each other and each was associated with a different pattern of cardiac admissions. In the first 2 weeks of the September 2010, there was an increase in acute
STEMI presentation and a lesser increase of SCM (N=6). In the week of the second earthquake, there were 3 times as many SCM cases within 4 days, without a spike in AMI. There are several possibilities for such distinct differences.

7.3.1 September 2010 morning earthquake and acute myocardial infarction

The September 2010 earthquake occurred at 4:36am, a cold morning, and was associated with a significant number of STEMI in 2 weeks. The pattern following this earthquake is similar to that reported after the Ji-Ji earthquake (1:47am)\(^22\), the Northridge earthquake (4:30am)\(^20\), the Hanshin-Awaji earthquake (5:46am)\(^21\) and the Newcastle earthquake (10:27am)\(^120\). There was a 35% rise in myocardial infarction presentations in the week following Northridge. A similar increase in the rate of myocardial infarction was reported in the weeks following the 1989 Newcastle earthquake, the Hanshin-Awaji earthquake of 1995 and the 1999 Ji-Ji earthquake in Taiwan. In contrast, the February 2011 earthquake occurred at 12.51pm while most people were awake. It did not result in a significant rise in AMI cases. Another well studied earthquake showed similar findings. The 1989 Loma Parieta earthquake struck at 5:04pm and did not cause a significant number of AMI\(^{127}\).

<table>
<thead>
<tr>
<th>EQ</th>
<th>Country</th>
<th>Magnitude</th>
<th>Date</th>
<th>Time</th>
<th>Effect on AMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newcastle</td>
<td>Australia</td>
<td>5.6</td>
<td>Dec 28, 1989</td>
<td>10.27 am</td>
<td>6 cases of fatal MI in 4 days (p=0.016)</td>
</tr>
<tr>
<td>Northridge</td>
<td>USA</td>
<td>6.7</td>
<td>Jan 17, 1994</td>
<td>4.30 am</td>
<td>35% increase in AMI in 1 week (p=0.02)</td>
</tr>
<tr>
<td>Hanshi-Awaji</td>
<td>Japan</td>
<td>7.2</td>
<td>Jan 17, 1995</td>
<td>5.46 am</td>
<td>3.5-fold increase in AMI in 4 weeks</td>
</tr>
</tbody>
</table>
It is well known from the literature that circadian variation exists for myocardial infarction and SCD. The risk of an acute cardiac event increases during the morning and also during wakening and rising. It was thought that morning increase in autonomic tone, vascular resistance, catecholamine level and coagulability as well as the mental stress associated with the transition from sleep to arousal may be responsible for the increased risk of onset of AMI. As suggested by Brown, it is certainly plausible that extreme emotional stress caused by a major earthquake superimposed on the physiological stress of awaking could enhance triggering of AMI.

The recent Great East Japan earthquake struck in March 2011. It resulted in a significant increase in ACS, SCD and CHF cases. This earthquake occurred in the afternoon at 2:46pm, therefore did not fit the hypothesis of morning earthquakes causing more AMI. However, the Great East Japan earthquake was different to

<table>
<thead>
<tr>
<th>Location</th>
<th>Country</th>
<th>Magnitude</th>
<th>Date</th>
<th>Time</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ji-Ji</td>
<td>Taiwan</td>
<td>7.3</td>
<td>Sep 21, 1999</td>
<td>1.47 am</td>
<td>50% increase in AMI in 6 weeks (p=0.009)</td>
</tr>
<tr>
<td>Darfield</td>
<td>NZ</td>
<td>7.1</td>
<td>Sep 04, 2010</td>
<td>4.46 am</td>
<td>2.25-fold increase in mean AMI in 2 weeks (p=0.016)</td>
</tr>
<tr>
<td>Loma Parieta</td>
<td>USA</td>
<td>7.0</td>
<td>Oct 17, 1989</td>
<td>5.04 pm</td>
<td>No increase in AMI</td>
</tr>
<tr>
<td>Christchurch</td>
<td>NZ</td>
<td>6.3</td>
<td>Feb 22, 2011</td>
<td>12.51 pm</td>
<td>No increase in AMI</td>
</tr>
</tbody>
</table>

Table 6 - Effects of earthquakes on AMI
the others as it also triggered a devastating tsunami and was associated with the threat of nuclear reactor meltdown in the Fukushima power plant. It is fair to say that multiple stressors existed – the emotional stress caused by the earthquake, the physical stress of fleeing from tsunami and the ongoing psychological stress of a potential nuclear accident. The added effect of several stressors could certainly trigger AMI.

