Iatrogenic Upper Limb Nerve Injuries

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Abstract

**Background:** Complications due to errors made by health practitioners are a major cause of concern and a source of distress, disability, and death in patients. In addition, they are associated with litigation and impose a major financial burden on healthcare budgets. Peripheral nerve injuries are among the most frequent iatrogenic complications. Recently, numerous studies have explored specific iatrogenic nerve injuries and possible ways of improving patient safety and preventing error. However, there are few data on the spectrum and relative frequency of iatrogenic nerve injuries and no national studies have been undertaken.

**Aim:** To describe the current spectrum of iatrogenic upper limb nerve injuries in New Zealand, focusing particularly on injuries that have an anatomical and possibly preventable component.

**Methods:** Three studies were undertaken. (1) A systematic review of English biomedical literature in the last ten years relating to major iatrogenic upper limb nerve injuries. The context, mechanism and frequency of nerve injuries were recorded. (2) A retrospective analysis of the Accident Compensation Corporation’s (ACC) accepted claims database from the first six months of 2009, focusing on iatrogenic nerve injuries. (3) An educational poster targeted at operating staff using international recommendations was produced in consultation with local practising anaesthesiologists.

**Results:** The systematic literature review revealed iatrogenic upper limb nerve injuries are relatively common and can affect patients in any surgical specialty. The spectrum of injuries has changed in parallel with technological advances in
surgery and medicine. Analysis of the ACC’s database revealed 151 successful treatment injury claims that could be classified as iatrogenic nerve injury during the study period. The majority of claimants were female (54.9%) and the elderly was over-represented with the median age being 51.5yrs, (range 0-83yrs). The five most frequent iatrogenic injuries were to the median nerve, sciatic nerve, common fibular nerve, radial nerve and ulnar nerve. An educational poster demonstrating the dos and don’ts of upper limb positioning under general anaesthesia was successfully produced.

**Conclusion:** This study has described for the first time the contemporary spectrum of iatrogenic nerve injuries in New Zealand as reported to the ACC. Appreciation and raising awareness of the risks associated with medical procedures is an essential first step in developing and implementing strategies to reduce iatrogenic injuries and improve patient safety. This study provides invaluable data by highlighting the procedures that need most attention. Future application of these results will hopefully benefit everyone involved in the New Zealand healthcare system.
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- Robbie McPhee for his help with producing the final upper limb positioning poster.
- All my friends who have made my year outside of research an amazing experience.

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Table of Contents

Abstract ........................................................................................................................................ ii
Acknowledgements .................................................................................................................. iv
Table of Contents ..................................................................................................................... v
List of Tables .............................................................................................................................. vii
List of Figures ............................................................................................................................ viii
List of Abbreviations ................................................................................................................ ix

Chapter 1: Introduction .................................................................................................................. 1

Chapter 2: Systematic literature review ..................................................................................... 7
  2.1 Introduction ......................................................................................................................... 7
  2.2 Methods .............................................................................................................................. 9
  2.3 Results ............................................................................................................................... 11
  2.4 Conclusions and relevance to proposed research .............................................................. 47

Chapter 3: Iatrogenic nerve injuries in New Zealand ................................................................. 48
  3.1 Introduction ......................................................................................................................... 48
  3.2 Methods ............................................................................................................................. 53
  3.3 Results ............................................................................................................................... 55
  3.4 Discussion .......................................................................................................................... 70

Chapter 4: Upper limb positioning injuries-designing an educational poster .......................... 79
  4.1 Introduction ......................................................................................................................... 79
  4.2 Methods ............................................................................................................................. 83
  4.3 Results ............................................................................................................................... 84
  4.4 Discussion .......................................................................................................................... 89
Chapter 5: Discussion .................................................................................................................. 93

References .................................................................................................................................. 100

Appendices .................................................................................................................................. 120

Appendix A Iatrogenic upper limb nerve injuries: a systematic review ........................................ 121
Appendix B Research Protocol .................................................................................................. 132
Appendix C ACC ethical approval ........................................................................................... 137
Appendix D Māori consultation ................................................................................................. 139
Appendix E Laterality of nerve injuries – full table ..................................................................... 142
Appendix F 2010 ANZACA conference poster .......................................................................... 145
List of Tables

Table 2.1. Systematic literature review search terms and relevant papers retrieved

Table 2.2. Brachial plexus injury

Table 2.3. Ulnar nerve injury

Table 2.4. Radial nerve injury

Table 2.5. Posterior interosseous nerve injury

Table 2.6. Axillary nerve injury

Table 2.7. Median nerve injury

Table 2.8. Anterior interosseous nerve injury

Table 2.9. Obturator nerve injury

Table 2.10. Sural nerve injury

Table 3.1. General demographics of included claimants from 2009

Table 3.2. Distribution of injured nerves (n=147)

Table 3.3. Laterality of selected nerves

Table 3.4. Named peripheral nerve injuries (n=101)

Table 3.5. Spinal nerve root injuries (n=10)

Table 3.6. Nerve plexus injuries (n=11)

Table 3.7. Cranial nerve injuries (n=20)

Table 3.8. Location of the injury with public/private distribution (n=142)

Table 3.9. Grade of health practitioners involved in an iatrogenic nerve injury (n=143)

Table 3.10. Specialty of health practitioner (doctor) involved in iatrogenic nerve injury (n=106)
List of Figures

Figure 2.1. Superficial branch of radial nerve injury (Modified from Zhang et al. 2011) .................................................................................................................. 36
Figure 2.2. Medial cutaneous nerve of forearm injury (Modified from Zhang et al. 2011) ................................................................. 39
Figure 2.3. Lateral cutaneous nerve of forearm injury (Modified from Zhang et al. 2011) ................................................................. 40
Figure 3.1. Age spectrum of individuals with accepted ACC claims (1st Jan-30th June 2009) (n=142) .......................................................... 57
Figure 3.2. Jan-Jun 2009 accepted claims by year of injury (n=142) ............... 57
Figure 4.1. Peripheral nerve cross section with its vascular supply (Reprinted from Neal et al. 2002) .............................................................................. 82
Figure 4.2. First poster draft ...................................................................................................................................................... 85
Figure 4.3. Second poster draft .............................................................................................................................................. 87
Figure 4.4. Final poster draft ...................................................................................................................................................... 88
# List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACC</td>
<td>Accident Compensation Corporation</td>
</tr>
<tr>
<td>ASA</td>
<td>American Society of Anesthesiologists</td>
</tr>
<tr>
<td>AIN</td>
<td>Anterior interosseous nerve</td>
</tr>
<tr>
<td>ANZACA</td>
<td>Australian and New Zealand Association of Clinical Anatomists</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>K-wiring</td>
<td>Kirschner-wiring</td>
</tr>
<tr>
<td>MPS</td>
<td>Medical Protection Society</td>
</tr>
<tr>
<td>NZSA</td>
<td>New Zealand Society of Anaesthetists</td>
</tr>
<tr>
<td>PIN</td>
<td>Posterior interosseous nerve</td>
</tr>
<tr>
<td>SBRN</td>
<td>Superficial branch of the radial nerve</td>
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Chapter 1: Introduction

During the past decade, medical error has been the focus of much research and improving patient safety has risen to prominence as a leading priority in many countries. There is a lack of research into iatrogenic injuries occurring in the New Zealand healthcare system. We were interested in exploring the spectrum of a subset of these injuries, namely iatrogenic upper limb nerve injuries. One of the goals of this research is to raise awareness among health practitioners of the risks of iatrogenic nerve injury, with the hope of helping to reduce the incidence of these injuries.

Since the birth of western medicine, physicians have recognised medicine’s potential to both heal and cause harm. The Hippocratic oath was historically taken by doctors to swear to practice medicine ethically. Its modern use is dwindling but the original oath includes a line that can be translated into English as “never do harm to anyone” (Hippocrates 5th century). From the beginnings of modern medicine, doctors have undertaken to refrain from harming their patients to the best of their abilities and judgments, cognisant of the fact that medicine has the potential to do ill.

The term ‘iatrogenesis (noun)/iatrogenic (adjective)’refers to complications caused by or resulting from medical intervention. Iatrogenesis is not restricted to doctors, but includes all healthcare professionals. Etymologically, iatrogenesis means “brought forth by a healer” (iatros meaning healer and gener meaning to create in Greek); in its earlier forms, iatrogenesis referred to both good and bad effects resulting from medical intervention. Only those iatrogenic events that result in an undesirable, “suboptimal outcome” are iatrogenic complications or injuries. However, the contemporary use of ‘iatrogenesis’ almost exclusively
refers to negative outcomes resulting from medical intervention (Jacobs et al. 2008). Ivan Illich introduced the notion of ‘iatrogenic illness’ to the wider public through his book *Medical Nemesis: The expropriation of health* in 1976. Illich (1976) and others subsequently focused on the harmful effects of medical intervention.

Iatrogenic complications are not necessarily synonymous with “adverse events”, another commonly used term within the context of patient safety. An adverse event is usually defined as "an unintended injury or complication resulting in prolonged hospital stay, disability or death and caused by healthcare management rather than by the patient's underlying disease" (de Vries et al. 2008). According to Jacobs et al. (2008), an iatrogenic complication may still be an expected outcome of a medical intervention. For example, hair loss and vomiting following chemotherapy which are expected and also accepted complications but an adverse event suggests an unexpected negative complication. Current Western medical ethics include a principle called 'non-maleficience'. The concept of non-maleficence is embodied by the phrase "Primum non nocere" or Florence Nightingale’s dictum “first do no harm” (Leape 1994) and can be traced to the predecessors of the modern physician. Despite being one of the fundamental moral principles of the practice of medicine, patients are still being harmed by health professionals. In 1964, Schimmel reported: “20% of patients admitted to a university hospital suffered an iatrogenic injury and 20% of those injuries were serious or fatal”. In 1981, Steel et al. found 36% of patients admitted to a university hospital suffered an iatrogenic injury, with a quarter of those injuries being serious or life threatening (both studies cited in Leape 1994). In reviewing these studies, Leape wondered why the issue of iatrogenic injury had not received more attention and suggested that the magnitude of the problem had not been appreciated fully because there was no systematic process of reporting iatrogenic injuries. The medical culture has strived for “error-free practice” and, combined with the fear of litigation and the lack of definitions of the nature of iatrogenic injuries, the historical reporting of these injuries has been inhibited (Leape 1994).
It is only in recent times that the subjects of patient safety and quality of healthcare have risen to prominence internationally and has gained momentum as a major focus of study in professional and health policy circles (Davis et al. 2002). The issue was kick-started in December 1999, when the Institute of Medicine published a report entitled "To Err is Human" which gave iatrogenic injuries huge public prominence. It stated that up to 98,000 hospitalised Americans died each year as a result of a preventable medical error and that these errors caused up to one million injuries (Kohn 1999). The National Health Service in the United Kingdom has also recently published two high profile reports on aspects of patient safety entitled: “An organisation with a memory: A report of an expert group on learning from adverse events in the NHS” and “Building a safer NHS for patients” (cited in Davis et al. 2002).

Following a heightened worldwide public awareness of iatrogenic complications, a large body of literature has been generated exploring the incidence of adverse events/iatrogenic injuries and possible ways of improving patient safety and preventing error. The Harvard Medical Practice Study reviewed over 30,000 records from 51 hospitals in New York State in 1984, and identified adverse events in 3.7% of hospitalisations, 14% of which were fatal. Many of these injuries can be attributed to negligent or substandard care (Brennan et al. 1991). A retrospective study of 1014 medical records in two London hospitals showed an adverse event rate of 11.7%, with half deemed to be preventable under ordinary standards of care (Vincent et al. 2001). In the 1990s the Quality in Australian Health Care Study reviewed 14,000 admissions to 28 hospitals in New South Wales and South Australia and revealed 16.6% of these admissions were associated with an iatrogenic injury with 4.9% resulting in death; 51% of the events were deemed to be preventable (Wilson et al. 1995). Similarly, a later Canadian Adverse Events Study showed that the adverse event rate was 7.5%, with 21% of these resulting in death and 37% judged to be preventable (Baker et al. 2004). Similar research has been carried out in New Zealand, quantifying the incidence of adverse events in public hospitals. The research showed 11.2% of hospital admissions were associated with an adverse event and 4.5% of these
events were fatal. The elderly were disproportionately over represented (Davis et al. 2002).

Iatrogenic complications are a major cause of concern and a source of distress, disability and death in patients. In addition, they are associated with litigation and impose a huge financial burden on healthcare systems. The estimated cost of litigation for adverse events in Utah and Colorado alone in 1999 was $660 million US dollars (Thomas et al. 1999). The cost of medical negligence in England has also become a major issue after a Select Committee report on the National Health Service’s Public Accounts revealed £1.8 billion of outstanding liabilities for claims of clinical negligence for the year 1997-1998 (cited in Goodwin 2000). An estimate of the cost to the Australian healthcare system of just the additional hospital bed-days as a result of the study by Wilson et al. (1995) was in excess of $800 million Australian dollars per year (Wilson et al. 1999).

We are not aware of any research that has described the spectrum of iatrogenic nerve injuries at a national level. The best data available on iatrogenic nerve injuries have resulted from closed claims analysis and research from neurosurgical hospitals. Cheney et al. (1999) analysed the closed claims database of the American Society of Anesthesiologists for iatrogenic nerve injuries and identified 16% of over 4000 claims were anaesthesia related. Ulnar neuropathy was most frequent, followed by brachial plexus injury. This research is limited as data were collected from liability insurers who approximately only cover half of the practising anaesthetists in the United States, and a claim is dependent on the patient filing a lawsuit. A large neurosurgical unit in Germany reported 17.4% (n=722) of surgically repaired nerve injuries were iatrogenic in origin. Nerves of the extremities were most frequently affected, including the superficial radial nerve and median nerve. However, the study sample was biased as patients who would benefit from nerve repair and who had suffered direct nerve trauma from a previous operation were over-represented (Kretschmer et al. 2001).
General aims and overview of the thesis

The main aim of this thesis is to describe the current spectrum of iatrogenic upper limb nerve injuries in New Zealand. We were particularly interested in injuries that have an anatomical and possibly preventable component but acknowledge from the outset that some iatrogenic nerve injuries are unavoidable (and even recognised) complications of certain procedures. The majority of the previous epidemiological research on patient safety has been carried out through rigorous retrospective assessment of hospital medical records. This is both time consuming and labour intensive. A prospective methodology is superior and less prone to bias (Hess 2004). However such a study would be very expensive and require a relatively long timeframe and is not feasible with our available resources. Consequently, we investigate the current spectrum and basic demographics of iatrogenic nerve injury by the novel interrogation of a large established dataset, namely that of a unique organisation only found in New Zealand, the Accident Compensation Corporation (ACC). Only after identifying and analysing the spectrum of iatrogenic nerve injuries can prevention strategies be considered.

The thesis is divided into five chapters. This first chapter introduces the issue, highlighting some historical aspects of iatrogenic injuries, previous studies and the overall scope of the problem. The second chapter is a systematic literature review of English language biomedical publications in the last ten years relating to iatrogenic upper limb nerve injuries (with the addition of two lower limb nerves), highlighting current reported international spectrum of major iatrogenic upper limb nerve injuries, from both a clinical and anatomical perspective. Chapter three represents the crux of the thesis and presents a retrospective analysis of ACC’s accepted claims from the first six months of 2009 focusing on iatrogenic nerve injuries. Following the systematic literature review and analysis of the ACC’s claims database, it was possible to identify a potential target for an education resource. Chapter four outlines the development of an educational poster aimed at raising awareness of and possibly reducing upper limb positioning injuries under general anaesthesia. The final chapter of the thesis is a discussion
reviewing the main findings of the thesis, and its limitations and exploring avenues for further research and application of the findings.
Chapter 2: Systematic literature review

2.1 Introduction

Iatrogenic nerve injury has undoubtedly occurred since the beginning of medical science. Various iatrogenic mechanisms as well as nerve sites at risk have been documented in the historical medical literature and specialised textbooks. However despite this availability of information, iatrogenic peripheral nerve injury is still a problem in the present era of medical treatment. Part of the problem is the rapid uptake of minimal access and endoscopic methods, with new surgical techniques presenting new surgical complications. In a large neurosurgical unit, 17.4% (126/722) of surgically treated nerve lesions were iatrogenic in origin, with a previous operation being the leading cause (Kretschmer et al. 2001).

The aim of this systematic review is to highlight the current spectrum of major iatrogenic peripheral nerve injuries, both from a clinical and anatomical perspective. A review of the English language literature between January 2000 and September 2010 was carried out. The emphasis is on the contemporary pattern of iatrogenic injury, namely literature published in the last ten years. There is a potential for publication bias as there is a tendency for complications and adverse events not to be published in the literature. Publication bias may also occur because some complications are well recognised and therefore not deemed newsworthy because the literature generally reports novel findings.

Only the major upper limb peripheral nerves were included in the review: brachial plexus, ulnar nerve, median nerve, radial nerve, axillary nerve and musculcutaneous nerve. Some cutaneous nerves in the upper limb were also
included in the review. Iatrogenic injuries to smaller nerves including the long thoracic nerve, suprascapular nerve, and thoracodorsal nerve were excluded, as were most iatrogenic injuries related to rare anatomical variants. Only the obturator nerve and sural nerve from the lower limb were included in this systematic review because of the vast nature of the subject and the numerous nerves in the lower limb. These nerves were simply chosen to illustrate iatrogenic nerve injury in the lower limb.
2.2 Methods

The electronic databases MEDLINE (1996-present), PubMed, the Cochrane Library and Google Scholar were searched for relevant articles listed between January 2000 and September 2010. The searches were limited to English language and humans in MEDLINE and PubMed and, in the case of Google Scholar, to the first 5 pages (50 hits). Search terms comprised the specific nerve and injury and/or surgery or iatrogenic. Table 2.1 shows the specific search terms used and the number of relevant papers identified. The relevant papers were downloaded or, if not accessible online, they were requested through Library Interloans. All included articles were reviewed together with relevant articles published between January 2000 and September 2010 cited in reference lists of retrieved articles that did not appear in the original search results.

Whenever possible, the following information was extracted from each article and input into a spreadsheet: the incidence of nerve injury and number of cases reported, the operative context, patient symptoms and outcome.
Table 2.1. Systematic literature review search terms and relevant papers retrieved

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<th>Relevant citations/hits</th>
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2.3 Results

Brachial plexus

The brachial plexus is formed by the ventral rami of the lower four cervical nerves (C5-C8) and the first thoracic ventral ramus. Contributions to the plexus by C4 and T2 vary. The roots of the brachial plexus form the superior, middle and inferior trunks, the trunks travel briefly before each bifurcating into an anterior and posterior division. The divisions form the lateral, medial and posterior cords and these cords form the terminal nerves of the brachial plexus (Standring 2008).

Iatrogenic brachial plexus injury secondary to inappropriate positioning under general anaesthesia was first described more than a hundred years ago (Budinger 1894 cited in Warner 2006) and is the second commonest nerve injury (after ulnar nerve injury) due to inappropriate positioning of the patient under general anaesthesia (Kretschmer et al. 2009). The brachial plexus is particularly vulnerable to injury because: (i) it has a relatively long and superficial course in the neck and axilla passing through a confined space between the clavicle and first rib; (ii) it is tethered proximally by nerve roots and the prevertebral fascia and distally by the fascia of the axillary sheath; and (iii) it lies in close proximity to bony structures such as the first rib, clavicle, coracoid process, and head of the humerus, against which it may be compressed. The plexus is at risk of stretching or compression injuries in the inappropriately positioned anaesthetised patient who is unable to perceive and respond to symptoms of pain, numbness, paraesthesiae, or weakness (Chin and Poole 2003; Pillai et al. 2007). This vulnerability to injury is compounded by the use of muscle relaxants in anaesthetised patients, resulting in loss of normal muscle tone allowing the arms to be moved into potentially hazardous positions which may stretch the plexus (Shankar et al. 2005). Animal studies have shown that the intraneural microcirculation is interrupted when nerves are stretched by 15% or more of their resting length (Lundborg and Rydevik 1973). This is because stretching has been shown to rupture minute intraneural capillaries and form small haematomas,
resulting in myelin disruption and conduction block. Similarly, a compression injury may displace nodal myelin, leading to conduction failure (Chin and Poole 2003). Injury causing neural shock and conduction block manifests as clinical neurologic symptoms (Shankar et al. 2005).

A brachial plexus stretch injury is more likely if the arms are abducted beyond 90° and externally rotated with the elbow extended and the forearm fully supinated. The use of shoulder braces in a head down (Trendelenburg) position, lateral flexion of the neck to the opposite side, and depression of the shoulder have also been implicated in these injuries. If shoulder pads are used they need to be placed directly over the acromioclavicular joint, if placed too lateral with an abducted arm, it can lead to the plexus being stretched caudally by the humeral head and if placed too medial the brachial plexus may be compressed against the first rib (Chin and Poole 2003). Lateral flexion and/or rotation of the head increase tension in the brachial plexus on the contralateral side (Ngamprasertwong et al. 2004). Any combination of these positions appears to have a cumulative effect although a study in healthy subjects suggested that there is considerable variation in susceptibility to stretch between individuals. A neutralising effect was also noted when nearby regions were positioned to allow pressure “unloading of the nervous system” (Coppieters et al. 2002). Obesity, hypovolaemia, hypotension, atherosclerosis, coagulopathy and diabetes mellitus are co-morbidities that are added risk factors for brachial plexus injury (Akinbingol et al. 2002). Congenital anatomical variations may also make the brachial plexus more vulnerable to injury. These include hypertrophy of the scalenus anterior and/or medius muscles, a cervical rib, and anomalous root derivation, either higher than C5 or lower than T1, thus placing greater tension on the anomalous roots (Cooper et al. 1988).