An important issue with studies conducted following the Great East Japan earthquake is that SCM was not specifically studied. Aoki et al found a significant increase in ACS after the event. They retrospectively examined medical recordings in the Miyagi Prefecture and the diagnosis of ACS was made by emergency doctors based on physical examination, ECG, echocardiography and laboratory findings. There was no coronary angiography data available. Nozaki et al also reported increased ACS after the earthquake after examining medical records prepared by emergency physicians. ACS was defined as chest pain with ECG changes or elevation of cardiac markers. Both studies failed to tease out the true incidence of SCM as they had a minimal dataset. They could have easily mistaken SCM for AMI. It is therefore possible that due to incomplete characterisation, the AMI rate may have been overestimated and SCM cases underreported or not reported at all.

### 7.3.2 February 2011 afternoon earthquake and stress cardiomyopathy

The February 2011 earthquake struck at 12.51pm and resulted in 21 cases of SCM in 4 days. The only other earthquake documented to have causes a cluster of SCM is the Niigata earthquake. This earthquake occurred at 13.01pm and triggered 25 cases of SCM within 4 weeks. Since the data is lacking in terms of earthquake related SCM, it is difficult to prove that there is a definite association between afternoon earthquakes and SCM. Our findings in concert with the case cluster after the Niigata earthquake raise the possibility of diurnal variation in susceptibility to SCM. Given our poor understanding of the
pathophysiology of SCM, one should be cautious in speculating at what might underlie this, but diurnal variation in autonomic tone is a possible factor.

Other possible explanations for the surge in SCM cases following the February earthquake include its location, strength and the extensive destruction that ensued. The February earthquake was extremely shallow with a hypocenter only 5 kilometres deep and only 10 kilometres from the Christchurch city centre. The vertical 2.2G force caused significant damage city wide. Unlike the September morning earthquake, most people were awake and were fully aware of the destruction immediately following this afternoon earthquake. There was also constant media coverage of the extent of chaos and damage in the city. Needless to say, emotional stress level was sure to rise in a population that was already stressed and perhaps sensitized following the first earthquake, with many still struggling with basic needs such as housing and water supply.

7.4 The study of 21 stress cardiomyopathy cases

This earthquake study is unique not only because it demonstrated different patterns of cardiac disease presentations after 2 earthquakes, it also provided detailed initial and follow up data on 21 cases of SCM triggered by the February earthquake. Most of the case series in the literature collected individuals with SCM triggered by a wide range of poorly characterized stressors occurring over a period of time. Except for Watanabe’s group\textsuperscript{125}, there were no studies on mass presentation of SCM as the result of a single stressor. However, Watanabe et al did not further research long-term outcome of the 25 patients who suffered from SCM after the Niigata earthquake. No previous studies exist to show the clinical outcomes of SCM patients when they are exposed to similar stressors (aftershocks) repeatedly after their initial insult.
The clinical features of the 21 SCM at initial presentation detailed in this study were very similar to previous case series. This includes chest pain on presentation, ECG changes of ST elevation followed by T wave inversion and QTc prolongation, modest elevation of myocardial injury markers, transient and reversible apical ballooning on echocardiography and the lack of significant coronary disease on angiography. The time course of disease recovery was also in accordance with the literature. Most patients had complete normalization of LV function and regional wall motion within a few weeks.

At 12 months, a telephone interview showed 100% survival rate with no ongoing cardiac issues. One third of the patients suffered from medical issues such as musculoskeletal problems, chronic airway disease, hyperthyroidism and renal colic. This is not unexpected given the median age of this cohort of patient is 72 years. At 15 months, there was 1 case of SCM recurrence (4.8%). The rate of recurrence is consistent with previous studies. The favorable 12 month outcome data of this cohort of patients is comparable to Parodi’s findings at 6 months. This is in contrast to Sharkey’s findings with 15% of mortality rate from 4 months to 4.7 years from SCM onset. Obviously, a longer study period for our cohort of SCM would be ideal to further assess prognosis of this syndrome.