The American Society of Anesthesiologists (ASA) recommends that in supine patients arm abduction is limited to 90° with the forearm in a neutral position (ASA Task Force, 2000). However, even 90° may be excessive in some individuals if anaesthesia is prolonged for several hours as any slight pressure or stretching may cause nerve dysfunction (Hida et al. 2008).
Table 2.2 lists iatrogenic brachial plexus injuries that have been reported in the literature in the last ten years. Most are case reports, involving lengthy operations with the arms abducted. Excessive sternal retraction will increase the distance between the fixed points of the brachial plexus, thereby stretching it. Median sternotomy and wide sternal retraction not only stretches the brachial plexus but can also compress its lower trunk between the first rib and clavicle or directly injure the latter if the first rib is fractured (Lin et al. 2000). Injury is more likely if the internal thoracic artery is harvested for coronary artery grafting, with asymmetrical traction of the sternal halves associated with higher risks. Multiple factors are often involved such as stretching, trauma from central venous catheterisation, and intraoperative hypotension resulting in neural ischaemia. Intraoperative monitoring of somatosensory evoked potentials in the ulnar and median nerves may help to reduce the risk of injury (Chong et al. 2003).

The cords and terminal nerves are most often affected by stretching and the ensuing injuries are typically poorly localised, involving different parts of the plexus (Kim et al. 2004). Postoperatively, a brachial plexus lesion must be distinguished from ulnar nerve pressure palsy, which is the commonest positioning injury under general anaesthesia (Kretschmer et al. 2009). This can be achieved by utilising nerve conduction studies, which can differentiate between an ulnar neuropathy and brachial plexus injury quite readily (Chong et al. 2003).

Mechanisms of injury during central venous catheterisation include needle trauma and haematoma formation causing neural ischaemia. Injury during subclavian vein catheterisation is more likely with multiple needle passes and typically affects the lower roots of the brachial plexus. The subclavian vein has a lower and more superficial course than the brachial plexus. If the needle is passed too laterally or too deeply the brachial plexus roots may be injured (Karakaya et al. 2000). Iatrogenic brachial plexus injuries have also been reported during supraclavicular, infraclavicular, or transaxillary biopsy and resection of tumours (Dubuisson et al. 2002).
With an incidence of 1.4 per 1000 births, brachial plexus injury is the commonest neurologic injury seen in neonates (Gherman et al. 2005). The classic explanation for most of these injuries is excessive or misdirected traction to the foetal head when the foetal shoulder is trapped above the mother's pubic symphysis (shoulder dystocia) (Noble 2005). Other risk factors include instrumental delivery and higher birth weight (Gherman et al. 2005). The upper roots of the brachial plexus are most commonly affected. Although spontaneous recovery is common, residual deficits are present in up to 30% of children (Malessy and Pondaag 2009). In recent years, there has been debate about whether this is a preventable complication, especially since many affected infants are born after an atraumatic spontaneous vaginal delivery and the affected shoulder may be the posterior one (Gei et al. 2003; Noble 2005). There is also evidence that about half the cases of brachial plexus injury occur in average sized or small babies and smaller babies have more persistent and severe degrees of brachial plexus injury (Jennett et al. 1992; Gherman et al. 2005). Indeed, it has been suggested that some obstetric brachial plexus lesions are caused by intrauterine malpositioning rather than traumatic delivery (McAbee and Ciervo 2006). In view of this uncertainty, only one such case with a definite iatrogenic cause has been included in Table 2.2.

The outcome of patients affected by an iatrogenic brachial plexus injury is very variable, ranging from transient symptoms resolving within days (Gei et al. 2003) or weeks (Fox et al. 2005) to permanent severe disability (Lin et al. 2000). Of all the cases with a known outcome in Table 2.2, over half had persistent neurological symptoms such as pain, paraesthesiae and disturbed motor functioning at the time of original case report publication.
Table 2.2. Brachial plexus injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Arm(s) position</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POSITIONING INJURIES UNDER GENERAL ANAESTHESIA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac surgery</td>
<td>Variable arm positions</td>
<td>0.5%-14%</td>
<td>1. Canbaz et al. (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Ünlü et al. (2006)</td>
</tr>
<tr>
<td>Thoracic surgery</td>
<td>Flexed &amp; externally rotated above head</td>
<td>5%</td>
<td>Fox et al. (2005)</td>
</tr>
<tr>
<td>Thoracoscopic surgery</td>
<td>Abducted 90°-100° and laterally rotated</td>
<td></td>
<td>Pandey et al. (2009)</td>
</tr>
<tr>
<td>Colorectal surgery</td>
<td>- Abducted and laterally rotated</td>
<td>6.7%</td>
<td>Brill and Walisch (2005)</td>
</tr>
<tr>
<td></td>
<td>- Both at side in Trendelenburg position</td>
<td></td>
<td>Chin and Poole (2003)</td>
</tr>
<tr>
<td>Plastic and reconstructive surgery</td>
<td>Both abducted 90°-120°</td>
<td></td>
<td>Grunwald et al. (2003)</td>
</tr>
<tr>
<td>Laparoscopic renal surgery</td>
<td>Suspended and hyperabducted (120°)</td>
<td></td>
<td>Ngamprasertwong et al. (2004)</td>
</tr>
<tr>
<td>Liver surgery</td>
<td>- Abducted 90°</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Both at side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthopaedic surgery</td>
<td>Both abducted &lt;90°, neck hyperextended</td>
<td></td>
<td>Anghelescu et al. (2008)</td>
</tr>
<tr>
<td>Radiology</td>
<td>- Both above head</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Both abducted &gt;120°</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INJECTION INJURIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Axillary regional block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Percutaneous central venous catheterisation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>BIRTH INJURY</strong></td>
<td></td>
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</tbody>
</table>

The original systematic review table has been simplified because of the number of references (See Appendix A).
**Ulnar nerve**

The ulnar nerve is the major terminal nerve of the medial cord of the brachial plexus. It travels distally on the anterior aspect of the medial head of triceps brachii to the posterior aspect of the medial epicondyle (Prielipp et al. 2002). The nerve passes deep to the cubital tunnel retinaculum and continues distally between the muscle bellies of flexor carpi ulnaris and flexor digitorum profundus (Contreras et al. 1998). At the wrist, the ulnar nerve passes through a fibro-osseous tunnel known as Guyon’s canal, medial to the carpal tunnel (Zeiss et al. 1992) and splits into a superficial and deep branch in the hand, though there is anatomical variability in the number of terminal branches (Bonnel and Vila 1985).

The commonest cause of iatrogenic ulnar neuropathy is from compression of the nerve at the elbow, either from external pressure and/or prolonged elbow flexion. In the cubital tunnel, the ulnar nerve is superficial and relatively unprotected; when the arm is extended and pronated, the nerve may become compressed against the floor of the tunnel by external pressure. Marked flexion of the elbow (arm/forearm angle <90°) tightens the retinaculum overlying the cubital tunnel, shrinking the tunnel and increasing the risk of nerve compression (Winfree and Kline 2005). Ulnar nerve compression can affect as many as 1 in 200 adult surgical patients; men are more commonly affected (Warner et al. 1999). Gender differences in the thickness of the subcutaneous fat behind the medial epicondyle may account for this observation, with females having between two and 19 times thicker fat deposition in this region (Contreras et al. 1998). Surprisingly, there was an absence of recent reported cases of ulnar neuropathy following malpositioning, reflective of its acceptance as a complication and leading to presumed publication bias.

The majority of the recent reports of iatrogenic ulnar nerve injury relate to orthopaedic procedures. Supracondylar fractures of the humerus are the second commonest fracture in children (Cheng and Shen 1993). Closed reduction and
percutaneous Kirschner-wiring (K-wiring) of displaced supracondylar fractures frequently causes iatrogenic ulnar nerve injury (Table 2.3). This technique is preferred over open reduction and internal fixation because 1) ulnar neuropathy is not eliminated in open reduction and 2) the surgical approach and extensive dissection required in open procedures result in an increased risk of other postoperative complications (Kalenderer et al. 2008). There is particular interest in determining the configuration of pin placement that provides adequate fixation with the lowest risk of nerve injury. Crossed pinning, with one pin inserted laterally and one medially provides greater biomechanical stability than two lateral pins. However, it is widely accepted that the medial pin can damage the ulnar nerve (Foead et al. 2004) because of the placement of the medial K-wire near the cubital tunnel (Gosens and Bongers 2003). The nerve may be impaled by the pin upon insertion or it may become kinked over the medial pin during flexion and extension of the elbow (Rose and Phillips 2002). Pin direction and elbow positioning during insertion may also alter the incidence of ulnar neuropathy. If the medial pin is inserted in an anterior to posterior direction in the sagittal plane, the risk of ulnar injury seems to increase probably because the pin causes tethering and constriction of the cubital tunnel retinaculum (Özçelik et al. 2006). Likewise, elbow positioning affects the rate of injury: medial pin insertion into a hyperflexed elbow can increase the risk of nerve injury up to four-fold compared to without hyperflexion (Skaggs et al. 2001). The risk of nerve injury may be reduced if the nerve or pin is electrically stimulated intraoperatively, which will assist in localising the nerve (Wind et al. 2002). Another method is to insert the medial pin through a mini-incision, which in one study resulted in an extremely low rate of ulnar neuropathy (Green et al. 2005).

Iatrogenic ulnar nerve injury can result from open reduction and internal fixation of distal humerus fractures. During plate insertion, ulnar neuropathy is a risk, as the nerve and its blood supply are exposed, mobilised and retracted. The nerve is not transposed unless there is no soft tissue between the metal implant and nerve (Soon et al. 2004).
Mobilisation and transposition of the ulnar nerve has inherent risks. During surgical treatment of cubital tunnel syndrome, mobilisation may jeopardise the blood supply to the ulnar nerve, putting it at risk of ischaemic necrosis. Transposition may devascularise the nerve by division of multiple mesentery-like vessels, which form its intrinsic blood supply and is critical to the delivery of oxygen to individual nerve fascicles (Vigler et al. 2008). The nerve can also be constricted by a fasciodermal sling or compressed by scarring after transposition (Polatsch et al. 2002).

Ulnar neuropathy may complicate elbow arthroplasty (Rozing 2000) and elbow arthroscopy as a result of traction, direct trauma, or ischaemia from a tourniquet or neurolysis. In elbow arthroscopy, prior to medial portal insertion, it is imperative to locate the ulnar nerve. Particular care is needed if there has been previous trauma, surgery, or a congenital anatomic variation because tethered or displaced nerves in unexpected locations may render them more vulnerable to injury during portal insertion (Gay et al. 2010).

The incidence of iatrogenic ulnar nerve injury during wrist arthroscopy appears low (Table 2.3). Despite the complexity of the surgeries and the proximity of nerves to the standard portals, the approximate rate of complications has been cited as 2% (De Smet 2002). However, arthroscopic procedures on the ulnar aspect of the wrist have potential to injure the dorsal branch of the ulnar nerve, despite the nerve being visualised and protected during surgical dissection (Berendjiklian et al. 2004). The dorsal branch is particularly at risk of being strangulated by sutures during repair of the triangular fibrocartilage complex (Chen et al. 2006). In simulated repairs in cadavers, sutures were found as close as 0.4mm to the dorsal branch and in 50% of specimens, the sutures exited on opposite sides of the nerve, which could lead to strangulation if the ends were simply tied together. A longitudinal incision to identify the dorsal branch of the ulnar nerve ensures it is not pierced by the suturing needle or strangulated by the sutures (McAdams and Hentz 2002).
During open carpal tunnel release, approaching the flexor retinaculum from its ulnar side may spare the palmar branch of the median nerve but may risk damaging the palmar cutaneous branch of the ulnar nerve (Akhtar et al. 2005). Accidental release of Guyon’s canal and transection of the ulnar nerve during endoscopic carpal tunnel release has been reported by Subasi et al. (2004) who attributed the error to insufficient surgical training.

Symptoms of ulnar neuropathy depend on the site of injury; complete anaesthesia in the little finger and the ulnar half of the ring finger has been reported after pinning of supracondylar humeral fractures (Kalenderer et al. 2001). Clawing of the ring and little fingers can result from a distal nerve injury, as the dorsal interossei and medial two lumbrical muscles are paralysed (Vigler et al. 2008).
Table 2.3. Ulnar nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative treatment of supracondylar fracture of humerus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- closed reduction</td>
<td></td>
<td>2. Özçelik et al. (2006)</td>
</tr>
<tr>
<td>- open reduction</td>
<td>1.5%</td>
<td>Green et al. (2005)</td>
</tr>
<tr>
<td>- mini-open technique</td>
<td>13%</td>
<td>Foead et al. (2004)</td>
</tr>
<tr>
<td><strong>Treatment of distal humeral fracture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- open reduction and internal fixation</td>
<td>5%1-13%2</td>
<td>1. Huang et al. (2005)</td>
</tr>
<tr>
<td>2. Soon et al. (2004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wrist arthroscopy</strong></td>
<td>2%</td>
<td>Beredjiklian et al. (2004)</td>
</tr>
<tr>
<td>Surgery to triangular fibrocartilage complex and ulnar styloid</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Carpal tunnel decompression</strong></td>
<td>10%</td>
<td>Müller et al. (2000)</td>
</tr>
<tr>
<td>- single portal endoscopic technique</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Anterior ulnar nerve transposition for cubital tunnel syndrome</strong></td>
<td>Case report</td>
<td>Vigler et al. (2008)</td>
</tr>
<tr>
<td>Ischaemic necrosis of nerve</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Elbow arthroscopy</strong></td>
<td>1%</td>
<td>Kelly et al. (2001)</td>
</tr>
<tr>
<td><strong>RADIAL ARTERY HARVESTING</strong></td>
<td>12%</td>
<td>Ilkizler et al. (2005)</td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CONTRACEPTIVE IMPLANT</strong></td>
<td>2 Case reports</td>
<td>Anon. (2008)</td>
</tr>
<tr>
<td>Subcutaneous hormone implant removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INJECTION INJURY</strong></td>
<td>0.2%</td>
<td>Kelly et al. (2001)</td>
</tr>
<tr>
<td>Local anaesthetic injection</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The original systematic review table has been simplified because of the number of references (See Appendix A).
Radial nerve

The radial nerve is a terminal branch of the posterior cord of the brachial plexus. Originating posterior to the axillary artery, the radial nerve passes laterally and posteriorly, running deep to triceps brachii, along the posterior surface of the humerus (Kim et al. 2001). The radial nerve pierces the lateral intermuscular septum and enters the anterior compartment of the arm about 10 cm proximal to the lateral epicondyle of the elbow (Carlan et al. 2007). Travelling distally, the radial nerve passes in front of the lateral epicondyle and divides into the posterior interosseous nerve (PIN) and the superficial branch of the radial nerve (SBRN) (Kim et al. 2001).

Recently reported iatrogenic injuries of the radial nerve in the arm are shown in Table 2.4. Although the radial nerve is injured primarily in one in eight humeral shaft fractures (Shao et al. 2005) it is also at risk during surgical treatment of these injuries. It is particularly vulnerable at two sites: in the region of the mid-shaft posteriorly where it is in direct contact with the periosteum of the humerus over a distance of about 6 cm near the deltoit tuberosity, and where it pierces and is tethered by the lateral intermuscular septum. The deltoit tuberosity is a consistent and practical anatomical landmark that can be used to determine the level of the radial nerve along the posterior humerus during fracture fixation (Carlan et al. 2007).

There are two main methods of surgical stabilisation of fractures of the humeral shaft: a) closed reduction and intramedullary fixation; and b) open reduction and internal plate fixation (Sarahurdi et al. 2009). Iatrogenic radial nerve injuries from fixation of humeral shaft fractures are nearly always caused by dynamic compression plates during open reduction and fixation (Table 2.4) because of the intimate anatomical relationship between the radial nerve and the humerus and the extensive dissection required to insert the plate (Martinez et al. 2004). It appears the direction of approach to plate fixation has little impact on the incidence of radial nerve injury, with the anterolateral, posterior, posteromedial and anterior
brachialis splitting approaches all causing iatrogenic radial nerve injury. Closed reduction and intramedullary fixation is not without risk, although it is less (Table 2.4). Nails can be used to fixate the fracture and the insertion of these nails in an antegrade direction puts the radial nerve at risk, especially in the distal third of the humerus, since the radial nerve is now in the anterior compartment of the arm (Carlan et al. 2007).

Symptoms depend on the site and severity of the injury but commonly include cutaneous sensory disturbances on the dorsolateral aspect of the hand, with or without wrist drop, and weakness of triceps brachii, brachioradialis and finger extensors. Neuroma formation can be associated with debilitating pain (Robson et al. 2008).

In common with several other upper limb nerves, the radial nerve is vulnerable to compression from poor positioning under general anaesthesia if the posterior aspect of the arm is unprotected and compressed against a rigid structure, such as an anaesthetic screen pole, armboard, or the edge of the operating room table (Winfree and Kline 2005). Neuropathy has also been reported from a blood pressure cuff attached to an automated monitoring device during surgery. The lower edge of the blood pressure cuff was in the region just superior to the lateral epicondyle, where the radial nerve is most superficial and the oscillating pressures in the cuff may have resulted in trauma to the myelin sheath (Lin et al. 2001). Fortunately, most of these injuries cause transient impairment only, with recovery mostly occurring within six months, though it may take longer due to the long course of the nerve (Winfree and Kline 2005).
Table 2.4. Radial nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative treatment of humeral shaft fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic compression plating</td>
<td>4%$^1$-13%$^2$</td>
<td>1. Wang et al. (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Putti et al. (2009)</td>
</tr>
<tr>
<td>Intramedullary nailing</td>
<td>1%$^1$-6%$^2$</td>
<td>1. Chen et al. (2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Blyth et al. (2003)</td>
</tr>
<tr>
<td>Elbow arthroscopy</td>
<td>Case report</td>
<td>Park et al. (2007)</td>
</tr>
<tr>
<td><strong>POSITIONING INJURIES UNDER GENERAL ANAESTHESIA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External compression</td>
<td>Case reports</td>
<td>Papadopoulou et al. (2006)</td>
</tr>
<tr>
<td><strong>INJECTION INJURIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intramuscular injection</td>
<td>Case reports</td>
<td>Pandian et al. (2006)</td>
</tr>
</tbody>
</table>

Table 2.5. Posterior interosseous nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
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<td></td>
</tr>
<tr>
<td>Repair of distal avulsed biceps brachii tendon</td>
<td>2%$^1$-22%$^2$</td>
<td>1. McKee et al. (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Moosmayer et al. (2000)</td>
</tr>
<tr>
<td>Elbow arthroscopy</td>
<td>0.2%</td>
<td>Kelly et al. (2001)</td>
</tr>
</tbody>
</table>

The original systematic review tables have been simplified because of the number of references (See Appendix A).
Posterior interosseous nerve

The PIN is dominantly a motor nerve and splits from the radial nerve anterior to the lateral epicondyle of the humerus to supply most of the extensor muscles of the forearm (Missankov et al. 2000). The PIN winds laterally around the radius, passing between the two heads of supinator (Kim et al. 2001). The nerve is at risk of iatrogenic injury during any orthopaedic procedure near the radial head and neck because of their anatomical proximity. In elbow arthroplasty, an arthroscope introduced through the anterolateral portal is on average 5mm from the PIN, risking nerve injury (Marshall et al. 1993).

Symptoms were persistent in half of the cases listed in Table 2.5. Isolated injuries of the PIN typically present with weakness of wrist and finger extension (but not wrist drop because extensor carpi radialis longus is innervated by the radial nerve), weakness of extension and abduction of the thumb, and a deep forearm discomfort or pain (Kim et al. 2006a).
Axillary nerve

The axillary nerve is one of the terminal branches of the posterior cord of the brachial plexus. Travelling from behind the axillary artery, the nerve runs obliquely anterior to subscapularis. At the inferior edge of subscapularis, the nerve passes through the quadrangular space, wrapping around the surgical neck of the humerus posteriorly. The majority of axillary nerves divide into an anterior and posterior branch in the quadrangular space, and each branch has a differing course into the deltoid (Apaydin et al. 2010).

Iatrogenic injury to the axillary nerve is a widely recognised complication of orthopaedic surgery, especially treatment of humeral fractures and shoulder surgery (Table 2.6). The incidence of nerve palsy following repair of a proximal humeral fracture has been reported to be up to 5% (Albritton et al. 2003) because the nerve is vulnerable to injury as it runs close to the surgical neck of the humerus (Bono et al. 2000). Injury can occur during external plate fixation from a variety of surgical approaches, including the deltopectoral, extended lateral, anterolateral, or deltoid-splitting method. Percutaneous wire fixation of humeral fractures is an alternative to plate fixation. There were no case reports identified using this search strategy, but one study that inserted K-wires laterally and anteroposteriorly into 40 cadaver shoulders penetrated the axillary nerve on three (7.5%) occasions by laterally inserted wires (Kamineni et al. 2004).

One cadaver study reported the axillary nerve crosses the humerus at an average of 6.1 ± 0.7 cm distal to the proximal tip of the humerus, and 1.7 ± 0.8 cm distal to the surgical neck of the humerus. This finding has prompted suggestions that extended lateral incisions more than 5 cm distal to the proximal tip of the humerus should be avoided (Bono et al. 2000). It is important to note that arm position during surgery can alter the course of the axillary nerve. One cadaver study using a lateral deltoid approach in 7 shoulders found that shoulder abduction to 60° moved the axillary nerve up to 14 mm closer to the mid-acromion (Cheung et al. 2009).
Arthroscopic procedures near the inferior glenoid rim are complicated by limited visibility and the potential for axillary nerve injury. The posterior branch of the axillary nerve to teres minor has been found to lie just 12.4 ± 0.8 mm from the inferior glenoid rim (Price et al. 2004). Some suggest that intraoperative monitoring of nerve function prevents significant nerve injury. Esmail et al. (2005) monitored electromyographic (EMG) activity in 20 patients undergoing thermal capsulorrhaphy, a process whereby the joint capsule is heated locally to induce shrinkage and improve joint stability. Heat application was immediately reduced when abnormal EMG activity was detected, possibly preventing nerve injury.