In terms of psychological outcomes, psychometric questionnaires showed that no one had a high level of health anxiety level and the majority were not depressed (94%) or anxious (72%). Only 4 patients had possible borderline PTSD. The limitation of the tests is the lack of baseline psychometric study data for the 21 SCM patients in the follow up study. The 3 psychometric questionnaires showed that the majority of the SCM patients were not
particularly anxious or depressed nor did they have PTSD at 12 month after the February 2011 earthquake. Ideally, they should all have similar tests during hospital admission immediately post event to establish baseline level of health anxiety, generalized anxiety, depression and tendency for PTSD.

In another study from the September 2010 earthquake, Zarifeh et al successfully obtained complete psychometric data from 6 SCM patients as well as from 5 patients with AMI and 6 with non-cardiac chest pain presentations. Within 6 weeks of the earthquake, these women underwent a semi-structured interview with a Senior Clinical Psychologist who was blinded to the patients’ cardiac diagnosis. They found that SCM following an earthquake is not specific to psychologically vulnerable women. In fact, women presenting with non-cardiac chest pain following an earthquake had higher anxiety and neuroticism scores than women with either AMI or SCM, and there was no excess of depression or depressive symptoms in any of the 3 groups. Our medium term data from the second earthquake adds to a picture of SCM occurring in otherwise psychologically robust women and carrying no medium-term psychological risk.

The other SCM publication emanating from the Christchurch earthquakes is a case report in Echocardiography. It details a woman who developed SCM after each earthquake, but with a different pattern of regional wall motion abnormality on the second occasion. This 76-year-old woman first presented on 4 September 2010 with 10 hours of chest pain and shortness of breath that began during the earthquake. She had abnormal ECG findings including inferolateral deep T wave inversion and QT prolongation. Her TNI peaked at 0.81 µg/L. Coronary angiography revealed diffuse atheroma with a moderate mid LAD lesion that was stented at the time. She had basal hyperkinesis with mid, distal and
apical ballooning on echocardiography. Discharge medications included aspirin, clopidogrel, simvastatin, and diltiazem but not beta-blocker or ACE inhibitor. A repeat echocardiogram showed complete recovery of her left ventricular function on 28 September. Unfortunately, she developed chest pain and shortness of breath during the 22 February 2011 earthquake. Her TNI peaked at 1.3 µg/L. Repeat coronary angiography found the stent to be widely patent with mild disease elsewhere, unchanged from previously. Echocardiogram showed a mid-wall variant takotsubo with apical sparing. A repeat study in July 2011 showed normal left ventricular function with no regional wall motion abnormality. There are case reports of patients with recurrent SCM presenting with different patterns of regional wall motion abnormality on each occasion \(^1^9^6,^1^9^7\). These cases along with our case report suggest that complex determinants of the pattern of left ventricular dysfunction in SCM exist. These determinants may vary in individuals from one event to another.

### 7.5 Strength of the study

Unlike other earthquake studies, this study is a single center experience. Christchurch Hospital is the only acute hospital for the region, and the same population were exposed to 2 different earthquakes in a 6 month time period. There was no significant migration in or out of Christchurch between the earthquakes. Furthermore, Christchurch Hospital and its patient management systems remained fully functional in spite of the disruption to the rest of the city, ensuring good data capture. This also helped facilitate patient follow up which was of utmost importance with the 21 SCM patients after the February event. Also, as a single centre, we were able to commence our research within a few weeks of the September event without having to coordinate with other health providers, unlike other earthquake studies. This was very important as the February earthquake destroyed many patients’ clinical files.
due to severe damage to the Clinical Record Department. Fortunately, our data collection for the first earthquake was completed prior to the second earthquake.

The other strength of the study is that we adopted the stringent methodology of reviewing every patient’s clinical files and investigation findings such as coronary angiograms and echocardiography studies. This was facilitated by the tight clustering of the presentations. It ensured a high accuracy of classifying admissions according to diagnosis. This method also allowed 100% pick up rate of SCM in this study. After having successfully identified all SCM cases, a further sub-study was done. This is significant given there were no previous data on long-term outcomes in patients with earthquake induced SCM.