Symptoms typically present as deltoid atrophy and weakness of arm abduction, and to a lesser extent flexion and extension (Imran et al. 2004), and loss of sensation in the ‘regimental patch’ region (Davidson et al. 2007). Motor and sensory disturbances can occur independently and symptoms vary depending on which branch of the axillary nerve is injured.

The axillary nerve is occasionally damaged by intramuscular injection into the deltoid. To avoid this complication, Davidson et al. (2007) propose that intramuscular injections should be given 5 cm from the lateral edge of the acromion. Similarly, a popular nursing text advises approximately three fingerbreadths or 2.5-5.0 cm below the lower edge of the acromion (Perry and Potter 2010). If the deltoid muscle is selected for intramuscular injection, a safer recommendation is the lateral aspect of the deltoid no more than 3 cm below the lower border of the acromion (Burkhead et al. 1992).
Table 2.6. Axillary nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORTHOPAEDIC SURGERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative treatment of proximal humeral fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retrograde nailing with interlocking screw</td>
<td>Case report</td>
<td>Lögters et al. (2008)</td>
</tr>
<tr>
<td>Plate fixation of proximal fractures</td>
<td>3%(^1)-7%(^2)</td>
<td>1. Martinez et al. (2009)</td>
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<td></td>
<td></td>
<td>2. Khan et al. (2009a)</td>
</tr>
<tr>
<td>Shoulder surgery</td>
<td>1%(^1)-1.4%(^2)</td>
<td>1. McFarland et al. (2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Wong and Williams (2001)</td>
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<td>POSITIONING INJURY UNDER GENERAL ANAESTHESIA</td>
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<tr>
<td>Compression/traction during thoracoscopic surgery</td>
<td>Case report</td>
<td>Nishimura et al. (2008)</td>
</tr>
<tr>
<td>INJECTION INJURIES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axillary nerve block</td>
<td>Case report</td>
<td>Imran et al. (2004)</td>
</tr>
<tr>
<td>Intramuscular injection of deltoid</td>
<td>Case report</td>
<td>Davidson et al. (2007)</td>
</tr>
</tbody>
</table>

The original systematic review table has been simplified because of the number of references (See Appendix A).
**Median nerve**

The median nerve is a terminal nerve of the brachial plexus, formed by the union of the lateral and medial cords. The median nerve gives off no branches in the arm. It enters the forearm between the two heads of pronator teres and then gives off a deep branch, the anterior interosseous nerve. The median nerve passes under a tendinous bridge formed by flexor digitorum superficialis and descends deep to this muscle but superficial to flexor digitorum profundus. Near the flexor retinaculum, the median nerve is lying between the tendons of flexor carpi radialis and palmaris longus. It passes under the retinaculum in the carpal tunnel and divides variably into five or six branches in the hand (Standring 2008).

In a consecutive series of 263 surgically treated iatrogenic peripheral nerve injuries at a large neurosurgical unit, median nerve injury was the commonest upper limb nerve injury requiring surgical repair, accounting for 16% of all cases. The median nerve is especially vulnerable during carpal tunnel release, during both open and endoscopic procedures (Kretschmer *et al.* 2009) (Table 2.7). The conventional treatment for carpal tunnel compression is open surgical release but this may be associated with postoperative pain, tenderness and weakness that delay a patient’s full recovery (Agee *et al.* 1992). Endoscopic surgical repair is a technique that aims to reduce postoperative morbidities by using smaller incisions; there are two principal methods using either a single or double portal. A recent meta-analysis of controlled trials comparing endoscopic and open carpal tunnel decompression supported endoscopic release results in less tenderness and better strength at three months follow-up (Thoma *et al.* 2004). However, there was no statistically significant improvement in primary symptom relief and time to return to work. This study also showed that endoscopic carpal tunnel release is three more times as likely to cause iatrogenic (albeit reversible) nerve damage.

Based on a review of the literature, Benson *et al.* (2006) reported median nerve injuries in about 0.1% of carpal tunnel releases. The actual incidence may be higher in clinical practice. Mechanisms include compression or stretch of the
nerve during insertion of the endoscopic cannula assembly inside the carpal tunnel or increased pressure inside the carpal tunnel from prolonged positioning of the hand during surgery (Uchiyama et al. 2004). Iatrogenic injury may affect the main trunk or one of its branches such as the recurrent thenar branch, a common digital nerve, or the palmar branch.

Symptoms of median nerve injury in the carpal tunnel include localised pain, paraesthesiae and burning sensation in the cutaneous distribution of the median nerve in the hand. Sensory loss or thenar muscle weakness may result from a more serious median nerve injury (Braun et al. 2002).

Variant anatomy of the median nerve is encountered in 3%-12% of cases, and may increase the risk of iatrogenic injury (Kretschmer et al. 2009). Usually, the only branch of the median nerve in the distal forearm is its palmar cutaneous branch but, rarely, a high bifurcation of the median nerve can result in a common digital nerve crossing the line of division of the flexor retinaculum during endoscopic carpal tunnel release (Jeon et al. 2002).

Injection of steroids into the carpal tunnel to alleviate symptoms of nerve compression also risks nerve damage. There is no consensus on the safest injection site. A suggested safe site for injection is through the tendon of flexor carpi radialis. In a series of 30 injections through flexor carpi radialis, no instances of electric discharge-like pain or tendon ruptures occurred (Dubert and Racasan 2006). In a cadaver study using a commonly employed injection technique, four of 15 simulated injections pierced the median nerve although in clinical practice the incidence of clinically detectable intraneural injection is much lower. In clinical practice patients are awake to alert the physician to the onset of paraesthesiae which can avoid intraneural injections and it is also likely that the median nerve can move away from the needle tip with the injection of the steroid because of the mobility of the surrounding tissue in the living patient (MacLennan et al. 2009).
Other reported causes of median nerve injury are shown in Table 2.7. Rarely, the median nerve has been confused with the palmaris longus tendon with disastrous consequences; due to the rarity of these reports, it is not clear whether this is more likely if palmaris longus is congenitally absent (Weber and Mackinnon 2007).
Table 2.7. Median nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operative treatment of ulna fracture</td>
<td>Case report</td>
<td>Thumroj et al. (2005)</td>
</tr>
<tr>
<td>Carpal tunnel release</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Dual portal endoscopic technique</td>
<td>15%</td>
<td>Uchiyama et al. (2004)</td>
</tr>
<tr>
<td>- Standard palmar incision open technique</td>
<td>1.5%</td>
<td>Uchiyama et al. (2004)</td>
</tr>
<tr>
<td>- Minimally open technique</td>
<td>Case report</td>
<td>Chapman et al. (2001)</td>
</tr>
<tr>
<td><strong>Tendon graft surgery</strong></td>
<td></td>
<td>Weber and Mackinnon (2007)</td>
</tr>
<tr>
<td><strong>INJECTION INJURIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peripherally inserted intravenous catheter</td>
<td>Case report</td>
<td>Alomari and Falk (2006)</td>
</tr>
<tr>
<td>Axillary/proximal brachial artery catheterisation</td>
<td>Case reports</td>
<td>Tsao and Wilbourn (2004)</td>
</tr>
</tbody>
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Table 2.8. Anterior interosseous nerve injury

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<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
<td></td>
<td></td>
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<tr>
<td>Operative treatment of ulna fracture</td>
<td>Case report</td>
<td>Parker et al. (2005)</td>
</tr>
<tr>
<td>Shoulder arthroscopy</td>
<td>Case report</td>
<td>Sisco and Dumanian (2007)</td>
</tr>
<tr>
<td>Open elbow capsulectomy</td>
<td>Case reports</td>
<td>Katolik and Cohen (2009)</td>
</tr>
<tr>
<td><strong>INJECTION INJURIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cubital fossa venipuncture</td>
<td>Case report</td>
<td>Zubairy (2002)</td>
</tr>
</tbody>
</table>

The original systematic review tables have been simplified because of the number of references (See Appendix A).
Anterior interosseous nerve

The anterior interosseous nerve (AIN) is a predominantly motor branch of the median nerve, arising 5-8 cm distal to the medial epicondyle of the humerus as the median nerve travels between the two heads of pronator teres. It follows the anterior aspect of the interosseous membrane, deep to the flexor muscles of the forearm (Puhaindran and Wong 2003).

Iatrogenic injury of the AIN may result directly from trauma such as venipuncture in the cubital fossa (Zubairy 2002) or indirectly from compression or traction during orthopaedic surgery (Table 2.8). Adherence of the nerve within pronator teres where it branches off the median nerve may render it more susceptible to traction injury (Sisco and Dumanian 2007; Katolik and Cohen 2009). Complete palsy typically results in a pinch deformity, with the patient unable to make an “O” with the thumb and index finger. Although uncommon, partial AIN palsy is frequently misdiagnosed as a single tendon rupture (Kim et al. 2006b). Pain in the proximal forearm is also a common feature of nerve injury, affecting up to 85% of patients (Puhaindran and Wong 2003).
Musculocutaneous nerve

The musculocutaneous nerve is a terminal branch of the lateral cord of the brachial plexus and innervates muscles of the anterior compartment of the arm. Terminal sensory fibers coalesce to emerge as the lateral cutaneous nerve of the forearm at the anterolateral border of the bicipital aponeurosis (Belzile and Cloutier 2001). Symptoms characterise the level at which a nerve injury has occurred: complete paralysis of arm flexors signifies a high musculocutaneous nerve lesion whereas an injury at the level of the elbow with pure sensory manifestations signifies a lateral cutaneous nerve of the forearm injury (Judge and Fecho 2010).

Only one report of iatrogenic musculocutaneous nerve injury was identified within the search study period in a patient who developed nerve entrapment after an arthroscopically assisted relocation of the tendon of the long head of biceps brachii (Ma et al. 2009).
Cutaneous nerves

The superficial branch of the radial nerve (SBRN) is a terminal branch of the radial nerve emerging from between the tendons of brachioradialis and extensor carpi radialis longus at around 9 cm proximal to the radial styloid process (Robson et al. 2008). It pierces the posterior antebrachial fascia to run subcutaneously beyond the radial styloid (Sheu and Yuan 2001), giving off a median of four branches on the dorsum of the hand (Robson et al. 2008).

The SBRN is at risk during a variety of surgical procedures as well as in the unconscious patient (Figure 2.1). The nerve or its branches may be damaged during reduction and fixation of a distal radial styloid process fracture because sensory branches are on average only 4 mm away from the radial styloid (Auerbach et al. 1994). This type of injury is illustrated by a cadaver study in which an experienced orthopaedic surgeon inserted percutaneous K-wires into 92 wrists; the SBRN was injured in 13 (14%) cases (Glanvill et al. 2006). In a clinical setting, the rate of injury to the SBRN may be as high as 20% (Singh et al. 2005). In De Quervain’s tenosynovitis the tendons of extensor pollicis longus and abductor pollicis brevis become inflamed within the first compartment of the extensor retinaculum. Surgical release of the tendons may injure the SBRN, even when it is identified and protected intra-operatively (Scheller et al. 2009). The risk of damage may be minimised by a longitudinal incision (Robson et al. 2008).

There is a close anatomical relationship between the SBRN and the cephalic vein at the wrist; they intersect at least once (and even up to three times) in highly variable positions. This has prompted some authors to suggest that the cephalic vein in the distal third of the forearm should be avoided for venous access because of the risk of nerve injury (Vialle et al. 2001; Robson et al. 2008). However, venous cannulation at this site is common and symptoms are typically transient.
The SBRN is also in close proximity to the radial artery at the radial styloid process. Neurologic complications were reported to be as high as 30% after radial artery harvest for coronary artery bypass grafting (Denton et al. 2001). Symptoms of SBRN injury include an area of paraesthesiae over the dorsum of the first web space and, in more serious cases, a painful and debilitating neuroma may form (Robson et al. 2008).

In all instances of iatrogenic nerve damage documented in Figure 2.1, it is assumed that the SBRN was injured. However, it should be noted that there is partial or complete overlap between the cutaneous territory of this nerve and that of the lateral cutaneous nerve of the forearm in 75% of individuals and therefore injury to the latter may account for some cases (Mackinnon and Dellon 1985).
Figure 2.1. Superficial branch of radial nerve injury (Modified from Zhang et al. 2011)
The *medial cutaneous nerve of arm* arises from the medial cord of the brachial plexus and runs distally with the ulnar nerve. There was only one report of iatrogenic injury to this nerve identified in the review period and this related to a patient who underwent failed cubital tunnel surgery (Sarris et al. 2002).

In contrast, there were numerous reports of damage to the *medial cutaneous nerve of forearm* (Figure 2.2). This nerve originates usually from the medial cord of the brachial plexus and divides into two main branches that pass anterior and posterior to the medial epicondyle (Sarris et al. 2002). The posterior branch is vulnerable during cubital tunnel surgery whilst the anterior branch is at risk during venipuncture. Insertion and removal of subdermal contraceptive implants in the arm may injure the nerve as it becomes cutaneous in the medial cubital fossa because of the proximity to the site of the implant (Wechselberger et al. 2006). Neuropathy may manifest as regional sensory disturbances, pain and/or a painful neuroma (Sarris et al. 2002).

The *lateral cutaneous nerve of forearm* is the distal termination of the musculocutaneous nerve and innervates the radial half of the forearm (Judge and Fecho 2010). This nerve is also at risk during invasive procedures involving access via the cubital fossa (Figure 2.3). Injury to the nerve during repair of distal biceps tendon ruptures is most likely related to the anterior incision and the retraction needed to expose the ruptured tendon (Bisson et al. 2008). Other invasive procedures include venipuncture, particularly when the cephalic vein is punctured just lateral to the biceps tendon and crossed by the nerve (Stitik et al. 2001). Patients with a lateral cutaneous nerve of forearm injury often complain of lateral forearm paraesthesiae without motor deficits (Judge and Fecho 2010).
It is surprising that there have not been more reports of injury to the cutaneous nerves of the forearm from venipuncture, particularly the medial cutaneous nerve which crosses superficial to the median cubital vein in about 40% of individuals (whereas the lateral cutaneous nerve runs deep to the vein in most cases) (Yamada et al. 2008). However retrospective data from blood donors suggests that these nerve injuries are indeed rare (Newman and Waxman 1996).

Iatrogenic digital nerve injury is a potential complication of fasciectomy for Dupuytren's disease, occurring in 2-5% of cases (Denkler 2005; Anwar et al. 2007), carpal tunnel release (Kiymaz et al. 2002), and other types of hand surgery. Phillips et al. (2005) were unable to find any report of iatrogenic digital nerve injury secondary to local anaesthetic nerve block in the literature but from a small cadaver study they concluded that this type of injury probably does occur but the effects of the injury are probably attributed to the condition for which the block was necessary, leaving the patient and surgeon unaware of the iatrogenic injury.
Figure 2.2. Medial cutaneous nerve of forearm injury (Modified from Zhang et al. 2011)

*Cosmetic surgery to remove loose skin and subcutaneous fat from under the arm
Figure 2.3. Lateral cutaneous nerve of forearm injury (Modified from Zhang et al. 2011)
Obturator nerve

The obturator nerve arises from the lower lumbar spine, with roots from the second, third, and fourth lumbar spinal nerves. It leaves the pelvis through the obturator canal, within which it divides into anterior and posterior divisions. The anterior branch travels distally between adductor longus and adductor brevis whilst the posterior branch travels on adductor magnus. The obturator nerve supplies all of the muscles in the medial compartment of the thigh and sensation to the overlying skin (Spinosa et al. 2007).

Iatrogenic obturator neuropathy is relatively uncommon and usually occurs acutely after a well-defined event, most often as a result of surgery. This is because the nerve lies deep within the pelvis and medial thigh, and is protected from direct external trauma by the overlying adductor muscles (Sorenson et al. 2002).

However as shown in Table 2.9, injury to the obturator nerve can still occur after a variety of pelvic surgeries. Affected patients complain of persistent pain and/or paraesthesiae in the region of the groin and medial aspect of the thigh and/or present with lower limb adductor weakness (Grant et al. 2001). These symptoms are a common denominator of obturator nerve injury regardless of aetiology. Most symptoms arise a few days after surgery, and usually resolve within six months with conservative treatment.

Total hip arthroplasty is a relatively common cause of iatrogenic obturator neuropathy. Sorenson et al. (2002) found 50% (7/14) patients with obturator injuries had previously undergone total hip arthroplasty. The obturator nerve runs very close to the anteromedial wall of the acetabulum (Grant et al. 2001) and any violation of this wall risks obturator nerve injury. Generally, injury to the obturator nerve is caused by medial extrusion of acetabular cement, which can compress or impinge on the nerve (Barrack and Butler 2003). Cement extrusion
can be confirmed by CT scans and obturator nerve damage can be confirmed by EMG studies (Grant et al. 2001).

Obturator neuropathy can complicate other operative procedures such as radical prostatectomy (Son-fat et al. 2008), pelvic lymphadenectomy (Guillonneau et al. 2002), and major gynaecologic surgery (Cardosi et al. 2002). A large retrospective study found that obturator nerve injury accounted for 40% (9/23) of all lower limb neuropathies after major gynaecologic surgery. All of the injuries were caused by surgery for gynaecologic tumours (Cardosi et al. 2002). Mid-urethral tension-free vaginal slings have become the surgical procedure of choice to treat stress urinary incontinence. Although the risk of obturator nerve damage is extremely low, it may still occur (Table 2.9). In a cadaver study using a transobturator approach, the sling passed within 1.1 cm of the most medial branch of the obturator nerve (Whiteside and Walters 2004).

Intraoperative malpositioning of the obturator nerve resulting in injury is rarely described (Winfree and Kline 2005). One case report was identified where the patient was in a prolonged prone position with a hip roll that caused an obturator neuropathy. It was suggested that instead of running within the obturator canal, the nerve in this case travelled over the superior ramus of the pubis and thus became compressed between the hip roll and the pubic bone but this implies anomalous anatomy (Khan et al. 2009b).
Table 2.9. Obturator nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hip arthroplasty</td>
<td>Case report</td>
<td>Mahadevan et al. (2009)</td>
</tr>
<tr>
<td>Femur fracture fixation</td>
<td>Case report</td>
<td>Hattori et al. (2004)</td>
</tr>
<tr>
<td><strong>UROLOGIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laparoscopic radical prostatectomy</td>
<td>0.17% - 1.9%</td>
<td>1. Guillonneau et al. (2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Son-fat et al. (2008)</td>
</tr>
<tr>
<td>Transurethral collagen injection</td>
<td>Case report</td>
<td>Dimachkie et al. (2000)</td>
</tr>
<tr>
<td><strong>GYNAECOLOGIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension-free vaginal tape procedure</td>
<td>0.0008 - 0.002%</td>
<td>1. Agostini et al. (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Meschia et al. (2001)</td>
</tr>
<tr>
<td>Radical hysterectomy</td>
<td>7.1%</td>
<td>Papacharalabous et al. (2009)</td>
</tr>
<tr>
<td>Laparoscopic retroperitoneal surgery</td>
<td>1.1%</td>
<td>Holub (2006)</td>
</tr>
<tr>
<td>Laparoscopic tubal occlusion</td>
<td>Case report</td>
<td>Jirsch and Chalk (2007)</td>
</tr>
<tr>
<td><strong>POSITIONING INJURY UNDER GENERAL ANAESTHESIA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scapulopexy surgery with patient prone</td>
<td>Case report</td>
<td>Khan et al. (2009b)</td>
</tr>
</tbody>
</table>
Sural nerve

The sural nerve is a sensory nerve of the lower limb innervating the posterolateral aspect of the lower third of the leg and the lateral region of the dorsum of the foot. The sural nerve is formed by the medial sural cutaneous nerve and the peroneal communicating branch from the lateral sural cutaneous nerve 11-20 cm from the lateral malleolus. The medial sural cutaneous nerve is a branch of the tibial nerve in the popliteal fossa and descends between the two heads of gastrocnemius but eventually pierces the overlying fascia and becomes superficial. The peroneal communicating branch “descends medially superficial to gastrocnemius fascia and joins the medial sural cutaneous nerve”. The sural nerve crosses the lateral border of the calcaneal tendon (Achilles tendon) posteriorly at a mean distance of 9.8 cm (6.6 – 16 cm) proximal to where the tendon inserts into the calcaneum. The anatomical relationship between the sural nerve and the calcaneal tendon and the high anatomical variability of the sural nerve puts it at risk during percutaneous repair of a ruptured Achilles tendon (Webb et al. 2000).

In the original percutaneous technique of repair of a ruptured Achilles tendon pioneered by Ma and Griffith in 1977, three stab incisions on the lateral aspect of the calcaneal tendon may jeopardise the sural nerve. The nerve is also at risk when sutures are run blindly between incisions, or during dissection of the peritendineum (Majewski et al. 2006; Lansdaal et al. 2007). To reduce the risk of sural nerve injury, some authors have suggested modifying the original technique by positioning the proximal lateral incision as close as possible to the tendon edge or using posterior incisions and careful soft tissue dissection to visualise the sural nerve (Cretnik et al. 2005; Majewski et al. 2006). Clinical symptoms of a sural nerve lesion can range from minor paraesthesiae to severe pain or loss of sensation in the distribution of the sural nerve (Majewski et al. 2006). The prognosis of sural disturbances is usually good; 80% of patients with sural nerve sensory loss did not consider the sensory loss uncomfortable in one prospective study (Lansdaal et al. 2007). A comparative study of percutaneous versus open repair of a ruptured calcaneal tendon showed a 4.5% incidence of sural nerve injury in the percutaneous group (n=132), compared to 2.8% in the open group.
(n=105) (Cretnik et al. 2005). However, this difference was statistically insignificant. Nevertheless, other studies support the suggestion that the risk of sural nerve injury is substantially higher with percutaneous repair when compared with open repair (Table 2.10).