7.6 Weakness of the study

Earthquakes are unheralded events. As with previous studies this study has the weakness that by necessity it is retrospective. The other weakness is that the study collected data solely from admissions to the Cardiology teams. In Christchurch Hospital all chest pain admissions that might be cardiac are admitted under the Cardiology service. However, occasionally, when very elderly patients with multiple medical problems present with ACS, they would be referred to the General Physicians for conservative management. Also, as many as 15% of population left Christchurch shortly after the earthquakes. Therefore, this study could have potentially underestimated the rate of ACS after the earthquakes.

Ascertainment bias could potentially affect the study. Since the September earthquake, the Christchurch Cardiology Department’s ability to suspect and recognise SCM had increased. This was especially true in the context of another major earthquake. We were expecting people to present with SCM after the February earthquake and were able to
diagnose the condition quickly and accurately. In the past, we might not be as vigilant thus leading to underreporting of SCM. Ascertainment bias could also occur when dealing with patients presenting with non-specific chest pain. It is possible that this group of people may be less vigorously investigated as there was great pressure to create surge capacity to cater for the more seriously ill patients. Consequently, people may be given the diagnosis of non-cardiac chest pain when they actually have a genuine cardiac condition. However, given our stringent study methodology, this would only apply to a very small number of patients, if at all.

Reporting bias may also existed for this study. The true incidence of SCM and ACS could be underreported for a variety of reasons. People who developed chest pain after the events might not have easy access to their usual medical care. Many had the mindset that they should reserve medical resources for the critically injured. One of the patients with SCM after the February earthquake slept in her car for 4 days with chest pain prior to finally presenting to hospital. She did not want to cause a bother and was waiting for her symptoms to resolve. The threshold for referral from primary carers to hospital might also be different in the immediate phase following the earthquakes. These reasons would lead to an underestimation of true disease incidence potentially. One method to estimate the overall incidence of coronary events would be to examine mortality rates due to SCD or IHD in the periods following the earthquakes. However, this was beyond the scope of our study.

The control period used in this study was limited to the year prior to respective earthquakes. The choice of 1 year is arbitrary. The pros is that it is unlikely for any fundamental shift to have occurred in terms of disease diagnosis, treatment and trend in
incidence. The downside is that the chosen year might be an unusual single year with less events thus with less power to show effects.

Finally, our study deals with 2 case clusters. This could be thought of as an epidemic form of SCM. It is possible that SCM is a heterogeneous condition. The findings in this thesis may not apply to sporadic cases.

7.7 Major clinical implication

The major implication of this study for clinicians and policymakers is that each earthquake, and by extrapolation each natural disaster, is different. This research provided an opportunity to identify the volume and pattern of non-traumatic chest pain presentations following major disasters. The medical and health care need of this specific disaster-stricken population was carefully analysed. Surge capacity had to be created quickly to accommodate the medical and health need of the population after each earthquake. For the February 2011 earthquake, Cardiology admitting staff adopted a strategy of early triage including echocardiography and streamlined access to the cardiac catheterisation laboratory for acute coronary angiography. Such a process relied heavily on experienced leadership and hard working staff to manage the large volume of chest pain presentations post earthquakes. This appears to have facilitated early diagnosis, appropriate management and swift discharges of a large number of patients, especially those with SCM. Although our ability to deliver usual care was not disrupted despite a significant increase in patient volume, there was significant strain on staff, many of whom had major issues to deal with at home. Fortunately, the Auckland Cardiology Department came to our aid in the 2nd week after the February earthquake. An Interventional Cardiologist with a team of medical and nursing staff provided extra assistance in the cardiac catheterisation laboratory and offered the overworked
Christchurch team temporary relief. We now know that the majority of earthquake induced acute cardiac presentations occurred within the first 2 weeks following the events. Such knowledge will allow better future disaster planning, especially focusing on efficient resource utilisation, personnel allocation and seeking assistance from other centres in the initial period following a catastrophe.