Another potential cause of injury to the sural nerve is from varicose vein surgery. The sural nerve lies close to the small saphenous vein throughout its length and is at risk during dissection of the saphenopopliteal junction and stripping of the small saphenous vein (Sam et al. 2004).
<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>ORTHOPAEDIC SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open repair of ruptured Achilles tendon</td>
<td>2.8% (^1) - 3.3% (^2)</td>
<td>1. Cretnik <em>et al.</em> (2005) 2. Jung <em>et al.</em> (2008)</td>
</tr>
<tr>
<td>Lateral malleolar fracture fixation</td>
<td>Case reports</td>
<td>Seror (2002)</td>
</tr>
<tr>
<td><strong>VASCULAR SURGERY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varicose vein surgery</td>
<td>Case reports</td>
<td>Seror (2002)</td>
</tr>
<tr>
<td>Small saphenous vein stripping</td>
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</table>
2.4 Conclusions and relevance to proposed research

This literature review outlines the contemporary spectrum of iatrogenic nerve injuries affecting the upper limb and selectively examines two lower limb nerve injuries. The true frequency of iatrogenic upper limb nerve injuries is difficult to determine, not least because the literature is subject to publication bias, tending to diminish the importance of more common types of nerve injury that have been previously recognised (for example, the absence of reported cases of ulnar neuropathy following malpositioning). What is clear however is that these injuries are common, are a potential cause of major disability, and can affect patients in any surgical specialty. The spectrum of iatrogenic upper limb nerve injuries has changed as surgical technology has evolved. Minimal access surgery does not mean minimal risk of peripheral nerve injury. Neither are diagnostic procedures free of these complications if performed under general anaesthesia. Some injuries, such as those associated with rare variant anatomy, may be unavoidable but many, if not most, cases are preventable by a detailed knowledge of anatomy and an understanding of situations in which peripheral nerves are particularly at risk.

No research into the spectrum of iatrogenic peripheral nerve injuries in New Zealand has been undertaken but, judging from the medical literature, these events occur in all healthcare systems. Although the evidence is lacking, it is quite likely that some if not many of these injuries relate to an inadequate knowledge of anatomy within the context of the clinical procedure being performed. We aim to determine the commonest types of iatrogenic peripheral nerve injuries in clinical practice in New Zealand by using data from the Accident Compensation Corporation of New Zealand which will be the subject of the next chapter.
Chapter 3: Iatrogenic nerve injuries in New Zealand

3.1 Introduction

During the past decade, the subjects of patient safety and the quality of healthcare systems have been the focus of much research. One of the major topics of interest has been complications due to errors made by health practitioners. These iatrogenic errors are a major cause of concern and a source of distress, disability, and death in patients. In addition, they are associated with litigation and impose a major financial burden on healthcare budgets. The report from the Institute of Medicine in 1999 entitled “To Err is Human” gave the issue of medical error huge public prominence when it stated that between 44,000 and 98,000 hospitalised Americans died each year as a result of preventable medical errors (Kohn 1999). The financial burden is equally shocking. A 2001 report from the National Audit Office in the U.K showed that the bill for medical negligence faced by the National Health Service amounted to £2.6 billion, double the amount paid out in 1997 (Ferriman 2001).

In New Zealand, one of the first epidemiological studies to highlight quality of care issues was a “survey of adverse drug events among 9000 admissions to Dunedin Hospital in the early 1970s” (Davis et al. 2002). Although numerous surgical audits and studies of anaesthetic error have since been reported, there is a lack of recently published epidemiological studies on the spectrum of iatrogenic injuries in New Zealand and an absence of research on the spectrum of iatrogenic nerve injuries. One study published by Davis et al. (2003) described the pattern of preventable in-hospital adverse events by using hospital admission records of
6579 patients in 1998. The authors found more than 5% of admissions were associated with a preventable in-hospital adverse event. An adverse event was defined as “an unintended injury resulting in disability and caused by healthcare management rather than the underlying disease process”. The context of injury was divided into broad clinical classifications. Half of the adverse events identified could be attributed to a systems error including medication error and delays in treatment. The definition of an adverse event is similar to an iatrogenic injury although the emphasis of this study was on in-hospital adverse events.

The focus of the present research does not include system errors but focuses exclusively on practitioner related injuries, specifically highlighting iatrogenic nerve injuries sustained by patients in the New Zealand healthcare system. Some of these injuries may be unavoidable complications but judging from the results of the literature review, most are preventable if the normal anatomy is fully understood and appreciated within the context of the procedure.

The aim of this research is to describe the current spectrum of iatrogenic nerve injuries in New Zealand. In addition, the hypothesis that the spectrum of iatrogenic upper limb nerve injuries in New Zealand is similar to the spectrum of injuries described in the international medical literature can be tested.

Medical Protection Society Casebooks

A review of the quarterly medicolegal journal ‘Casebook’ published by the Medical Protection Society (MPS) provided an initial insight into the current spectrum of iatrogenic nerve injuries in modern healthcare systems. MPS is one of the world’s largest medical defence organisations, providing comprehensive professional indemnity and expert advice to health professionals around the globe, including New Zealand. In each issue of the journal, there is a selection of ten case reports that aim to alert MPS members of pitfalls that others have encountered. MPS Casebooks from March 2003 to September 2010 were
reviewed for cases of anatomically based iatrogenic nerve injuries in clinical practice.

Ten case reports of iatrogenic nerve injuries were identified. These included: brachial plexus injury from intraoperative malpositioning; lingual nerve damage from salivary gland excision; and sural nerve injury from percutaneous repair of a ruptured Achilles tendon. These case reports highlight important mechanisms of iatrogenic injury but this type of literature is highly selective and limited in context. Each of these case reports did not describe the context of injury in detail because of legal constraints.

We encountered a low volume of iatrogenic nerve injury case reports because of a low hit rate (10/220) of these reports in the years specified above. Because of this, case reports from MPS only provided a glimpse of the epidemiology of iatrogenic nerve injuries. The application to New Zealand is tenuous because MPS publish case reports from countries around the world with different healthcare systems and different legal environments. However, an important benefit of reviewing the medicolegal literature is revealing the large monetary costs of iatrogenic injuries. The majority (60%) of the identified case reports were settled in a range between $20,000-$200,000 US dollars.

In New Zealand, a unique organisation known as the Accident Compensation Corporation (ACC) oversees a centralised national database that collects vital epidemiological data on all accidental injuries. Studying ACC claim files presents an exciting and rare opportunity to undertake novel research of potential clinical value in New Zealand.

**Brief overview of the Accident Compensation Corporation**

The ACC started operations in 1974 to administer a new publicly funded government ‘no fault’ scheme for compensating people with personal injuries, replacing the former tort-based system. Injured patients receive compensation through the ACC; in exchange, patients gave up the right to sue for medical
malpractice. Almost all personal injury litigation was foreclosed. The new scheme encompassed a broad range of accidental harms, including workplace injuries and injuries sustained during sporting activities. ACC is financed from a variety of sources, including an employee levy, general government taxation and levies included in the price of petrol and the motor vehicle licensing fee (Bismarck and Paterson 2006; Kachlia et al. 2008).

Under the initial scheme, rulings in the courts determined that ‘medical injuries’ did not enjoy the same ‘no-fault’ status of other injuries. Only injuries as a result of ‘medical misadventure’ were compensatable. The courts laboured over the definition of this term, and its meaning was only clarified in 1992. To be eligible for compensation under the medical misadventure criteria, a patient must have experienced a “medical error” or a “medical mishap”. A “medical error” is defined as “a failure to observe a standard of care and skill reasonably expected in the circumstances”. A “medical mishap” was defined as “consequence of properly given treatment that is rare (occurring in no more than one percent of cases) and severe (leading to more than 14 days hospitalisation, significant disability lasting more than 28 days, or death)” (Accident Rehabilitation and Compensation Insurance Act 1992). Despite the “medical mishap” definition, application of the criteria was challenging, as it was difficult determining whether complications fell below the one percent threshold. Moreover, this threshold may be a moving target. It was just as difficult applying the “severe disability” criteria, which can be highly subjective and open to interpretation (Bismarck and Paterson 2006; Kachlia et al. 2008).

Criticisms of the clumsy criteria and the inconsistency between “medical error” and the “no fault” basis of the rest of the ACC system prompted a legislative reform in 2005. The old terms were replaced with “treatment injury”, which broadened coverage to include “all personal injuries suffered while receiving treatment from health professionals”. This change shifted the system closer towards a true “no-fault” compensation scheme. A causal link between treatment and injury is still required, and injuries that are a “necessary part” or “ordinary
The ACC claims process is relatively straightforward and robust. The injured patient initiates the claim process through a health provider. All claims are decided in the ACC's national claims unit by Clinical Advisors. Decisions follow legislative guidelines and are based on information provided by patients and their health provider, and may include advice from independent clinical experts. Expert external clinical advisors provide advice on more complex claims. The majority of claim decisions are made within 21 days of the claim being lodged, with a statutory requirement for all decisions to be made within nine months. Patients have the right to request a review of a coverage or compensatory decision, and if unsuccessful, they have the right of court appeal (Bismarck and Paterson 2006; Kachlia et al. 2008).

The advantages of using ACC’s database to study iatrogenic nerve injuries in New Zealand are clear. The ACC is a comprehensive national database, encompassing reports of injury from the whole of New Zealand. Unlike medicolegal/patient safety literature and case publications which only represent a small fraction of patients, ACC’s data relate to the whole population. The ACC runs a ‘no-fault’ system to such an extent that quality and patient safety systems around New Zealand encourage the disclosure and reporting of errors causing injury to the ACC. Medicolegal publications and the majority of case studies are written in a tort legal environment and there are numerous problems with rates of reporting accidental injury. As described by Bismark and Paterson (2006), in a tort-based system: “most injured patients do not qualify for compensation, because their injuries were not negligently caused. And even negligently injured patients, especially those who are poor or elderly are unlikely to sue and receive compensation”. Under the scheme run by the ACC, there are no major legal repercussions for health practitioners for medical errors; hence the rate of reporting injury is high and makes the ACC database of claims relatively robust (Davis et al. 2003).
3.2 Methods

A research protocol for our project was drawn up with the principal investigator (MDS) in order to obtain ethical approval (See Appendix B). Ethical approval was granted by the ACC Research Ethics Committee (#178) (Appendix C) and the University of Otago Human Research Ethics Committee. Local Māori consultation was also undertaken (Appendix D).

Following ethical approval, summary data on accepted treatment injuries in New Zealand for all of 2009 were provided by ACC. This research only uses data from the first six months (1st Jan-30th June). The data were anonymised. The initial summary data were reviewed by two co-investigators (JZ and AM) to optimise information gathering and only claims relating to nerve injury were extracted. The inclusion criteria were:

- No symptoms of the specific nerve injury before the treatment and,
- Primary/secondary treatment injury classified as one of the following:
  - nerve damage
  - nerve compression
  - brachial plexus damage/injury
  - neuroma
  - Erb’s Palsy
  - strain/sprain – neck, back, other

Nerve compression injuries secondary to haematoma formation and iatrogenic compartment syndrome were specifically excluded from this study since the nerve injury in such cases is a secondary event to another iatrogenic complication.

If any uncertainty arose on whether a claim was an iatrogenic nerve injury, a third opinion from the principal investigator (MDS) was sought and a decision was made by consensus.
Following the initial review, further information on claim files with a suggestion of iatrogenic nerve injury were requested and received from the ACC. These files included:

- ACC 167 – Claimant authority for the collection and disclosure of information
- ACC 2152 – Treatment injury claim filled out by the health provider
- ACC 2184 – Treatment injury cover decision tool
- ACC 45 – Accident injury claim form filled out by the claimant
- ACC 51 – Notification of cover decision
- ECA – External clinical advisor opinion
- MA – Internal medical advisor comment
- T150 – Letter of notification to claimant regarding acceptance of treatment injury claim
- VFC 006 – Specialist, general practitioner, nursing and operative notes

The following information was retrieved from the above documents:

- Specific nerve involved in claim
- Age (at time of injury in years), gender and self-reported ethnicity
- Setting: hospital (ward, operating theatre, specialist rooms, delivery suite); general practice; dental practice; other clinic.
- Type of setting: public hospital; private practice
- Brief description of incident
- Practitioner (doctor [grade and specialty if known], nurse, dentist, physiotherapist, midwife, chiropractor)
- Functional disability if known
- Further investigations if known

The information was compiled into an Excel spreadsheet and each subheading was analysed. An exhaustive attempt was made to identify every variable but in some cases, the supplied information was lacking in detail. Analysis of the Excel database occurred after data collection.
3.3 Results

A total of 5,227 claims for treatment injury were accepted by the ACC in 2009. In the first six months (1st Jan-30th June) of 2009, there were 151 successful treatment injury claims that could be classified as iatrogenic nerve injury. Included within these were seven sprain/strain primary injuries that led to neurological symptoms. Of these, three were neck sprains and four were back sprains. These injuries were not subjected to further analysis because the primary injury was most likely musculoskeletal in nature, and the neurological symptoms were secondary to the initial injury. Despite these patients suffering some neurological symptoms, uncertainties remain over whether nerve roots or peripheral nerves were injured. Two neuromas were not included for further analysis because there was insufficient information to identify the affected nerve. Hence, a total of 142 claims were subjected to further analysis. The initial screening of all treatment injury claims took approximately ten hours. Compiling information for each of the 151 claims on average took 15 minutes and in total approximately 30 hours. Most claims had between three and ten documents from ACC.

The basic demographics of nerve injury claimants in the first six months of 2009 are compared to the whole of 2009 in Table 3.1. Generally, the baseline characteristics of claimants in the first six months of 2009 are very similar to all nerve injury claimants from 2009. This shows that the analysis of data from the first six months of 2009 is likely to reflect the whole year statistics. Self-reported ethnicity was recorded from ACC’s patient medical injury claim form (ACC45). Some claims did not have ACC45, and the ethnicity of some of these claimants was unclassified by ACC. Claimants identifying themselves as Samoans have been categorised into the Pacific People ethnicity subgroup. The great majority of injured individuals are likely to be economically active (18-65yrs) and any treatment injury will have a detrimental effect on their contribution to the economy (Figure 3.1). Nearly all (89%) of the injuries that led to an accepted claim in the first six months of 2009 occurred in either 2008 or 2009 (Figure 3.2).
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1st Jan – 30th June</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of claims</td>
<td>2492</td>
<td>5227</td>
</tr>
<tr>
<td>Iatrogenic nerve injuries</td>
<td>142</td>
<td>298</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>64 (45.1%)</td>
<td>132 (44.1%)</td>
</tr>
<tr>
<td>Female</td>
<td>78 (54.9%)</td>
<td>165* (55.9%)</td>
</tr>
<tr>
<td>Age at injury (years)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median [Range]</td>
<td>51.5 [0-83]</td>
<td>51 [0-88]</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>17.5</td>
<td>18.7</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>5 (3.5%)</td>
<td>11 (3.7%)</td>
</tr>
<tr>
<td>Maori</td>
<td>7 (4.9%)</td>
<td>18 (6.0%)</td>
</tr>
<tr>
<td>NZ European</td>
<td>112 (78.9%)</td>
<td>236 (79.2%)</td>
</tr>
<tr>
<td>Other European</td>
<td>1 (0.7%)</td>
<td>1 (0.3%)</td>
</tr>
<tr>
<td>Other</td>
<td>10 (7.0%)</td>
<td>17 (5.7%)</td>
</tr>
<tr>
<td>Pacific People</td>
<td>3 (2.1%)</td>
<td>9 (3.0%)</td>
</tr>
<tr>
<td>Unclassified</td>
<td>4 (2.8%)</td>
<td>6 (2.0%)</td>
</tr>
</tbody>
</table>

*One claimant’s gender in the second half of 2009 could not be determined

The ethnicity percentages for 2009 do not add up to 100% because of decimal rounding.
Figure 3.1. Age spectrum of individuals with accepted ACC claims (1st Jan - 30th June 2009) (n=142)

Figure 3.2. Jan-Jun 2009 accepted claims by year of injury (n=142)
In total there were 147 separate nerve injuries arising from the 142 claims. In two claims there were two separate nerves injured at the same time. Bilateral nerve injury was recorded in three claims: two were bilateral ulnar positioning injuries during the same procedure and one was a bilateral radial neuropathy from multiple venipuncture attempts. The nerve injuries were broadly classified into peripheral nerve, which originate from the spinal cord or cranial nerve, which originate from the brain and brainstem. A peripheral nerve was further divided into: spinal nerve root, nerve plexus and named peripheral nerve (Table 3.2). Further nerve injury distribution of each category is listed in Tables 3.4-3.7. There were 25 different named peripheral nerves injured in the claims accepted by the ACC in the study period. Their relative frequency and most common cause are listed in Table 3.4.

Summary data on the laterality of nerve injuries is shown in Table 3.3 (full table included in Appendix E). For nerve injuries where n≥2, the left:right ratio was very close to 1:1. Injuries to the brachial plexus (malpositioning), inferior alveolar and facial nerves had a unilateral preponderance, but the sample sizes are too small to draw conclusions. Analysis of laterality for the whole of 2009 might offer interesting insights.

There were three scenarios in which the injured nerve was not explicitly delineated in the ACC database. Firstly, some claims did not identify a nerve at all, secondly, there were sometimes conflicting reports on which nerve was injured and lastly, there were times when the identified injured nerve was blatantly incorrect. For some of these claims we assuredly labeled which nerve was injured based on the signs and symptoms and in some cases clinical advisor’s comments and they have been classified as that nerve. For five claims we could not confidently assume which nerve was injured based on the received information and they have been categorised as “assumed named peripheral name” (Table 3.2).
Table 3.2. Distribution of injured nerves (n=147)

<table>
<thead>
<tr>
<th>General Classification</th>
<th>No. of claims (% of total)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peripheral Nerve</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinal nerve root</td>
<td>10 (6.8%)</td>
<td>Range: C7-Sacral Most common vertebral level: L4</td>
</tr>
<tr>
<td>Nerve plexus</td>
<td>11 (7.5%)</td>
<td>Brachial and lumbosacral Most common: brachial plexus</td>
</tr>
<tr>
<td>Named peripheral nerve</td>
<td>101 (68.7%)</td>
<td>25 different named peripheral nerves injured Most common: median, sciatic and common fibular</td>
</tr>
<tr>
<td>Crani al Nerve</td>
<td>20 (13.6%)</td>
<td>Four different cranial nerves injured, most commonly branches of trigeminal nerve (V3)</td>
</tr>
<tr>
<td>Assumed named peripheral nerve</td>
<td>5 (3.4%)</td>
<td>Mostly from venipuncture.</td>
</tr>
</tbody>
</table>

Table 3.3. Laterality of selected nerves

<table>
<thead>
<tr>
<th>Affected nervous structure</th>
<th>Left</th>
<th>Right</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial plexus (malpositioning)</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Inferior alveolar</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Facial</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 3.4. Named peripheral nerve injuries n=101

<table>
<thead>
<tr>
<th>No. of claims (% of total)*</th>
<th>Affected nerve</th>
<th>Most common causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 (15.8%)</td>
<td>Median (15)</td>
<td>Venipuncture and intravenous cannulation</td>
</tr>
<tr>
<td></td>
<td>-Anterior interosseous (1)</td>
<td></td>
</tr>
<tr>
<td>15 (14.9%)</td>
<td>Sciatic (11)</td>
<td>Total hip replacement (sciatic)</td>
</tr>
<tr>
<td></td>
<td>-Sural (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Tibial (1)</td>
<td></td>
</tr>
<tr>
<td>14 (13.9%)</td>
<td>Common fibular (12)</td>
<td>Intraoperative malpositioning</td>
</tr>
<tr>
<td></td>
<td>-Deep fibular (1)</td>
<td>and knee surgery</td>
</tr>
<tr>
<td></td>
<td>-Superficial fibular (1)</td>
<td></td>
</tr>
<tr>
<td>12 (11.9%)</td>
<td>Radial</td>
<td>Intravenous cannulation</td>
</tr>
<tr>
<td></td>
<td>-Superficial branch of radial (12)</td>
<td></td>
</tr>
<tr>
<td>11 (10.9%)</td>
<td>Ulnar</td>
<td>Intraoperative malpositioning</td>
</tr>
<tr>
<td>6 (5.9%)</td>
<td>Lateral cutaneous nerve of thigh</td>
<td>External compression and iliac crest bone grafts</td>
</tr>
<tr>
<td>4 (4.0%)</td>
<td>Digital</td>
<td>Multiple causes</td>
</tr>
<tr>
<td>4 (4.0%)</td>
<td>Ilioinguinal</td>
<td>Inguinal hernia repair</td>
</tr>
<tr>
<td>4 (4.0%)</td>
<td>Femoral (2)</td>
<td>Multiple causes</td>
</tr>
<tr>
<td></td>
<td>-Anterior cutaneous nerve of thigh (1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Saphenous (1)</td>
<td></td>
</tr>
<tr>
<td>4 (4.0%)</td>
<td>Recurrent laryngeal</td>
<td>Anterior cervical retraction and cervical discectomy</td>
</tr>
<tr>
<td>3 (3.0%)</td>
<td>Obturator</td>
<td></td>
</tr>
<tr>
<td>2 (2.0%)</td>
<td>Greater auricular</td>
<td></td>
</tr>
<tr>
<td>2 (2.0%)</td>
<td>Lateral cutaneous nerve of forearm</td>
<td></td>
</tr>
<tr>
<td>1 (1.0%)</td>
<td>Genitofemoral</td>
<td></td>
</tr>
<tr>
<td>1 (1.0%)</td>
<td>Long thoracic</td>
<td></td>
</tr>
<tr>
<td>1 (1.0%)</td>
<td>Phrenic</td>
<td></td>
</tr>
<tr>
<td>1 (1.0%)</td>
<td>Intercostobrachial</td>
<td></td>
</tr>
</tbody>
</table>

*Percentages do not add up to 100% because of decimal rounding
For number of claims where n<4, there was not one most common cause.
Table 3.5. Spinal nerve root injuries n=10

<table>
<thead>
<tr>
<th>Nerve root level</th>
<th>Number of claims</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7-T1</td>
<td>1</td>
<td>Two major mechanisms of injury: nerve root traction during discectomy and misplaced pedicle screw during spinal surgery, (spinal decompression/fusion/laminectomy/discectomy). Other causes of injury include chiropractic spinal manipulation leading to radiculopathy and a misplaced transforaminal injection.</td>
</tr>
<tr>
<td>L3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>L5-S1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sacral</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Unspecified</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.6. Nerve plexus injuries n=11

<table>
<thead>
<tr>
<th>Nerve plexus</th>
<th>No. of claims</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial</td>
<td>10</td>
<td>Mostly due to intraoperative malpositioning (n=5) or Erb's palsy (n=4) following a difficult delivery with shoulder dystocia.</td>
</tr>
<tr>
<td>Lumbosacral</td>
<td>1</td>
<td>Self-retaining retractor injury following total abdominal hysterectomy.</td>
</tr>
</tbody>
</table>

Table 3.7. Cranial nerve injuries n=20

<table>
<thead>
<tr>
<th>No. of claims</th>
<th>Affected nerve</th>
<th>Most common causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Inferior alveolar</td>
<td>Teeth extraction and injection of local anaesthetics for both inferior alveolar nerve and lingual nerve.</td>
</tr>
<tr>
<td>5</td>
<td>Lingual</td>
<td>Salivary (parotid/submandibular) gland excision.</td>
</tr>
<tr>
<td>4</td>
<td>Facial</td>
<td>Neck lymph node dissection.</td>
</tr>
<tr>
<td>3</td>
<td>Accessory</td>
<td>Partial parotidectomy.</td>
</tr>
<tr>
<td>1</td>
<td>Hypoglossal</td>
<td></td>
</tr>
</tbody>
</table>
These injuries occurred in nine different healthcare settings with over half (55.6%) occurring in private practice (Table 3.8). The majority of iatrogenic nerve injuries occurred in a surgical context, with 62% of all injuries recorded in the operating theatre.

Venipuncture accounted for all nerve injuries occurring in the pathology laboratory with the median nerve most commonly injured. Venipuncture also accounted for the majority of injuries in the emergency room.

The vast majority of injuries in general practice were due to needle injuries. There were three nerve injuries in the forearm from venipuncture, two injuries (thigh and forearm) from steroid injections and two sciatic nerve injuries from intramuscular gluteal injections (Depo-Provera and analgesics).

Nerve injuries occurring at the dentist were almost exclusively caused by tooth extraction or injection of local anaesthetics; in all cases the inferior alveolar nerve or lingual nerve were injured.
<table>
<thead>
<tr>
<th>Setting</th>
<th>Number of cases (% of total)*</th>
<th>Public/Private</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating theatre</td>
<td>88 (62%)</td>
<td>47/41</td>
</tr>
<tr>
<td>Pathology laboratory</td>
<td>12 (8.5%)</td>
<td>0/12</td>
</tr>
<tr>
<td>General Practice</td>
<td>10 (7.0%)</td>
<td>0/10</td>
</tr>
<tr>
<td>Dentist</td>
<td>9 (6.3%)</td>
<td>0/9</td>
</tr>
<tr>
<td>Specialist rooms</td>
<td>7 (4.9%)</td>
<td>1/6</td>
</tr>
<tr>
<td>Ward</td>
<td>7 (4.9%)</td>
<td>6/1</td>
</tr>
<tr>
<td>Emergency room</td>
<td>5 (3.5%)</td>
<td>5/0</td>
</tr>
<tr>
<td>Delivery suite</td>
<td>3 (2.1%)</td>
<td>3/0</td>
</tr>
<tr>
<td>Catheter laboratory</td>
<td>1 (0.7%)</td>
<td>1/0</td>
</tr>
</tbody>
</table>

*Percentages do not add up to 100% because of decimal rounding
A total of 143 health practitioners were responsible for an iatrogenic nerve injury; one claim had two different practitioners identified as having caused the injury. The grade of health practitioner is shown in Table 3.9. The physician – other category was a musculoskeletal specialist. The grade of the anaesthetists was generally not detailed in the documents supplied by ACC, but it is expected that most of the ungraded anaesthetists would be consultants.

The specialties of doctors involved in an iatrogenic nerve injury claim are listed in Table 3.10. The surgical specialties are the nine listed by the Royal Australasian College of Surgeons plus two others: oral and maxillofacial surgery, and obstetrician and gynaecologists. Anaesthetists have been classified as an independent specialty and remaining specialties have been classified under the ‘medical’ heading. Nerve injuries solely caused by intraoperative positioning under general anaesthesia have been attributed to the anaesthetist because patient positioning is their responsibility and not the operating surgeon although this does not exclusively imply culpability as it is most likely a team effort.
Table 3.9. Grade of health practitioners involved in an iatrogenic nerve injury (n=143)

<table>
<thead>
<tr>
<th>Practitioner - Grade</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon - Consultant</td>
<td>74 (51.7%)</td>
</tr>
<tr>
<td>Surgeon - Registrar</td>
<td>5 (3.5%)</td>
</tr>
<tr>
<td>Physician - Consultant</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Physician - Registrar</td>
<td>2 (1.4%)</td>
</tr>
<tr>
<td>Physician - Other</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>General practitioner</td>
<td>6 (4.2%)</td>
</tr>
<tr>
<td>Anaesthetist – Consultant</td>
<td>4 (2.8%)</td>
</tr>
<tr>
<td>Anaesthetist – Technician</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Anaesthetist – Grade unknown</td>
<td>12 (8.4%)</td>
</tr>
<tr>
<td>House Surgeon</td>
<td>2 (1.4%)</td>
</tr>
<tr>
<td>Nurse</td>
<td>8 (5.6%)</td>
</tr>
<tr>
<td>Phlebotomist</td>
<td>10 (7.0%)</td>
</tr>
<tr>
<td>Midwife</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Dentist/Dental Surgeon</td>
<td>9 (6.3%)</td>
</tr>
<tr>
<td>Chiropractor</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>6 (4.2%)</td>
</tr>
</tbody>
</table>
Table 3.10. Specialty of health practitioner (doctor) involved in iatrogenic nerve injury (n=106)

<table>
<thead>
<tr>
<th>Specialty</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surgical</strong></td>
<td></td>
</tr>
<tr>
<td>Orthopaedic</td>
<td>37 (25.9%)</td>
</tr>
<tr>
<td>General</td>
<td>12 (8.4%)</td>
</tr>
<tr>
<td>Vascular</td>
<td>5 (3.5%)</td>
</tr>
<tr>
<td>Plastic and Reconstructive</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>3 (2.1%)</td>
</tr>
<tr>
<td>Cardiothoracic</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Otolaryngology Head and Neck</td>
<td>6 (4.2%)</td>
</tr>
<tr>
<td>Urology</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Oral &amp; Maxillofacial Surgery</td>
<td>4 (2.8%)</td>
</tr>
<tr>
<td>Gynaecology and Obstetrics</td>
<td>9 (6.3%)</td>
</tr>
<tr>
<td>Paediatric</td>
<td>0 (0%)</td>
</tr>
<tr>
<td><strong>Medical</strong></td>
<td></td>
</tr>
<tr>
<td>General practitioner</td>
<td>6 (4.2%)</td>
</tr>
<tr>
<td>Cardiologist</td>
<td>2 (1.4%)</td>
</tr>
<tr>
<td>Radiologist</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td>Musculoskeletal specialist</td>
<td>1 (0.7%)</td>
</tr>
<tr>
<td><strong>Anaesthetics</strong></td>
<td></td>
</tr>
<tr>
<td>Anaesthetist</td>
<td>16 (11.1%)</td>
</tr>
<tr>
<td>Anaesthetic technician</td>
<td>1 (0.7%)</td>
</tr>
</tbody>
</table>
The ACC has a category termed “actual consequence to patient” for each claim. A major consequence is a short to medium lessening of bodily function (sensory, motor, physiologic or intellectual) unrelated to the natural course of the illness and differing from the expected outcome of patient management or resulting in an increased length of hospital stay or requiring surgical intervention as a result of the treatment injury. A minor consequence results in minimal lessening of bodily function and may require an increased level of care and further investigation or referral to another clinician. Just under half (n=64, 45.1%) of iatrogenic nerve injuries were classified as a major consequence to the patient while 77 claims (54.2%) were classified as minor. One claim was classified as a ‘serious’ consequence, which meant the treatment injury has the potential to result in the patient’s death or major permanent loss of function unrelated to the patient’s underlying illness.

**Functional disability**

How the injury affects the patient’s functioning is a key indicator of its severity. Functional disability is a more useful measure of outcome than a patient’s symptoms because each injury affects a patient differently within the context of their everyday activities while the symptoms experienced by patients are usually consistent for the same nerve injured. For the five most frequently injured named peripheral nerves the spectrum of disability was recorded. Specific disabilities are described below but common disabilities experienced by patients are 1) impaired ability to work 2) disturbed sleep because of pain; and 3) inability to carry out activities of daily living.

*Common fibular nerve*

All patients commented on their decreased mobility as a result of the injury. Nearly all of the patients had a foot drop, and this negatively impacted on their ability to stand and walk. The more seriously debilitated patients required a walking aid and could not stand for long periods of time. One affected individual
was fired after being unable to stand and work for long periods of time. Another affected individual fell downstairs because their foot was numb.

*Sciatic nerve*
Difficulty walking was the major disability affecting patients after sciatic nerve injury. Some patients complained of a limp. Certain positions (including driving) which increased pressure on the gluteal region exacerbated the pain.

*Median nerve*
Patients were impaired in their ability to fully use their affected hand and arm, especially when gripping items. The majority of patients were able to continue work, but a few had pain severe enough to stop them from working. One affected individual experienced difficulty working with lifting pots and pans after suffering a median nerve injury after venipuncture.

*Ulnar nerve*
Patients’ ability to use their hands was adversely affected. Writing and grasping objects were particularly difficult. A medical student commented on her inability to write after a nerve injury in her dominant hand.

*Radial nerve*
Disability ranged between impaired functioning of the affected hand to no functional disability. An example of a functional deficit was one farmer who was unable to continue milking his cows.
Further investigations

Affected individuals were commonly referred to another health practitioner. The most common referrals were to a neurologist to conduct a neurological examination and/or a neurophysiologist to carry out an EMG and assess the patient’s nerve conduction. Physiotherapist referrals for patients were also common, aiming to improve motor function and aid rehabilitation. Only three patients required further unplanned surgery as a result of their injury. Two of these patients required surgical removal of a misplaced pedicle screw impinging on a nerve root. One patient required surgical repair of the dorsal branch of the ulnar nerve that had been injured during wrist arthroscopy and repair of the triangular fibrocartilage complex.

Iatrogenic nerve injuries usually require referrals to another practitioner or medical service, thus these nerve injuries not only have a detrimental effect on the patient, but also imposes a burden on the rest of the healthcare system and may negatively affect the quality of healthcare for other patients requiring the limited services.
3.4 Discussion

This is the first national study of iatrogenic nerve injuries ever to be completed. There are several major findings from the analysis of the ACC database: the anatomical distribution of nerve injuries and the context and physical place of injury, the types of practitioners involved in these injuries and the general epidemiology of affected patients.

Only claims that were accepted in the first six months of 2009 were included in this study. The analysis of these nerve injuries do not represent all of the nerve injuries happening in that time period. Some nerve injury claims from 2009 will be accepted in 2010. Conversely over half of the accepted claims in the study period were nerve injuries that occurred prior to 1st Jan 2009, the majority happening in 2008.

The five most commonly injured named peripheral nerves are the median, sciatic, SBRN, ulnar, and common fibular. Together, they account for 46% of all iatrogenic nerve injuries reported to the ACC in the study period. For each of these nerves, there is a consistent pattern of injury that accounts for most cases.

There were seven median nerve injuries from venipuncture and five from intravenous cannulation. Phlebotomists caused the majority of these injuries. No details were given by the ACC on the possibilities of aberrant anatomy (this was probably unknown), but the normal course of the median nerve is deep to the superficial veins that are most commonly selected for venipuncture (median cubital vein). The median nerve should not be injured in the cubital fossa by phlebotomy. More research is needed on the anatomical knowledge and practice of phlebotomists to discern why these injuries are occurring. No case reports on median neuropathy following venipuncture were identified in the recent literature, but it is difficult to know whether it is because these injuries are not occurring elsewhere, which is unlikely, or because they are not sufficiently novel to warrant publication (publication bias).
Contrary to international literature, there were no claims for median nerve injury after carpal tunnel release in the first six months of 2009, which is an unexpected result because there are numerous reports of iatrogenic injury during this operation (Table 2.7).

There were no reports of injury to the radial nerve in the arm during the study period. Only the superficial branch of the radial (SBRN) nerve at the level of the wrist was iatrogenically injured. Most of these injuries were due to venipuncture and intravenous cannula insertion. Anaesthetists were responsible for all of the latter injuries as they prepared patients in the operating theatre for surgery. The most common site of injury was at the wrist, where the cephalic vein and the SBRN are closely associated. These two structures have been reported to intersect once (and up to three times) in a highly variable fashion (Vialle et al. 2001). The risk of nerve damage in this area has prompted some authors to suggest the cephalic vein in the distal forearm and wrist should be avoided for venous access (Robson et al. 2008). However, cephalic vein access remains popular and this risks SBRN injury. In contrast to the case reports in the systematic literature review, no other types of radial nerve injuries occurred in the timeframe of the ACC study.

Ulnar neuropathy from malpositioning under general anaesthesia accounted for 55% all ulnar nerve injuries in the ACC study but was not identified as a major mechanism of injury from the literature review. In these cases, the upper limbs were inappropriately positioned during various orthopaedic, cardiac and abdominal operations. The patients’ actual positioning during surgery was unclear but the most common site of ulnar injury was behind the medial epicondyle at the elbow. The anatomy of the ulnar nerve in this region and the risk factors identified with intraoperative positioning injuries are discussed in the next chapter.

In view of the positioning injuries to the ulnar nerve and brachial plexus, we were prompted to produce an educational poster on the correct positioning of the upper limbs under general anaesthesia. This poster, aimed at operating theatre staff,
including anaesthetists, nurses and technicians, highlights some hazardous upper limb positions and the common sites of nerve injury and is the subject of the next chapter. It is hoped that improved education may help prevent some of these intraoperative positioning injuries from happening in the future.

The *common fibular* nerve was injured primarily in two ways: positioning/compression or knee surgery. The common fibular nerve wraps around the fibula neck, and at this level the nerve is very superficial and susceptible to trauma or acute compression. The nerve can be stretched over the neck of the fibula in the lithotomy position, or compressed between the fibula neck and the operating table or its supports in the lateral position. The common fibular nerve was also injured once by plaster cast application and once by compression from a moonboot in the ACC study period. Common fibular nerve injury is a recognised complication following knee surgery; the injury mechanism can include improper positioning, use of a tourniquet, incorrectly placed portals for arthroscopy and direct surgical trauma. Prevention must begin with careful positioning of the patient and a thorough understanding of the regional anatomy (*Kim et al. 2002*).

The majority of *sciatic* nerve injuries (seven of 11) occurred during total hip arthroplasty (n=5) or hip resurfacing surgery (n=2). Sciatic nerve palsy post hip surgery is a widely reported complication, with numerous mechanisms described. Some of these include: direct trauma, suture constriction, vascular compromise, retractor compression and “heat from polymerizing cement”. A recent study suggested that sciatic nerve palsy could also occur as a result of compression by the gluteus maximus tendon, and the authors suggested prophylactic release of the tendon during total hip arthroplasty (*Hurd et al. 2006*).

This thesis has a predominant focus on iatrogenic nerve injuries to the upper limb. The results of the systematic literature review suggested upper limb nerves formed an important spectrum of iatrogenic nerve injuries and this has been confirmed by these results. Three of the five most commonly injured peripheral
nerves are in the upper limb, with the most common being the median nerve (and anterior interosseous nerve). The relative frequencies show that upper limb nerves accounted for 44.6% of all iatrogenic named peripheral nerve injuries, a relatively large proportion and over represented category considering the total number of named peripheral nerves in the body. We have not discussed the other nerves that combined form the majority of the spectrum of iatrogenic nerve injury, however individually; these top five nerves have the greatest potential for reduction.

From the systematic literature review, nearly all nerve injuries occurred in an operating theatre. The results of the ACC study confirm this perception that most iatrogenic nerve injuries occur in the operating theatre (62%) but there was an important group of injuries that happened outside of the operating theatre that may have been given insufficient emphasis previously. The ACC data analysis uncovers concerns about nerve injuries associated with needles (venipuncture, steroid injection, intravenous cannulation or intramuscular injections). Nerve injuries happening at the dentist also seem to be repeatedly reported, most happening during teeth extraction and/or local anaesthetic injection. These recurring mechanisms of nerve injury outside the operating theatre are a concern and methods of reducing these injuries should be investigated.

The results of this study do not support the hypothesis that the spectrum of iatrogenic upper limb nerve injuries in New Zealand is similar to the spectrum of injuries described in the international medical literature. The spectrum of nerve injuries reported in the literature suggests that the vast majority of nerve injuries occur in the operating theatre. However, nerve injuries in other healthcare settings accounted for 38% of all injuries in the ACC study. Many types of injury identified in the systematic literature review were not repeated in the ACC’s claims database (for the first six months of 2009 at least). One possible reason is that some of these complications are very rare (some complications were described in the literature for the first time) and, because of the relatively small population in New Zealand, some of these injuries simply do not occur that often. Also, the international medical literature is prone to publication bias; accepted or
recognised complications are rarely repeatedly reported. This could for example be why needle injuries were nearly absent from the systematic literature review. Our hypothesis only relates to nerves of the upper limb, because a systematic literature review of lower limb nerve injuries was not undertaken.

Previously to our knowledge there have been no data on the incidence of iatrogenic injuries in private practice, only anecdotal reports in medical defence society journals. These injuries must not be overlooked because the majority of identified iatrogenic nerve injuries in the ACC data (55.6%) happened at a privately owned health provider. There was also an even split between public and private sectors in relation to nerve injuries occurring in operating theatres. However, it should be noted that in 2002 there were 445 hospitals in New Zealand, 80% of which were privately owned, comprising 48% of all available hospital beds (Statistics New Zealand 2004). The focus on reducing iatrogenic injuries needs to be equally split between public and private sectors, as the number of private hospitals have been increasing steadily since 1980 (Parliamentary Library 2009).

From this analysis, it is clear that the majority of iatrogenic nerve injuries are the responsibility of consultants. We initially recorded which public hospitals were teaching hospitals because we wanted to record the role of trainee doctors but this detail became irrelevant since 55.2% of these injuries were attributable to a consultant grade doctor while only 1.4% of injuries were attributable to a house surgeon. In particular orthopaedic surgeons and anaesthetists seem to be implicated in the greatest proportion of nerve injuries. This is also supported by the literature review, which highlighted orthopaedic procedures as the dominant source of nerve injuries. Anaesthetists are implicated in a significant proportion of iatrogenic nerve injuries because they are ‘responsible’ for positioning injuries and most of the intravenous cannulation injuries.

The demographics of claimants from the first six months are very similar to the characteristics of claimants from all of 2009. However, when compared to
national population statistics, there are some key differences. The elderly are disproportionately over represented while ethnic minorities are under-represented. The median age of the population in 2006 was 39 years (Statistics New Zealand 2006), and the median age of the patients with an iatrogenic nerve injury from 2009 was 51.5 years. The graph of age at injury (Figure 3.1) shows a distribution that is skewed to the right. This result is expected as there have been multiple international studies that have shown that older patients are more susceptible to an in-hospital adverse event (Rothschild et al. 2000; Thomas and Brennan 2000). In the Harvard Medical Practice Study of medical injury and malpractice litigation, older patients (≥65yrs) were twice more likely to suffer a postoperative complication. The higher risk of harm faced by the older population can be essentially explained by two major factors: i) this population will undergo more surgical procedures, thus increasing their exposure to risk of a nerve injury; and ii) the potential for a nerve injury increases with increasing age, as blood supply to nerves diminish, leading to higher chance of ischaemic nerve injury and lower rates of recovery (Danielidis et al. 1999).

NZ European was over-represented as an ethnicity while all of the other recorded ethnicities were under-represented but further research is required to elicit why this might be.

Limitations

There are some disadvantages in using these data provided by the ACC. In 2009, there were 24 declined treatment injury claims relating to nerve injuries because they were deemed to be ordinary or necessary consequences of treatment. These claims were excluded from this study because they are considered unpreventable. However, an identifiable treatment injury still occurred. This limited number of claims had no discernible pattern of injury, and would not have affected the overall validity of the results from our study had they been included, but future studies could consider including this subset of claims received by the ACC.
There will be patients who sustained an iatrogenic nerve injury that would not have reported the injury or initiated a claims process with the ACC. It is difficult to estimate what proportion of all iatrogenic nerve injuries the ACC database captures, but because of the ‘no-fault’ scheme for medical practitioners, the open encouragement of injury reporting, and the potentially disabling effects of nerve injury (other than minor transient impairments), the expectation is that the rate of injury reporting of more serious injuries is high. Importantly, injuries are likely to be under-reported and our study therefore underestimates the true incidence of nerve injuries.