7.8 Future research

Our study demonstrated clearly the cardiovascular consequences following 2 major earthquakes in Christchurch. The 2 earthquakes occurred within 6 months of each other and each was associated with a different pattern of cardiac admissions. The early morning September earthquake caused a large increase in AMI and the afternoon February earthquake which was stronger and more destructive triggered more than 3 times more SCM. It is plausible that the superimposed stress from the earthquake to the natural physiological stress of morning waking is responsible for such surge in AMI cases. This raises the possibility that as well as diurnal variation in AMI there is diurnal variation in propensity to SCM with significantly more cases with afternoon stressors. There is no answer to this question currently given the lack of research in earthquake induced SCM. Further studies using our methodology are warranted to confirm our finding in other study patient populations post major earthquakes. Also, given there is currently no clear understanding of the factors contributing to susceptibility to SCM, further characterisation would be helpful. Ideally, this would involve more detailed assessment in the acute setting.

Our follow up study at 12 months demonstrated favorable outcomes for earthquake induced SCM patients. A longer follow up period is necessary to fully assess prognosis of this unique syndrome.
7.9 Summary

The 2 earthquakes we report here were large enough to precipitate cardiac events but not so large as to cripple the operation of the region’s single acute hospital. Similar to previous studies, our data shows the short-term impact on cardiac disease after a major earthquake. We witnessed a significant increase in acute cardiac admissions for 2 weeks after an acute event. Our research shows earthquakes were associated with increased presentations with both AMI and SCM and also with non-cardiac chest pain. Our data is consistent with diurnal variation in susceptibility to AMI and raises the possibility that such variation also exists for SCM. The follow up study of the 21 SCM patients adds to the published data showing that women who developed SCM after earthquakes were normal and psychologically robust with favourable longer-term psychological outlook.
Chapter Eight - Conclusion

Earthquakes and other natural disasters occur at random, making cardiovascular research in this area difficult. The initial health care focus is on acute casualties caused by trauma. However, previous research and this current study have demonstrated clearly that the cardiovascular complications that ensue also pose a great burden on the health care system.

Two major earthquakes struck Christchurch within a period of 6 months between September 2010 and February 2011 causing major destruction with many lives lost. Fortunately, Christchurch Hospital remained operational. Our Cardiology Department functioned at full capacity in receiving and treating patients presenting acutely with chest pain triggered by the earthquakes. We were able to conduct a single centre study to examine the effects of the 2 earthquakes on acute cardiac presentations.

Our key findings were:

1. The Christchurch Earthquakes were associated with an overall increase in cardiovascular admissions – this was especially true in the 2 weeks following the first earthquake in September 2010 with a total of 220 patients admitted acutely (p<0.003). This finding confirms previous research in other countries indicating an association between natural disaster and subsequent cardiovascular events.

2. The Christchurch earthquakes were associated with an increased incidence of SCM. SCM admissions increased after both large earthquakes, but to a greater extent in February 2011.
3. Two major earthquakes of different intensity, occurring at different times differed in their effect on acute cardiac events such as AMI and SCM – The early morning September earthquake triggered a significant number of AMI (20 cases, p=0.016) in the first 2 weeks. There were 6 cases of SCM. The afternoon February earthquake, which was far more destructive and associated with direct fatalities, was associated with a significant increase of 21 SCM cases in the first 4 days (p<0.05).

4. Medium term outcome was excellent for patients with earthquake induced SCM – A subgroup analysis and follow up study of the 21 SCM patients at 12 months following the February earthquake showed 100% survival rate with no recurrence of disease. The majority of patients remained healthy both physically and psychologically despite been exposed to incessant aftershocks since February 2011.

Our study is unique given it was a single center experience with good population capture when the two earthquakes happened. There has not been a study like this previously. The findings of this study are important as the knowledge of the pattern of cardiovascular presentations that follow major natural disasters will enable appropriate management plans and efficient resource allocation and will minimize subsequent cardiac mortality and morbidity.
Appendix A

Telephone survey questionnaire

1. What was your main symptom (e.g. chest pain, SOB, palpitations…) when you presented to hospital following the February earthquake?

2. Have you had further similar symptoms in the past year? If yes, were they related to aftershocks? How many episodes? Did you seek medical advice – GP or hospital? What was the outcome?