The quality of data for each claim was generally high, but there were some discrepancies between the original ACC database and the follow up documents, some of which could be identified as data entry errors. The handwriting on original documents (ACC 2152, VFC 006) was sometimes illegible to the investigators, and this might have also been the case for those entering data into ACC’s database. The quantity of follow up documents was very variable between claims. All of the documents mentioned in the methods section were provided in most claims, while in some, there was only a selection of extra files; this meant some details in some claims were missing from the analysis. The nature of the ACC data means that medical records were available for the claimant leading up to and during the treatment injury, but few records or documents existed on how the patient was recovering after the claim had been lodged and processed. The functional disability recorded by ACC does not differentiate between what was caused by the original illness and procedure or the unplanned iatrogenic nerve injury but we were mostly able to discern which functional disabilities directly resulted from the nerve injury. The ACC did not provide information on the financial costs of each of the injury claims which could have added further analysis to the study.

The ACC claims process means that the treatment provider can submit a claim on behalf of the claimant. However legislation does not specify who has to fill out the form, ACC 2152. In the large majority of cases; it was filled out by someone
else from the same health provider who may not know all the specifics of the claim. Also the forms were sometimes incomplete. This made identifying who caused the injury or which specific nerve was injured in certain cases impossible, especially if the injury happened in an emergency department, ward or laboratory setting. However, even if we had received perfectly complete data from ACC, it is very unlikely to have changed our results substantially.

The focus of this study was on iatrogenic nerve injuries that might be preventable if the normal anatomy is better understood. The majority of claims probably fall under this category, but included in the analysis may be claims that are solely attributable to a failure or error in technique, despite knowing the relevant anatomy. However, it is impossible to make this distinction with certainty based on the available information. Regardless of the mechanism of iatrogenic nerve injury, the future goal is to reduce the frequency of these injuries.

Injuries occurred in some claims because of difficult or aberrant anatomy with the practitioner not anticipating this variation. These injuries are still iatrogenic in nature but may not have been preventable even with adequate understanding of the regional anatomy. But by definition, aberrant anatomy is very rare and was not knowingly the problem underlying the five most frequent nerve injuries. Difficult anatomy was encountered, in one patient undergoing surgery for varicose veins surgery and another having an inguinal hernia repair, with the surgeons commenting on the abnormal course of the nerves that were injured.

**Conclusion**

This unique study is the first to describe the contemporary spectrum of iatrogenic nerve injuries in New Zealand. We have been able to successfully encapsulate recent iatrogenic nerve injuries in New Zealand, with three main findings emerging from this study. First, the nerves most commonly injured are major named peripheral nerves in body (three of the top five were upper limb nerves) and their injury resulted in significant functional deficits for the patient. The
reality that these nerves are injured most is paradoxical because their normal and variant anatomy should be understood best. The fact that these injuries occur on the scale that has reported been to the ACC suggest that there is either a lack of anatomical knowledge by practising clinicians or there is a disconnect between knowledge and actual clinical practise. Second, the majority of injuries are occurring in the operating theatre; however injuries occurring in other healthcare settings make up an important slice of the spectrum of iatrogenic injuries. Nearly 40% of injuries occurred outside the operating theatre and the majority of these injuries were needle related which makes for a concerning statistic. Evidence has also shown for the first time that over half of all iatrogenic nerve injuries can be attributed to a private sector hospital. Third, our analysis has shown that consultant doctors are responsible for most of these iatrogenic injuries, in particular orthopaedic surgeons and anaesthetists. Eventually the goal is to try and reduce these iatrogenic nerve injuries in clinical practice in New Zealand; the first step to prevention is knowing the epidemiology of these injuries. This study has described for the first time the spectrum of contemporary iatrogenic nerve injuries in New Zealand, and this knowledge will contribute to future prevention and educational strategies.
Chapter 4: Upper limb positioning injuries - designing an educational poster

4.1 Introduction

Following the results of the systematic literature review and the study of the ACC’s claims database, one recurring mechanism of injury is intraoperative malpositioning. Analysis of more than 4000 adverse anaesthetic outcomes by the American Society of Anesthesiologists (ASA) a decade ago identified damage to the ulnar nerve and brachial plexus from malpositioning as leading causes of claims, accounting for almost 10% of all cases (Cheney et al. 1999). In 2009, there were 13 ulnar nerve and 11 brachial plexus injury claims from malpositioning under general anaesthesia accepted by the ACC in New Zealand. These treatment injuries accounted for 8.1% (24/298) of all iatrogenic nerve injuries recorded by the ACC in 2009. Internationally, ulnar nerve neuropathy has been shown to affect as many as 1 in 200 adult surgical patients (Warner et al. 1999). Although it has been suggested that men are more commonly affected (Warner et al. 1999) the analysis of ACC data showed a similar gender distribution (3M:2F) in the five patients with an intraoperative ulnar nerve positioning injury but the numbers are too small for meaningful conclusions.

Iatrogenic brachial plexus and ulnar nerve injury secondary to inappropriate positioning under general anaesthesia were first described more than a hundred years ago by Budinger (Warner 2006). The brachial plexus is particularly vulnerable to injury because: (i) it has a relatively long course in the neck and axilla passing through a confined space between the clavicle and first rib; (ii) it is tethered proximally by nerve roots and distally by the fascia of the axillary sheath;
and (iii) it lies in close proximity to bony structures against which it may be compressed. A brachial plexus stretch injury is more likely if the arms are abducted beyond 90° and externally rotated with the elbow extended and the forearm fully supinated. Lateral flexion and/or rotation of the head further increase tension in the brachial plexus on the contralateral side (Ngamprasertwong et al. 2004). A study utilising the brachial plexus tension test was carried out in healthy subjects with combinations of hazardous upper limb and neck positions. Their results showed shoulder abduction, wrist extension and contralateral neck flexion decreased the range of motion at the elbow, increased pain intensity and produced symptoms of paraesthesiae in the subjects. The available range of motion at the elbow was "considered to correspond with the submaximal extensibility" of the peripheral nerves. It can be inferred the decreased range of motion corresponds to increasing tension or lengthening of peripheral nerves because of the simultaneous appearance of neurologic symptoms. Any combination of these positions appeared to have a cumulative effect (Coppieters et al. 2002).

Most ulnar nerve malpositioning injuries occur from compression of the nerve at the elbow, either from external pressure and/or prolonged elbow flexion. In the cubital tunnel, the ulnar nerve is superficial and relatively unprotected; when the arm is extended and pronated, the nerve may become compressed against the floor of the tunnel by external pressure. Marked flexion of the elbow (arm/forearm angle <90°) tightens the overlying cubital tunnel retinaculum, shrinking the tunnel and increasing the risk of nerve compression (Winfree and Kline 2005). Forearm pronation can also increase pressure in the cubital tunnel (Warner et al. 1999).

The vulnerability of injury to these two nervous structures is further compounded because i) the malpositioned anaesthetised patient is unable to perceive and respond to neurologic symptoms and ii) the use of muscle relaxants in anaesthetised patients results in loss of normal muscle tone allowing the arms to be moved into potentially hazardous positions which may stretch the nerves (Shankar et al. 2005). Injuries can be easily avoided with knowledge of safe upper limb positions and understanding common sites of injury.
It is important to be aware of other predisposing factors that increase a patient’s risk to a positioning injury. Pre-existing co-morbidities including diabetes mellitus, peripheral vascular disease, hypotension and malnutrition increase the risk of developing an intraoperative positioning nerve injury presumably because these diseases can all impair neural microcirculation. The use of “intraoperative hypothermia” has also been correlated to the development of peripheral nerve injuries (Winfree and Kline 2005).

**Blood supply of peripheral nerves**

There are two functionally independent (but communicating) vascular circulations that provide a continuous and adequate supply of nutrients critical to peripheral nerve functioning (Figure 4.1): an extraneural system (epineurial capillary vessels running parallel to nerves) and an intraneural system (longitudinal microvessels in the endoneurium) (Standring 2008). Animal studies have shown that intraneural microcirculation is interrupted when nerves are stretched by 15% or more of their resting length (Lundborg and Rydevik 1973; Ogata and Naito 1986). It has been demonstrated that complete ischaemia of intraneural circulation is followed by deterioration in nerve functioning and changes in sensory axon excitability following ischaemia may underlie the onset of paraesthesiae (Han et al. 2008). It is suggested that stretching can rupture minute intraneural capillaries which can form small haematomas, resulting in myelin disruption and conduction block. Similarly, a compression injury may displace nodal myelin, leading to conduction failure (Chin and Poole 2003). One recent study explored changes in human sensory axonal excitability induced by focal nerve compression, with results suggesting similar biophysical mechanisms contributed to the appearance of neurological symptoms in both stretch induced ischaemia and focal nerve compression (Han et al. 2010).
Figure 4.1. Peripheral nerve cross section with its vascular supply (Reprinted from Neal et al. 2002)

The aim of this section of the thesis was to produce an educational poster for operating theatre staff including anaesthetists, theatre nurses and technicians, outlining the dos and don’ts of upper limb positioning under general anaesthesia in an attempt to increase awareness of these injuries and hopefully reduce their frequency. There were certain criteria that this poster had to meet;

- aesthetically appealing, structured in layout, simple to follow and not crowded by text
- effective at portraying our message
- clinically sound (adequately referenced and vetted by end-users including local consultant anaesthetists)
4.2 Methods

During the systematic literature review, several publications on intraoperative positioning injuries were identified. One of these publications was a practice advisory written by the ASA for its members on the prevention of perioperative peripheral neuropathy. The Royal College of Anaesthetists (United Kingdom) and the New Zealand Society of Anaesthetists (NZSA) were also approached but they currently do not have any specific guidelines or instructions on how to safely position the upper limbs of patients under general anaesthesia. The poster was developed using the ASA recommendations and in consultation with local practising anaesthetists. Common standard operating postures and their variations were selected to illustrate appropriate positioning of the upper limb. A number of drafts were hand drawn before a series of photographs of a mock patient were taken using theatre equipment and under the supervision of a consultant anaesthetist (Dr. Robyn Chirnside). Photographs of both correct and incorrect positions were taken to illustrate sites of nerve vulnerability and to highlight correct upper limb positioning. The whole upper limb (including finger tips) was generally required to be in each photograph.

An A3 draft was produced and presented at a local anaesthetic forum at Dunedin Hospital (5/11/10), and constructive feedback was used to make minor modifications to the poster. A second draft was produced incorporating these suggestions. A final poster with the layout changed to a portrait orientation was produced in A2 size.

The poster has been submitted to the NZSA, seeking their endorsement and further comment with the aim of producing a poster that can be displayed in operating theatres around the country.
4.3 Results

The title of the poster is “The Dos and Don’ts of Arm Positioning under General Anaesthesia” (Figure 4.2). We have chosen to use arm instead of upper limb because the target audience includes nurses and operating personnel other than anaesthetists. Text has been kept to a minimum; captions only detail the important aspects of each photograph.

Three common patient postures were selected. These were supine, prone (with a bellybox) and lateral (with a lateral armboard/Krause armboard). For each posture, a selection of common upper limb positions in theatre were chosen to illustrate their correct positioning and one hazardous upper limb position was chosen to illustrate their incorrect positioning. To visually reinforce the incorrect upper limb positioning we used; a red cross superimposed over the photograph and shaded the background and border red.
The Dos and Don’ts of Arm Positioning under General Anaesthesia

Major nerve injuries from incorrect positioning of the arms under general anaesthesia continues to be a problem worldwide; in New Zealand in 2009 alone, there were 24 such injuries. The two commonest injuries are:

1. Pressure on the ulnar nerve at the elbow (behind the medial epicondyle); and
2. Stretching of the brachial plexus

Anaesthetised patients are unable to respond to neurologic symptoms and the use of muscle relaxants may encourage limbs to be placed in unnatural and hazardous positions. The following illustrations show how to safely position the arms in patients under general anaesthesia.

Supine

- Arms folded across chest
- Elbows supported with soks & padding
- Arms by side
- Palms facing thighs
- Elbows padded to prevent compression by table or surgeons
- Arm on foam armboard level with operating table
- Shoulder abducted ≤90°
- Supinated forearm
- Head in neutral position or facing abducted arm

Lateral (armboard)

- Upper elbow free
- Lower arm/forearm angle >90°
- Shoulder abducted ≤90°
- Pronated forearm
- Head turned to opposite side

Lateral (pillows)

- Upper arm/forearm angle >90°

Lateral (armboard)

- Upper shoulder abducted ≥90°
- Lower arm/forearm angle <90°
- Patient lying on lower arm


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Figure 4.2. First poster draft
A second draft (Figure 4.3) was produced incorporating suggestions from the hospital anaesthetic forum at which approximately 15 anaesthetic staff attended. The changes made were as follows:

- The blue background for correct positioning was changed to green
- The prone (bellybox) with arms secured by the side position was swapped for a more commonly used position, which is with the arms secured on armboards in a ‘superman’ position
- The lateral photo of the prone (bellybox) position with arms supported with skis was retaken because i) the neck was hyperextended and ii) the fingers were obscured by the ski
- Black lines were added to selected photos to emphasise the arm/forearm angle

Finally, a final draft of the poster was produced in a portrait orientation to align the correct and incorrect positions for all three patient postures (Figure 4.4). This version was emailed to the NZSA for further comment. Unfortunately, at the time of thesis submission the NZSA have not been able to convene and provide feedback.

The final version of the poster was presented at the 7th annual meeting of the Australian and New Zealand Association of Clinical Anatomists (ANZACA) in Hobart, Tasmania in December 2010 (Appendix F). Comments received were positive, with one keynote speaker using the poster as an illustration of the modern application of clinical anatomy.
The Dos and Don’ts of Arm Positioning under General Anaesthesia

Major nerve injuries from incorrect positioning of the arms under general anaesthesia continue to be a problem worldwide; in New Zealand alone, there were 24 such injuries. The two commonest injuries are:
1) Pressure on the **ulnar nerve** at the elbow (behind the medial epicondyle); and 2) Stretching of the **brachial plexus**

Anaesthetised patients are unable to respond to neurologic symptoms and the use of muscle relaxants may encourage limbs to be placed in unnatural and hazardous positions. The following illustrations show how to safely position the arms in patients under general anaesthesia.¹

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John Zhang, Robyn Chimside, Mark Stringer (University of Otago & Dunedin Hospital)

Figure 4.3. Second poster draft
The Dos and Don’ts of Arm Positioning under General Anaesthesia

Major nerve injuries from incorrect positioning of the arms under general anaesthesia continues to be a problem worldwide; in New Zealand in 2009 alone, there were 24 such injuries. The two commonest injuries are:
1) Pressure on the ulnar nerve at the elbow (behind the medial epicondyle)
2) Stretching of the brachial plexus

Anaesthetised patients are unable to respond to neurologic symptoms and muscle relaxants may encourage limbs to be placed in unnatural and hazardous positions. The following illustrations show how to safely position the arms in patients under general anaesthesia.¹

Supine

- Arms folded across chest
- Elbows supported with skins & padding
- Arms by side
- Palms facing thighs
- Elbows padded to prevent compression by table or surgeons
- Arm on foam armboard level with operating table
- Shoulder abducted ≤90°
- Supinated forearm
- Head in neutral position or facing abducted arm
- Arm on foam armboard below level of table
- Shoulder abducted ≥90°
- Pronated forearm
- Head turned to opposite side

Prone (Belly box)

- Elbow free
- Forearm padded and supported with skins
- Arm/forearm angle >90°
- Elbow free
- Forearm secured on armboard
- Arm/forearm angle >90°
- Shoulder abducted ≤90°
- Elbow pressed against operating table
- Arm/forearm angle <90°

Lateral (armboard)

- Upper elbow free
- Lower arm/forearm angle >90°
- Shoulder abducted ≤90°
- Padding in lower axilla
- Upper arm/forearm angle >90°
- Lower arm/forearm angle ≤90°
- Patient lying on lower arm

Lateral (pillows)

- Upper arm/forearm angle >90°
- Lower arm/forearm angle ≤90°
- Patient lying on lower arm


John Zhang, Robyn Chimeside, Mark Stringer (University of Otago & Dunedin Hospital)

Figure 4.4. Final poster draft
4.4 Discussion

To our knowledge, this is the first educational resource to illustrate the dos and don’ts of arm positioning under general anaesthesia. There are no current guidelines or recommendations from the NZSA on this topic relevant to safe anaesthesia.

Intraoperative positioning injuries are a largely avoidable source of distress and morbidity. Patients suffering from a positioning injury commonly complain of several symptoms: numbness and other sensory disturbances in the upper limb in the distribution of the ulnar nerve or more diffusely in the case of brachial plexus injury; and weakness in the affected limb. These nerve injuries result in significant functional deficits to the patient affecting their ability to write, pick up or lift objects, impairing activities of daily living and work. Knowledge of the common sites of nerve injury in the upper limb during general anaesthesia and careful correct positioning of the upper limbs should help to prevent many of these injuries.

Intraoperative iatrogenic ulnar nerve injury

Traditionally anaesthesia-related ulnar neuropathy was thought to be exclusively associated with external compression or stretch caused by intraoperative malpositioning. However, recent findings suggest that other factors may also be involved in ulnar nerve injury. Three findings point to a multifactorial contribution: 1) 70-90% of patients who develop intraoperative ulnar neuropathy are male; 2) many patients that present with an ulnar neuropathy have a “high frequency of contralateral nerve conduction dysfunction”, suggesting that these patients either had asymptomatic but abnormal ulnar nerves prior to their operation or increased vulnerability to ischaemic nerve injury generally; 3) many patients do not present with symptoms of ulnar neuropathy until 48 hours after their operation (Warner 2006). Gender differences in the configuration of the cubital tunnel and/or thickness of the subcutaneous fat behind the medial
epicondyle may account for gender differences in susceptibility, with females having between two and 19 times thicker fat deposition and thus greater protection from external compression in this region (Contreras et al. 1998). Despite the relevance of these other factors in the development of intraoperative ulnar nerve neuropathy, the major causative mechanisms of injury remain external compression and prolonged extreme flexion.

**Intraoperative iatrogenic brachial plexus injury**

The principle cause of brachial plexus injury is ischaemia of the intraneural microvessels that supply the brachial plexus. From the systematic literature review, ischaemic injury was primarily caused by stretching of the brachial plexus, however some case reports identified compression as the main cause of injury. These two mechanisms are not mutually exclusive and it is likely in most cases the brachial plexus is subjected to both (Cooper et al. 1988). The majority of injuries were transient with patients fully recovered by six months, however two patients have permanent neurologic sequelae. Combining case reports from the systematic literature review and claims accepted by the ACC revealed there was no unilateral preponderance, with L:R ratio of 0.9:1 (n=25). The M:F ratio is 1.9:1 (n=26), but the systematic literature review has not identified any publications that indicate males are more susceptible to brachial plexus injury. Iatrogenic brachial plexus injury can occur during various types of surgical procedures, but is a widely recognised complication of open heart surgery with sternal retraction. Median sternotomy and wide sternal retraction stretches the brachial plexus by increasing the distance between the fixed points of the brachial plexus and can also compress its lower trunk between the first rib and clavicle (Lin et al. 2000). Injury is more likely if the internal thoracic artery is harvested for coronary artery grafting, with asymmetrical traction of the sternal halves associated with higher risks (Chong et al. 2003).

The cords and terminal nerves are most often affected by stretching and the ensuing injuries are typically poorly localised, involving different parts of the
plexus (Kim et al. 2004). In diagnosing a brachial plexus injury, it is important to remember that an injury at the level of the plexus will involve more than one named peripheral nerve, as each nerve is formed from more than one spinal nerve. Postoperatively, brachial plexus neuropathies must be distinguished from other upper limb nerve neuropathies because the symptoms may be overlapping. Nerve conduction studies can readily differentiate between a brachial plexus injury or the more commonly occurring ulnar neuropathy following malpositioning (Chong et al. 2003; Kretschmer et al. 2009).

Educational strategies

Before developing a poster, various educational strategies were considered. The advantages and disadvantages of developing a podcast, short video or poster were discussed. The main disadvantage of a podcast or short video was the issue of their dissemination to operating theatre staff. There was no method of ensuring that a podcast or video would be accessed by the staff that we would like to educate. Developing a poster was considered the best strategy, because i) it is a familiar method of conveying information, and can be produced rapidly and cheaply ii) if the poster is able to be displayed in an operating theatre, there is guaranteed access to a target audience and iii) a poster does not take long to read, and can effectively portray a message. The main obstacle is getting the target audience to actually read the poster, but we believe this is less of an issue if the poster is simple and effective. It would be interesting to access theatre staff after the poster had been displayed to determine if the message was conveyed.

Limitations

This poster did not discuss the possibility of preventing positioning injuries to other nerves, including others in the upper limb. The radial and axillary nerves can also be injured through intraoperative malpositioning, as highlighted by two case reports in the systematic literature review. The proposed mechanism of injury to the radial nerve was compression against a self-retaining sternal retractor during
cardiac surgery (Papadopoulou et al. 2006). The radial nerve can also be externally compressed against the edge of the operating table (Winfree and Kline 2005). The axillary nerve injury was a result of compression (and/or traction) in the lateral decubitus position during thoracic surgery (Nishimura et al. 2008). No radial or axillary nerve injury claims as a result of malpositioning were identified in the ACC data from the first six months of 2009, suggesting that the incidence of these injuries is low in New Zealand. The poster only focuses on the ulnar nerve and the brachial plexus because reducing their injuries will have the biggest positive impact on the frequency of intraoperative positioning injuries.

**Conclusion**

We have attempted to make the poster applicable to most operating theatre departments in New Zealand. However we acknowledge that different hospitals or operating theatre suites may have different procedures or practices for positioning patients in the operating theatre. Some operating theatres may not even use the same equipment. This poster was not developed to be used as a set of strict rules for operating staff, rather as an educational resource to increase awareness of hazardous positions that may precipitate nerve injury. Regardless of the surgical context of the patient under general anaesthesia, the most common sites of nerve injury in the upper limb remain the same. Thus, this poster is a relevant resource for the operating theatre, highlighting both correct and incorrect positions of the upper limb under general anaesthesia.

It is hoped that this educational resource will eventually be adopted by hospitals and operating theatres nationwide with NZSA endorsement. Currently we believe there is a gap in highlighting these dangers of positioning to operating theatre staff. It is also possible that this poster will prompt operating theatre staff to review their procedures, or to consider introducing their own guidelines to improve clinical practice.
Chapter 5: Discussion

In the aftermath of the shocking revelation by the Institute of Medicine which revealed the impact of medical errors (Kohn 1999), extensive efforts were made to improve patient safety. However, there is uncertainty about the level of success of these efforts. A recent retrospective study of 100 admissions per quarter between January 2002 and December 2007 carried out in North Carolina USA, showed “high level of engagement in efforts to improve patient safety” but results showed no improvement in the rates of harm among hospital patients (Landrigan et al. 2010). It is clear that iatrogenic injuries remain problematic, even following concerted efforts to improve patient safety and reduce iatrogenic errors. This fact reinforces the importance and pertinence of this epidemiological study of iatrogenic nerve injuries in New Zealand; patient safety can only be improved when you know the areas needing improvement.

The main focus of this thesis is on the spectrum of iatrogenic nerve injuries in New Zealand. A systematic literature review of the English biomedical literature was firstly carried out, to identify the international contemporary spectrum of iatrogenic nerve injuries affecting the upper limb (and including two lower limb nerves). Whilst this revealed what was reported in the literature, the problem of publication bias means that this is not necessarily the true pattern of iatrogenic injuries. No research into the spectrum of iatrogenic nerve injuries has previously been undertaken in New Zealand but judging from the medical literature, these injuries occur in all healthcare systems. Nevertheless, the literature review revealed that these types of injuries are common, are a potential cause of major disability and can affect patients in any medical and surgical specialty. The main crux of this thesis was the analysis of ACC's accepted claims database from the first six months of 2009. Thus, this was the first analysis to describe the
contemporary spectrum of iatrogenic nerve injuries in New Zealand. Eventually, the goal is to try to develop strategies to reduce these iatrogenic nerve injuries in clinical practice in New Zealand; the first step to prevention is knowing the epidemiology of these injuries. Through the development of an educational poster, we have attempted to raise awareness of one particular recurring mechanism of injury, intraoperative positioning injuries to the ulnar nerve and brachial plexus in patients under general anaesthesia. Hopefully, knowledge of these two common sites of nerve injury and careful safe positioning of the upper limbs should help to prevent many such injuries.

**Anatomy education**

It may be no coincidence that iatrogenic nerve injuries are common given the widespread view that the level of anatomical knowledge among medical students and surgical trainees in the United Kingdom and Australasia has declined in recent years. Modern medical educational reforms have focused on introducing clinical integration and problem-based learning with concerns being raised about the reduction in the amount of teaching allocated to the basic sciences, including anatomy in this new approach (McKeown *et al.* 2003; Insull *et al.* 2006). Comparison of anatomy teaching hours in Australasian medical schools in 2008 with historical data by Craig *et al.* (2010) indicates that there has been a major decline in time allocated to teaching gross anatomy. Furthermore, there was considerable variability in teaching hours between schools, unsurprising since an absence of a national framework leaves anatomy teaching at the discretion of individual institutions (Craig *et al.* 2010). This trend is similar in other countries, according to figures published by the Association of American Medical Colleges; curriculum time reduction for anatomy was 8% from 1991 to 1997 (cited in Leung *et al.* 2006) and a 2000 survey of 21 medical schools in the United Kingdom and Ireland show a loss of gross anatomy curricular time following the publication of *Tomorrow’s Doctors* by the General Medical Council (United Kingdom) in 1993 (Heylings 2002).
The effects of reduced anatomy teaching are reflected in several recent surveys. A cross-sectional survey carried out among senior medical students at the University of Auckland in 2005 found that only 33% of respondents considered their anatomy adequate for safe medical practice (Insull et al. 2006). A questionnaire circulated to 235 consultant surgeons in London found that a third of consultants thought the anatomy knowledge of specialist registrars was below average, 72% thought senior house officers’ knowledge was below average, and 88% thought this was true for medical students (Tibrewal 2006). Clearly, the perception is that anatomical knowledge of trainee doctors and medical students in these training systems is below what is expected for safe clinical practice. Students themselves have recognised their lack of self-confidence in understanding and applying anatomy and consultants have commented on their trainees’ lack of knowledge of basic anatomy. The fact is that time dedicated to teaching basic anatomy has declined in the majority of medical schools around the world and results of the above surveys suggest this extrapolates to trainee doctors, who may lack an adequate level of anatomy for safe clinical practice.

If anatomy knowledge is declining – the case has not been proven but a recent prospective study in England showed medical students taught on a traditional curriculum have a significantly higher level of basic anatomical knowledge than those taught on an integrated course, contrary to results from previous European studies (Hinduja et al. 2005) – then this might result in more medical negligence and increasing medico-legal claims, as witnessed in the United Kingdom. A review of claims accepted by the Medical Defence Union revealed that the most common reason for compensation in general and vascular surgery (32% of all claims) was "damage to underlying structures" (Goodwin 2000). It is very likely that some of these are related to an inadequate knowledge of anatomy. The same analysis of claims disclosed that the most common operative procedures for general and vascular surgery claims were varicose vein surgery, local excision of tumour and cholecystectomy. It is no stretch to imagine that many of these claims are a result of an anatomical error or anatomical based complication. Discussions need to be had on whether anatomy education should be a casualty of the new
medical education curriculum (both under- and post-graduate) and what effect the reduction in anatomy teaching will have on the future practice of doctors.

This thesis cannot address the link between the perceived decline in anatomy knowledge and the cause of iatrogenic nerve injuries but it is interesting to note that the reduction of anatomy teaching has occurred in parallel to the increasing focus iatrogenic injuries, which include a significant proportion of anatomical based errors.

Limitations

The research within this thesis has some limitations. Specific limitations of the ACC study were discussed in chapter three, but there are other general limitations of a retrospective study. The chosen study design was constrained by available resources, and a retrospective study was considered the most profitable way to approach the problem. However, this type of study relies on the accuracy of written records (Hess 2004). The utility of a retrospective study is entirely dependent on the available data. As already discussed, there were minor inaccuracies and omissions in the ACC database which will negatively impact on the quality of data analysis. Observer bias can be an issue but the investigators attempted to be as consistent as possible through all steps of this study and this was further miminised by duplicate consensual data entry and input from a further adjudicator (MDS) in any uncertain cases.

Normally, in this type of study, it can be difficult to control for confounders and establish cause and effect. However, the main aim of this study was to establish and describe the spectrum of iatrogenic upper limb nerve injuries in New Zealand and this aim was achieved. It is not possible to identify causation through a retrospective analysis, but the context and relative frequency of these injuries has been described which will assist further research into prevention.
The ability to replicate this analysis and compare patterns of nerve injuries in other countries is limited by the uniqueness of the ACC database. We have described the spectrum of iatrogenic nerve injuries within the context of the New Zealand healthcare system by using this unique national database. There are few other organisations around the world that are comparable to the ACC, elevating the importance of this study. The major types of injury seen in claims reported to the ACC are likely to be similar to other industrialised countries with advanced healthcare technology. Needle injuries, positioning injuries and direct iatrogenic surgical trauma are unlikely to be dissimilar in other comparable countries. After all, the common sites of nerve injury do not change as testified by the systematic literature review, so this study has relevance to other countries.

Unlike many other countries, New Zealand has a tort-free legal system in regards to medical errors. This might distort the rates of reported injury when compared to a tort-based legal system but we believe this is positive, since reported injuries are likely to be more complete when there are no threats of legal proceedings.

**Future research/application**

There is enormous potential for further studies. A total of 5,227 claims were accepted by the ACC under the treatment injury category in 2009. From these claims, we have identified 298 iatrogenic nerve injuries (151 in the first six months). Iatrogenic nerve injuries are an important part of the spectrum of iatrogenic injuries in New Zealand, but further research needs to be undertaken to explore the other claims that have been classified as treatment injuries and which may be preventable, some which may have an anatomical basis. A browse through the ACC accepted claims during the study period show numerous other recurring injuries that could be the focus of future research. These included 69 visceral perforations (39 bowel, 11 bladder, ten uterus plus others), 17 instances of bladder damage, 17 tendon injuries, 15 vaginal injuries, 14 arterial injuries, 11 bile duct injuries, six ureteric injuries and four pneumothoraces. Some of these injuries may be unavoidable complications associated with specific procedures but research
into the context and demographics of such injuries is needed before prevention strategies can be considered.

A large number of treatment injuries reported to the ACC are secondary injuries following the initial procedure and have no specific anatomical basis. They are typically multifactorial and relate to factors such as the patient’s underlying health condition. These include but are not limited to: wound – dehiscence, infection; cellulitis; haematoma; thrombophlebitis; cerebro vascular accidents; deep vein thrombosis and pulmonary embolism and pressure ulcers and burns. These injuries are more related to procedural technique or the patient's illness but there is potential for further research into what aspects of these injuries are preventable. There also remain numerous claims that can be attributed to failure of systems of care. The majority of these are medication errors, causing allergic reactions, anaphylaxis or other adverse drug reactions and delay/failure to provide treatment that resulted in an adverse outcome. There were also three successful claims in the first six months of 2009 for ‘wrong site surgery’. These injuries were outside the scope of our study but there is potential for novel research into why these injuries are occurring at an alarming frequency.

Future research might include denominator data regarding some of the treatment events allowing an estimate of the incidence of some of the more common iatrogenic nerve injuries. One possible source of these data is the National Minimum Dataset administered by the Ministry of Health. This dataset collects discharge information from public and private hospitals which may allow estimates of the total number of various documented procedures performed in 2009. Estimating an absolute rate of iatrogenic injury for specific procedures may provide a clearer perspective of the scope and severity of this problem.

One useful purpose of a retrospective study is paving the way for future prospective studies. From the results of the ACC study, the question of anatomy education and its potential role in the incidence of iatrogenic nerve injuries has been raised. We have attempted to raise awareness and hopefully reduce
intraoperative positioning injuries to the ulnar nerve and brachial plexus under general anaesthesia because we believe there is a gap in highlighting these dangers of positioning to operating theatre staff. However, malpositioning is only one mechanism of injury. There is potential for other education strategies such as an approach to reducing needle injuries associated with venipuncture or intravenous cannulation. Research could also be undertaken to investigate the anatomical knowledge of orthopaedic surgeons and investigate why so many nerve injuries are occurring in this discipline. We have developed a poster as a new educational resource but there is the potential for other resources to be produced, as it is important to convey educational messages via different media.

**Conclusion**

Appreciation of the risks associated with medical procedures is an essential first step in developing and implementing strategies to reduce iatrogenic injuries and improve patient safety. This study has successfully attempted for the first time to describe the contemporary spectrum of iatrogenic nerve injuries in New Zealand with a focus on upper limb nerves. This is a starting point for further research into how these nerve injuries can be prevented, and this study provides invaluable data by highlighting the areas of risk that need most attention. In the interest of everybody involved with the New Zealand healthcare system, reducing iatrogenic nerve injuries should be a priority and an achievable target.
References


Benson LS, Bare AA, Nagle DJ, Harder VS, Williams CS, Visotsky JL. 2006. Complications of endoscopic and open carpal tunnel release. *Arthroscopy* **22**: 919-924


Dubert T, Racasan O. 2006. A reliable technique for avoiding the median nerve during carpal tunnel injections. *Joint Bone Spine* **73**: 77-79


Hess DR. 2004. Retrospective studies and chart reviews. *Respir Care* **49**: 1171-1174


Huang TL, Chiu FY, Chuang TY, Chen TH. 2005. The results of open reduction and internal fixation in elderly patients with severe fractures of the distal humerus: a critical analysis of the results. *J Trauma* 58: 62-69


Appendices
Appendix A

Iatrogenic upper limb injuries: a systematic review
Iatrogenic upper limb nerve injuries: a systematic review

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Key words
brachial plexus injury, neuropathy, positioning injuries.

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MS, FRCS.

Due to space constraints, it has not been possible to cite all the references consulted in producing this systematic review. A fully referenced version of the article is available online.

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Abstract

Purpose: Peripheral nerve injuries are among the most frequent iatrogenic complications and are responsible for considerable morbidity and litigation. Most occur within surgical settings and upper limb nerves are most frequently involved.

Methods: A systematic review of major iatrogenic upper limb nerve injuries was undertaken to evaluate the contemporary spectrum of such injuries. The electronic databases MEDLINE, PubMed, Cochrane Library and Google Scholar were searched for relevant articles listed between January 2000 and May 2010. Iatrogenic injuries to the brachial plexus, radial, axillary, ulnar, median, musculocutaneous and major cutaneous nerves were analysed, focusing on context, mechanisms of injury and incidence.

Results: Iatrogenic upper limb nerve injuries are relatively common and can affect patients in any surgical specialty. Even patients undergoing diagnostic procedures under general anaesthesia are at risk. Orthopaedic surgery and plastic and reconstructive surgery figure prominently in these complications. The spectrum of iatrogenic peripheral nerve injuries has changed in parallel with technological advances in surgery, anaesthesia and medicine.

Conclusions: Some iatrogenic upper limb peripheral nerve injuries may be unavoidable, but most cases are probably preventable by an adequate knowledge of surgical anatomy and an awareness of the types of procedures in which peripheral nerves are particularly vulnerable.

Introduction

Iatrogenic peripheral nerve injuries are a major source of distress and disability and figure prominently in litigation.1,2 A review of treatment injury claims accepted in the first 6 months of 2009 by the New Zealand Accidents Compensation Corporation identified 112 peripheral nerve injuries. 48 of these were upper limb nerve injuries. Fifty of these were upper limb nerve injuries. In the United States, the American Society of Anesthesiologists’ evaluation of over 4000 adverse anaesthetic outcomes from the files of 35 professional liability insurance companies identified nerve damage as the second most common category of claims, accounting for 16% of all cases.3 Ulnar neuropathies were the most frequent, followed by injuries to the brachial plexus and lumbosacral nerve roots. The aim of this systematic review is to highlight the current spectrum of major iatrogenic upper limb nerve injuries, both from a clinical and anatomical perspective.

Methods

The electronic databases MEDLINE, PubMed, The Cochrane Library and Google Scholar were searched for relevant articles listed between January 2000 and May 2010. The searches were limited to English language and humans and, in the case of Google Scholar, to the first five pages (50 hits). Search terms comprised the specific nerve and injury and/or surgery or iatrogenic. All relevant articles were reviewed together with those published between 2000 and May 2010 cited in reference lists of retrieved articles. Only major upper limb peripheral nerves were included in the review. Iatrogenic injuries to the long thoracic nerve, suprascapular nerve and thoracodorsal nerve were excluded, as were most iatrogenic injuries related to true anatomical variants.

Brachial plexus

Iatrogenic brachial plexus injury secondary to inappropriate positioning under general anaesthesia was first described more than a hundred years ago and is the second commonest nerve injury in this situation.4 The brachial plexus is particularly vulnerable to injury because (i) it has a relatively long course in the neck and axilla passing through a confined space between the clavicle and first rib; (ii) it is tethered proximally by nerve roots and the prevertebral fascia and distally by the axillary sheath; and (iii) it lies in close
### Table 1: Brachial plexus injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>Positioning injuries under general anesthesia</td>
<td></td>
</tr>
<tr>
<td>Cardiac surgery (variable arm position)</td>
<td>14% (n = 42)</td>
</tr>
<tr>
<td>Median sternotomy + coronary artery bypass grafting with internal thoracic artery</td>
<td>0.5% (n = 573)</td>
</tr>
<tr>
<td>Thoracic surgery (pericardium) arm fixed &amp; externally rotated above head</td>
<td>5% (n = 588)</td>
</tr>
<tr>
<td>Thoracoscopic surgery (arms abducted 90-100° and laterally rotated)</td>
<td>Case reports</td>
</tr>
<tr>
<td>Sympathectomy</td>
<td></td>
</tr>
<tr>
<td>Robot-assisted thymectomy</td>
<td></td>
</tr>
<tr>
<td>Colectomy</td>
<td>6.7% (n = 451)</td>
</tr>
<tr>
<td>Arm abducted and laterally rotated</td>
<td></td>
</tr>
<tr>
<td>Arms at side in Trendelenburg position</td>
<td></td>
</tr>
<tr>
<td>Plastic and reconstructive surgery arms abducted 90-120°</td>
<td></td>
</tr>
<tr>
<td>Breast surgery</td>
<td></td>
</tr>
<tr>
<td>Latissimus dorsi incision/drainage</td>
<td></td>
</tr>
<tr>
<td>Laparoscopic renal surgery</td>
<td></td>
</tr>
<tr>
<td>Lateral decubitus position with arm suspended and hyperabducted 120°</td>
<td></td>
</tr>
<tr>
<td>Supine, arm position not stated</td>
<td></td>
</tr>
<tr>
<td>Liver surgery</td>
<td></td>
</tr>
<tr>
<td>Supine, arm abducted 90°</td>
<td></td>
</tr>
<tr>
<td>Supine, arms at side (compression between first rib and clavicle from rib retraction)</td>
<td></td>
</tr>
<tr>
<td>Orthopaedic surgery</td>
<td></td>
</tr>
<tr>
<td>Shoulder hypercoracoplasty, posterior cord transected</td>
<td></td>
</tr>
<tr>
<td>Total shoulder arthroplasty</td>
<td></td>
</tr>
<tr>
<td>Lower limb surgery; arms abducted +30°, neck hyperextended</td>
<td></td>
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<tr>
<td>Radiology</td>
<td></td>
</tr>
<tr>
<td>C1/Guided treatment of liver metastases; arms above head</td>
<td></td>
</tr>
<tr>
<td>Embolization of spinal tumour; supine with arms abducted +120°</td>
<td></td>
</tr>
<tr>
<td>Injection injuries</td>
<td></td>
</tr>
<tr>
<td>Axillary regional block</td>
<td>13 cases</td>
</tr>
<tr>
<td>Axillary/proximal brachial artery catheterization for angiography</td>
<td></td>
</tr>
<tr>
<td>Intercostal block ± drug neurotoxicity</td>
<td>8 cases</td>
</tr>
<tr>
<td>Pressure to control bleeding after removal of axillary angiography catheter</td>
<td></td>
</tr>
<tr>
<td>Percutaneous central venous catheterization</td>
<td></td>
</tr>
<tr>
<td>Intravascular subclavian-vein (needle trauma ± haematomatous</td>
<td></td>
</tr>
<tr>
<td>Internal jugular vein (ICJ not compressed by catheter)</td>
<td></td>
</tr>
<tr>
<td>Birth injury</td>
<td></td>
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<tr>
<td>Direct neck pressure from forceps blade</td>
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</table>

Table 1 lists iatrogenic brachial plexus injuries that have been reported in the last 10 years. Most are case reports, involving lengthy operations with the arms abducted. Median sternotomy and wide external retraction not only stretch the brachial plexus but can also compress its lower trunk between the first rib and clavicle or cause direct injury if the first rib is fractured. Injury is more likely if the internal thoracic artery is harvested for coronary artery grafting. Multiple factors are often involved such as stretching, trauma from central venous catheterization, intra-operative hypotension and underlying arterial disease. Intra-operative monitoring of somatosensory evoked potentials in the ulnar and median nerves may help to reduce the risk of injury. Postoperatively, a brachial plexus lesion must be distinguished from an ulnar nerve pressure palsy which is the commonest positioning injury under general anaesthesia. Mechanisms of injury during central venous catheterization include needle trauma and haematoma formation causing neural ischaemia. Injury during subclavian vein catheterization is more likely with multiple needle passes and typically affects the lower roots. Iatrogenic brachial plexus injuries have also been reported during supraclevicular, infraclavicular and transaxillary biopsy and resection of tumours.
With an incidence of 1.4 per 1000 births, brachial plexus injury is the commonest neurologic injury seen in neonates.19 The classical explanation for most of these injuries is excessive or redirected traction to the fetal head when the fetal shoulder is trapped above the mother's pubic symphysis (shoulder dystocia). Other risk factors include instrumental delivery and higher birth weight.20 The upper roots of the brachial plexus are most commonly affected. Although spontaneous recovery is common, residual deficits are present in up to 30% of children.18 In recent years, there has been debate about whether this is a preventable complication, especially since many affected infants are born after normal spontaneous vaginal delivery and the affected shoulder may be the posterior one.18 Indeed, it has been suggested that some obstetric brachial plexus lesions are caused by intrauterine malpositioning rather than traumatic delivery.18 In view of this uncertainty, only one such case with a definite iatrogenic cause has been included in Table 1.

The outcome of patients affected by an iatrogenic brachial plexus injury is very variable ranging from transient symptoms resolving within days or weeks to permanent severe disability.18 Of the 54 cases with a known outcome in Table 1, 24 had persistent neurological symptoms at the time of the publication.

**Ulnar nerve**

The commonest cause of iatrogenic ulnar neuropathy is from compression of the nerve at the elbow, either from external pressure and/or prolonged elbow flexion. This affects as many as one in 200 adult surgical patients and it appears that men are more vulnerable.21,22 Symptoms often manifest a few days after surgery and may be permanent. The lack of reports of this complication in the last 10 years (Table 2) is likely to reflect publication bias since this is a well-recognized complication of positioning under general anesthesia.