3. Have you been admitted to hospital in the past year? Reasons? How long did you stay in hospital? Treatment outcome?

4. Any other health problems not mentioned above in the past year? Treatment required?

5. Do you exercise regularly? If yes, what do you do? How often? For how long? Is your exercise capacity better, worse or the same compared to prior to the earthquake? If worse, what is the limiting factor?

6. What is your stress level like now compared to 1 year ago? Higher? Lower? The same?

7. What medications are you on?
   a. Aspirin?
   b. β blocker?
   c. ACEI/ARB?
   d. Statin?
   e. Calcium channel blocker?
   f. Nitrate?
   g. Anti-anxiolytic/anti-depressant?

8. Are you still in the same house?
# Appendix B

The Health Anxiety Questionnaire

<table>
<thead>
<tr>
<th></th>
<th>not at all or rarely</th>
<th>some-times</th>
<th>often</th>
<th>most of the time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>Do you ever worry about your health?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Are you ever worried that you may get a serious illness in the future?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>Does the thought of a serious illness ever scare you?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>When you notice an unpleasant feeling in your body, do you tend to find it difficult to think of anything else?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>Do you ever examine your body to find whether there is something wrong?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>6</strong></td>
<td>If you have an ache or pain do you worry that it may be caused by a serious illness?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>7</strong></td>
<td>Do you ever find it difficult to keep worries about your health out of your mind?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>8</strong></td>
<td>When you notice an unpleasant feeling in your body, do you ever worry about it?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>9</strong></td>
<td>When you wake up in the morning do you find you very soon begin to worry about your health?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>10</strong></td>
<td>When you hear of a serious illness or death of someone you know, does it ever make you more concerned about your own health?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td><strong>11</strong></td>
<td>When you read or hear about an illness on TV or radio does it ever make you think you may be suffering from that illness?</td>
<td><img src="not-at-all-or-rarely" alt="Not at all or rarely" /></td>
<td><img src="some-times" alt="Some-times" /></td>
<td><img src="often" alt="Often" /></td>
</tr>
<tr>
<td></td>
<td>Question</td>
<td>not at all or rarely</td>
<td>sometimes</td>
<td>often</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>12</td>
<td>When you experience unpleasant feelings in your body do you tend to ask friends or family about them?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Do you tend to read up about illness and diseases to see if you may be suffering from one?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Do you ever feel afraid of news that reminds you of death (such as funerals, obituary notices)?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Do you ever feel afraid that you may die soon?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Do you ever feel afraid that you may have cancer?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Do you ever feel afraid that you might have heart disease?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Do you ever feel afraid that you may have any other serious illness?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Which illness?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>........................................................................................................</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Have your bodily symptoms stopped you from working during the past six months or so?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Do your bodily symptoms stop you from concentrating on what you are doing?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Do your bodily symptoms stop you from enjoying yourself?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For each question score 0 for "not at all or rarely", 1 for "sometimes", 2 for "often", and 3 for "most of the time".

Add scores for 1, 4, 6 – 9, 11 & 18 to give health worry & preoccupation score =

Add scores for 2, 3, 10 & 14 – 17 to give fear of illness and death score =

Add scores for 5, 12 & 13 to give reassurance-seeking behavior score =

Add scores for 19, 20 & 21 to give interference with life score =

Total score =

91
### Appendix C

**Hospital Anxiety and Depression Scale**

<table>
<thead>
<tr>
<th>D</th>
<th>A</th>
<th>D</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>I feel tense or ‘wound up’</td>
<td>3</td>
<td>I feel as if I am slowed down:</td>
</tr>
<tr>
<td>2</td>
<td>Most of the time</td>
<td>2</td>
<td>Nearly all the time</td>
</tr>
<tr>
<td>1</td>
<td>A lot of the time</td>
<td>1</td>
<td>Very often</td>
</tr>
<tr>
<td>0</td>
<td>From time to time, occasionally</td>
<td>0</td>
<td>Sometimes</td>
</tr>
<tr>
<td></td>
<td>Not at all</td>
<td></td>
<td>Not at all</td>
</tr>
</tbody>
</table>

| 0   | Definitely as much               | 0   | Not at all                       |
| 1   | Not quite so much                | 1   | Occasionally                     |
| 2   | Only a little                    | 2   | Quite Often                      |
| 3   | Hardly at all                    | 3   | Very Often                       |

| 3   | I get a sort of frightened feeling as if something awful is about to happen: | 3   | Definitely                      |
| 2   | Very definitely and quite badly  | 2   | I don’t take as much care as I should |
| 1   | Yes, but not too badly           | 1   | I may not take quite as much care |
| 0   | A little, but it doesn’t worry me| 0   | I take just as much care as ever |

| 3   | Not at all                       | 3   | I have lost interest in my appearance: |
| 2   | As much as I always could        | 2   | Very much indeed                 |
| 1   | Not quite so much now            | 1   | Quite a lot                     |
| 0   | Definitely not so much now       | 0   | Not very much                   |

| 3   | Worrying thoughts go through my mind: | 3   | As much as I ever did            |
| 2   | A great deal of the time         | 2   | Rather less than I used to       |
| 1   | A lot of the time                | 1   | Definitely less than I used to   |
| 0   | From time to time, but not too often | 0   | Hardly at all                    |

| 3   | I feel restless as I have to be on the move: | 3   | Very much indeed                 |
| 2   | Not at all                        | 2   | Quite a lot                     |
| 1   | As such as I always could         | 1   | Not very much                   |
| 0   | Definitely not so much now        | 0   | Not at all                       |

| 3   | I look forward with enjoyment to things: | 3   | Very much indeed                 |
| 2   | Not at all                        | 2   | Quite a lot                     |
| 1   | Not at all                        | 1   | Not very much                   |
| 0   | From time to time, but not too often | 0   | Not at all                       |

| 3   | I can sit at ease and feel relaxed: | 3   | Very much indeed                 |
| 2   | Not at all                        | 2   | Quite a lot                     |
| 1   | Not at all                        | 1   | Not very much                   |
| 0   | From time to time, but not too often | 0   | Not at all                       |

Please check you have answered all the questions.

**Scoring:**

- **Total score:** Depression (D) ___________ Anxiety (A) ___________
- **0-7 = Normal**
- **8-10 = Borderline abnormal (borderline case)**
- **11-21 = Abnormal (case)**

92
Appendix D

The Impact of Event Scale - Revised

Below is a list of difficulties people sometimes have after stressful life events. Please read each item, and then indicate how distressing each difficulty has been for you DURING THE PAST SEVEN DAYS with respect to _____________________, how much were you distressed or bothered by these difficulties?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Not at all</th>
<th>A little bit</th>
<th>Moderate</th>
<th>Quite a bit</th>
<th>Extremely</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Any reminder brought back feelings about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I had trouble staying asleep.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Other things kept making me think about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>I felt irritable and angry.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I avoided letting myself get upset when I thought about it or was reminded of it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I thought about it when I didn’t mean to.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I felt as if it hadn’t happened or wasn’t real.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>I stayed away from reminders of it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Pictures about it popped into my mind.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>I was jumpy and easily startled.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>I tried not to think about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>I was aware that I still had a lot of feelings about it, but I didn’t deal with them.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>My feelings about it were kind of numb.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>I found myself acting or feeling like I was back at that time.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>I had trouble falling asleep.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>I had waves of strong feelings about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>I tried to remove it from my memory.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>I had trouble concentrating.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Reminders of it caused me to have physical reactions, such as sweating, trouble breathing, nausea, or a pounding heart.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>I had dreams about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>I felt watchful and on guard.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>I tried not to talk about it.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

The maximum mean score on each of the three subscales is ‘4’, therefore the maximum ‘total mean’ IES-R score is 12. Lower scores are better. A total IES-R score of 33 or over from a theoretical maximum of 88 signifies the likely presence of PTSD.
References


5. McSaveney E. *Historic earthquakes - The 1931 Hawke’s Bay earthquake.*


7. Maclean C. *Wellington places - Wellington City.*


induced "Takotsubo cardiomyopathy" from the time course of the 12-lead surface electrocardiogram. Am J Cardiol 2003;92(2):230-3.


190. Nissen K, Potter D. Where did people relocate to? Experimental cell phone data analysis of population movements following the 22nd February Christchurch Earthquake. PANZ biennial conference "New Zealand's Demographic Futures : Where to from Here." University of Auckland 2011.