Many of the recent reports of iatrogenic ulnar nerve injury relate to orthopedic procedures where the nerve may be transected, stretched or compressed. Supracondylar fractures of the humerus are the second commonest fracture in children. Closed reduction and percutaneous K-wiring of displaced supracondylar fractures frequently causes iatrogenic ulnar nerve injury. Although there is debate about the relative merits of crossed (medial and lateral) versus lateral plating of these fractures,23 it is widely accepted that the medial pin can damage the ulnar nerve either during insertion or with elbow movement after insertion or by constricting the cubital tunnel.24 Slabogan et al.25 calculated that one iatrogenic injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>Orthopedic surgery</td>
<td>Orthopedic treatment of supracondylar fracture of humerus K-wiring, crossed wire fixation Closed reduction Open reduction Min-open technique K-wiring, crossed versus lateral wire fixation Closed reduction Treatment of distal humeral fracture Open reduction and internal fixation via posterior approach Open reduction and plate fixation Open reduction and internal fixation of medial epicondylar fracture Wrist arthroscopy Surgery to triangular fibrocartilage complex, ulnar styloid etc</td>
</tr>
<tr>
<td>Cephalic tunnel decompression</td>
<td>Single portal (laparoscopic technique Dual portal (Chouli endoscopic technique Open release Anterior ulnar nerve transposition for cubital tunnel syndrome Compression by fasciotomy sling Ischemic necrosis of nerve Elbow surgery Elbow arthroscopy Total elbow replacement Arthroscopic contracture release Other orthopedic procedures Open fixation of metacarpal fractures Hook of hamate excision Extensor indicus transfer to thumb Radial artery harvesting Coronary artery bypass grafting Positioning injuries Postoperative immobilization of arm in sling Contrastive implant Subcutaneous hormone implant removal Injection injury Local anesthetic injection (elbow arthroscopy)</td>
</tr>
</tbody>
</table>
occurred in every 28 cases treated by cross-wiring. Both pin direction and elbow positioning during insertion may alter the incidence of this complication. The risk of nerve injury may be reduced by either stimulating the nerve or the pin looking for ulceration prior to final pin placement or by inserting the medial pin through a small incision.

Mobilization and transposition of the ulnar nerve for the treatment of cubital tunnel syndrome can jeopardize its blood supply which is dominantly dependent on the inferior ulnar collateral artery. The nerve can also be compressed by scarring after transposition. Ulnar neuropathy may complicate elbow arthroplasty as a result of traction, direct trauma or ischemia from a tourniquet or neurolysis. Despite transposing or decompressing the nerve during the operation, ulnar neuropathy still complicates 3–10% of procedures.

When performing an elbow arthroscopy, particular care is needed if there has been previous trauma, surgery or a congenital anomaly because tethered or displaced nerves may render them vulnerable to injury during port insertion. In contrast, the incidence of ulnar nerve injury during wrist arthroscopy is low despite the proximity of nerves to portals. The dorsal branch of the ulnar nerve is particularly at risk of being damaged by needles during arthroscopic repair of the triangular fibrocartilage complex. In simulated repairs in cadavers, nerves were frequently found to have looped around this nerve. During open carpal tunnel release, approaching the flexor retinaculum from its ulnar side may spare the palmar branch of the median nerve but may risk damaging the palmar cutaneous branch of the ulnar nerve. Endoscopic carpal tunnel release may also be complicated by ulnar nerve injury (Table 2).

Although radial artery harvesting for coronary artery bypass grafting is more often associated with injury to the superficial branch of the radial nerve, there are reports of ulnar nerve injury complicating this procedure. However, in a small randomized controlled study, Dogan et al. found that patients undergoing coronary artery bypass grafting had similar frequencies of ulnar nerve impairment whether or not their radial artery was harvested, suggesting that mechanisms other than local ulnar nerve ischemia are involved.

Radial nerve
Recently reported iatrogenic injuries of the radial nerve are shown in Table 3. Although the radial nerve is injured primarily in one in eight humeral shaft fractures, it is also at risk during surgical treatment of these injuries. It is particularly vulnerable at two sites: in the region of the mid-shaft posteriorly where it is in direct contact with the peristemeum of the humerus over a distance of about 8 cm, and where it pierces and is tethered by the lateral intermuscular septum. Symptoms depend on the site and severity of the injury but commonly include cutaneous sensory disturbances on the dorsolateral aspect of the hand, with or without wrist drop, and weakness of brachioradialis and finger extensors. Neurapraxia can be associated with debilitating pain.

Being in common with several other upper limb nerves, the radial nerve is vulnerable to compression from poor positioning under general anaesthesia if the posterior aspect of the arm is compressed against a rigid structure such as an anaesthetic screen pole, arm board or the edge of the operating room table. Neurapraxia has also been reported due to a blood pressure cuff attached to an automated monitoring device during surgery (Table 3). Fortunately, most of these injuries cause transient impairment only.

Deep branch of radial nerve (posterior interosseous nerve)
The posterior interosseous nerve splits from the radial nerve anterior to the lateral epicondyle of the humerus and supplies most of the

| Table 3: Radial and posterior interosseous nerve injury |
|---|---|
| Context | Frequency |
| Orthopaedic surgery | 4–13% (based on a total of 789 patients) |
| Operative treatment of humeral shaft fracture | Case report |
| Dynamic compression plating | 6–13% (n = 52) |
| Anterolateral or anterior brachialis-splitting approach | 10% (n = 31) |
| Posteromedial approach | 1–8% (n = 166) |
| Anterolateral or posterior approach | Case report |
| Approach not documented | |
| Intermuscular splitting | |
| Coring (triceps or biceps) fractures | |
| Elbow arthroscopy | Case report |
| Deltoid injury | |
| Posterior injuries under general anaesthesia | 29 cases seen soon at neurophysiology clinic |
| External compression against retractor support during cardiac surgery | Case reports |
| Compression against arm board | |
| Compression from blood pressure cuff | |
| Injection injuries | |
| Posterior interosseous injection in distilled | |
| Orthopaedic surgery | 2% (n = 53) + Case reports |
| Repair of distal avulsed biceps tendon | 0.2% (n = 473) + Case report |
| Reattachment of avulsed tendon to radial tuberosity | |
| Elbow arthroscopy | |
| Port insertion or compression by instruments | |
extensor muscles of the forearm. After giving off branches to the extensor carpi radialis brevis and supinator, it winds laterally around the radius between the two heads of the supinator. The nerve is at risk of iatrogenic injury during orthopaedic procedures in the elbow region including arthroplasty, operative repair of fractures of the radial head and neck, synovectomy, radial head excision and those listed in Table 3. Symptoms were persistent in half of these cases. Isolated injuries of the posterior interosseous nerve typically present with weakness of wrist and finger extension (but not wrist drop because extensor carpi radialis longus is innervated by the radial nerve), weakness of extension and abduction of the thumb and a deep forearm discomfort.  

**Axillary nerve**

The proximity of the axillary nerve to the inferior aspect of the glenohumeral joint renders it vulnerable to injury during open and arthroscopic shoulder surgery (Table 4). In cadavers, the axillary nerve lies, on average, 10–12 mm from the inferior margin of the glenoid labrum  and 3 mm from the inferior margin of the shoulder joint capsule. 

Nerve damage results in weakness of abduction and, to a lesser extent, flexion and extension of the arm together with deltoid muscle wasting and sensory loss in the “regimental patch” area. 

The degree of motor and sensory deficit depends on the type of injury and the branching pattern of the nerve. 

To avoid injury to the axillary nerve at surgery, it is recommended that lateral shoulder incisions should not extend more than 5 cm distal to the acromion. However, cadaver studies indicate that the axillary nerve runs between 4 cm and 7.5 cm below the mid-portion of the acromion or proximal limit of the head of the humerus and so the 5 cm guideline does not offer absolute protection. Furthermore, whereas humeral rotation and flexion cause minimal displacement of the nerve, abduction of the arm to 90° moves the nerve closer to the acromion (but still beyond 4 cm). 

Intra-operative monitoring of nerve function is an alternative approach to reducing the risk of injury. 

The axillary nerve is occasionally damaged by intramuscular injection into the deltoid. To avoid this complication, Davidson et al. propose that intramuscular injections should be given 5 cm from the lateral edge of the acromion. Similarly, a popular nursing text advises approximately three fingerbreadths or 2.5–5.0 cm below the lower edge of the acromion. These sites are potentially hazardous. If the deltoid muscle is selected for intramuscular injection, a safer recommendation is the lateral aspect of the deltoid no more than 4 cm below the lower border of the acromion. 

**Median nerve**

In a consecutive series of 263 surgically treated iatrogenic peripheral nerve injuries at a large neurosurgical unit, median nerve injury was the commonest upper limb nerve injury requiring surgical repair, accounting for 10% of all cases. The median nerve is especially vulnerable during carpal tunnel release, during both open and endoscopic procedures. Besson et al. reported median nerve injuries in about 0.1% of carpal tunnel releases, although the actual incidence may be higher in clinical practice. Mechanisms include compression or stretch of the nerve during insertion of the endoscopic cannula or with hand positioning. Iatrogenic injury may affect the main trunk or one of its branches such as the recurrent thenar branch, a common digital nerve, or the palmar branch. Variant anatomy of the median nerve may increase risk of iatrogenic injury. 

Usually, the only branch of the median nerve in the distal forearm is its palmar cutaneous branch but, rarely, a high bifurcation of the median nerve can result in a common digital nerve crossing the line of division of the flexor retinaculum. 

Injection of steroids into the carpal tunnel to alleviate symptoms of nerve compression is also not without risk of nerve damage. There is no consensus on the safest injection site. 

In a cadaver study using a commonly employed injection technique, four of 15 simulated injections pierced the median nerve, although in clinical practice, the incidence of clinically detectable intraneural injection is much lower. 

Other reported causes of median nerve injury are shown in Table 5. The median nerve has been confused with the palmaris longus tendon with disastrous consequences, due to the rarity of 

---

**Table 4: Axillary nerve injury**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthopedic surgery</td>
<td>Case report</td>
</tr>
<tr>
<td>Operative treatment of proximal humeral fracture</td>
<td>Case report</td>
</tr>
<tr>
<td>Retrograde nailing of humeral shaft fracture with proximal interlocking screw</td>
<td>7% (n = 14)</td>
</tr>
<tr>
<td>Plate fixation of proximal fractures</td>
<td>3% (n = 60)</td>
</tr>
<tr>
<td>Plate fixation via anterolateral deltoid-splitting approach</td>
<td>1% (n = 128)</td>
</tr>
<tr>
<td>Plate fixation via extended lateral deltoid-splitting approach</td>
<td>1% (n = 14 277) + Case reports</td>
</tr>
<tr>
<td>Plate fixation via latrophactor approach</td>
<td>Case report</td>
</tr>
<tr>
<td>Shoulder surgery</td>
<td>Case report</td>
</tr>
<tr>
<td>Open anterior stabilization via a subscapularis muscle-splitting approach</td>
<td>Case report</td>
</tr>
<tr>
<td>Positioning injury under general anesthesia</td>
<td>Case report</td>
</tr>
<tr>
<td>Compression fracture of nerve during thoracoscopic surgery</td>
<td>Case report</td>
</tr>
<tr>
<td>Injection injuries</td>
<td>Case report</td>
</tr>
<tr>
<td>Axillary nerve block</td>
<td>Case report</td>
</tr>
<tr>
<td>Intramuscular injection of deltoid</td>
<td>Case report</td>
</tr>
</tbody>
</table>

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126
Table 5 Median and anterior interosseous nerve injury

<table>
<thead>
<tr>
<th>Context</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median nerve</strong></td>
<td></td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
</tr>
<tr>
<td>Operative treatment of olecranon fracture</td>
<td>Case report</td>
</tr>
<tr>
<td>Tension band wiring</td>
<td>15% (n = 67)</td>
</tr>
<tr>
<td>Cubital tunnel release</td>
<td>1.5% (n = 6)</td>
</tr>
<tr>
<td>Dual portal endoscopic technique</td>
<td>Case report</td>
</tr>
<tr>
<td>Standard palmar incision open technique</td>
<td>Case report</td>
</tr>
<tr>
<td>Minimally open technique</td>
<td>Case report</td>
</tr>
<tr>
<td>Tendon graft surgery</td>
<td>Case report</td>
</tr>
<tr>
<td>Median nerve ligation for palmaris longus tendon</td>
<td>Case report</td>
</tr>
<tr>
<td>Other surgery</td>
<td>Case report</td>
</tr>
<tr>
<td>“Accidental” biopsy</td>
<td>Case report</td>
</tr>
<tr>
<td>Injection injuries</td>
<td></td>
</tr>
<tr>
<td>Catheter insertion</td>
<td>Case report</td>
</tr>
<tr>
<td>Peripherally inserted central venous catheter</td>
<td>0.01% (n = 10 000)</td>
</tr>
<tr>
<td>Peripheral intravenous catheter</td>
<td>7 cases</td>
</tr>
<tr>
<td>Axillary/proximal brachial artery catheterization for angiography</td>
<td></td>
</tr>
<tr>
<td><strong>Anterior interosseous nerve</strong></td>
<td></td>
</tr>
<tr>
<td>Orthopaedic surgery</td>
<td></td>
</tr>
<tr>
<td>Operative treatment of olecranon fracture</td>
<td>Case report</td>
</tr>
<tr>
<td>Tension band wiring</td>
<td>Case report</td>
</tr>
<tr>
<td>Treatment of open radial and ulna fractures</td>
<td>Case report</td>
</tr>
<tr>
<td>Closed reduction and percutaneous pinning</td>
<td>Case report</td>
</tr>
<tr>
<td>Arthroscopy</td>
<td>Case report</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Case report</td>
</tr>
<tr>
<td>Elbow</td>
<td>Case report</td>
</tr>
<tr>
<td>Open capsulotomy</td>
<td>Case report</td>
</tr>
<tr>
<td>Elbow tenotomy</td>
<td>Case report</td>
</tr>
<tr>
<td>Injection injuries</td>
<td></td>
</tr>
<tr>
<td>Cubital fossa venepuncture</td>
<td>5 cases</td>
</tr>
<tr>
<td>Peripheral intravenous catheter</td>
<td>0.01% (n = 10 000)</td>
</tr>
</tbody>
</table>

For example, the nerve or its branches may be damaged during operations near the radial styloid, such as when inserting K-wires to maintain reduction of a displaced distal radial fracture. The superficial branch of the radial nerve is, on average, only 6 mm away from the radial styloid. In one study in which an experienced orthopaedic surgeon inserted K-wires percutaneously into 92 cadaver wrists, the superficial radial nerve was injured in 14% of cases. In de Quervain’s tenosynovitis, the tendons of abductor pollicis longus and extensor pollicis brevis become inflamed within the first compartment of the extensor retinaculum. When conservative treatment fails, surgical release of the tendons is indicated; the risk of damage to the superficial branch(es) of the radial nerve may be minimized by using a longitudinal incision. In view of the close relationship between the superficial branch of the radial nerve and the cephalic vein at the wrist, the nerve may be injured by venipuncture. This may be more likely when the forearm is pronated and the wrist is flexed, which renders the nerve less mobile. This has prompted some authors to suggest that the cephalic vein in the distal forearm should be avoided for venous access. However, venous cannulation at this site is common and symptoms are typically transient and so this recommendation must be balanced against the risks at alternative sites. The radial artery forearm flap can be harvested as a free fasciocutaneous flap along with a length of radial artery and either the cephalic vein or venous comitantes; avoiding the cephalic vein appears to reduce the incidence of damage to the superficial radial nerve. In a similar context, the nerve must also be at risk when

these reports, it is not known whether this is more likely if palmaris longus is congenitally absent. The median nerve may also be injured during the percutaneous insertion of vascular catheters, but we found no recent reports of injury following brachial artery catheterization for cardiac studies.
Fusioning a radiocephalic fistula, although we found no recent report of this complication.

In all instances of iatrogenic nerve damage documented in Figure 1, it is assumed that the superficial branch of the radial nerve was injured. However, it should be noted that there is partial or complete overlap between the cutaneous territory of this nerve and that of the lateral cutaneous nerve of the forearm in 75% of individuals, and therefore, injury to the latter may account for some cases.25

There was only one report of iatrogenic injury to the medial cutaneous nerve of arm identified in the review period and this related to a patient who underwent cubital tunnel surgery.26

In contrast, there were numerous reports of damage to the medial cutaneous nerve of forearm (Fig. 2). This nerve divides into two main branches that pass anterior and posterior to the medial epicondyle.27 The posterior branch is vulnerable during cubital tunnel surgery, while the anterior branch is at risk during venipuncture. Neuropathy may manifest as sensory disturbances and/or a painful neuroma.28

The lateral cutaneous nerve of forearm is also at risk during invasive procedures involving access via the cubital fossa (Fig. 3). This includes venipuncture, particularly when the cephalic vein is punctured just lateral to the biceps tendon and crossed by the nerve.29

It is surprising that there have not been more reports of injury to the cutaneous nerves of the forearm from venipuncture, particularly the medial cutaneous nerve which crosses superficial to the median cubital vein in about 40% of individuals (whereas the lateral cutaneous nerve runs deep to the vein in most cases).29 Retrospective data from blood donors suggest that these nerve injuries are indeed rare.29

Iatrogenic digital nerve injury is a potential complication of fasciotomy for Dupuytren’s disease, occurring in 2–5% of cases,30 carpal tunnel release31 and other types of hand surgery. Phillips et al.30 were unable to find any report of iatrogenic digital nerve injury secondary to local anaesthetic nerve block in the literature, but from a small cadaver study, they concluded that this type of injury probably does occur, but the effects of the injury are probably attributed to the condition for which the block was necessary.

Conclusions

The true frequency of iatrogenic upper limb peripheral nerve injuries is difficult to determine, not least because the literature is subject to publication bias, tending to diminish the importance of more common types of nerve injury. What is clear, however, is that these injuries are common,1 are a potential cause of major disability and can affect patients in any surgical specialty. The spectrum of iatrogenic upper limb nerve injuries has changed as surgical technology has evolved. Minimal access surgery does not mean minimal risk of peripheral nerve injury. Neither are diagnostic procedures performed...
under general anaesthesia free of these complications. Some injuries, such as those associated with rare variant anatomy, may be unavoidable, but many if not most cases are preventable by a detailed knowledge of anatomy and an understanding of situations in which peripheral nerves are particularly at risk.

References

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Supplementary Information. Intracranial upper limb nerve injuries: a systematic review (full references).

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.
Appendix B
Research protocol
ANATOMICAL-BASED ERRORS IN CLINICAL PRACTICE

Short title: Anatomical-based errors in medicine

Research Protocol
February 2010

PI: Prof. Mark D Stringer
Co-Investigators: Abigail Moore BBioMedSc (Hons) and PhD candidate
John Zhang Medical Student and BMedSc (Hons) candidate

Background
Complications due to errors made by health practitioners are a major cause of concern and a source of distress, disability, and death in patients. In addition, they are associated with litigation and a major financial burden on healthcare budgets. During the past decade, medical error has been the focus of much research. The report from the Institute of Medicine in 2000 entitled “To Err Is Human” gave the issue of medical error huge public prominence when it stated that between 44,000 and 98,000 hospitalized Americans died each year as a result of preventable medical errors (1). The financial burden is equally shocking, a 2001 report from the National Audit Office in the U.K showed that the bill for medical negligence faced by the National Health Service amounted to £2.6 billion, double the amount paid out in 1997 (2).

Errors in surgery have been the focus of considerable research but studies have tended to focus on systems of care, surgical techniques and operating theatre protocols. Some of these studies have utilized malpractice claims as a method of defining common patterns of error (3). However, few if any researchers have specifically focused on errors related to inadequate understanding of anatomy. This is particularly relevant given the widespread view that the anatomical knowledge of medical students and surgical trainees in the USA, UK and New Zealand has declined in the past twenty years (4-6).

No research into anatomical-based errors has been undertaken in New Zealand but a recent report by the Quality Improvement Committee called “Serious and Sentinel Events in New Zealand Hospitals 2008/09” showed a total of 308 potentially preventable serious and sentinel events, with 39% of these events arising from clinical management problems, including errors in procedures, treatment and diagnosis (7).
The PI has previously undertaken a research project using ACC data, highlighting the ongoing anatomical problem of sciatic nerve injury following misplaced intramuscular injection. The PI successfully collaborated with Dr. Dylan Tapp, Clinical Analyst at the ACC. The findings are due to be published in the *International Journal of Clinical Practice* (8).

**Research Question**
What are the most frequent types of anatomical-based errors in clinical practice as determined from ACC claims?

**Aims**
The aim of this research is to determine the commonest types of anatomical-based errors in clinical practice in New Zealand. Initial work will focus on the Accident Compensation Corporation (ACC) of New Zealand’s database in an effort to identify leading causes of accepted claims to the ACC where inadequate knowledge of anatomy may be a major factor. The type, frequency, time trends, and demographics of these claims will be analysed. The project will involve extensive data collection and analysis and a critical review of relevant medical and anatomical literature. It is hoped that suitable educational strategies might then be developed to reduce the risk of anatomical errors in clinical practice.

The ACC is a unique organisation as it provides coverage to all residents of New Zealand and collects vital information on types, trends, and localities of all accidental injury in New Zealand. Studying ACC claim files would present an exciting and rare opportunity to undertake novel research of potential clinical value in New Zealand.

**Methods**

*Study sample*
The proposed study sample will consist of computerised claim files from the ACC, specifically accepted claims in the first six months (1st Jan-30th June) of 2009. We estimate that there may be approximately 3,000 accepted claims during this period. If approval is granted, these data will be accessed from the Dunedin Service Centre, adhering to strict confidentiality. Only *anonymised* data will be extracted i.e. no identifiable personal information will be recorded, either in relation to claimants or health practitioners documented in claim reports. A primary review of all accepted claim files during this period will initially be undertaken to exclude those with no suggestion of an anatomical error.

The quality of the data is certain to be variable but it is hoped that some or all of the following information can be retrieved:
- Anatomical structure involved in claim
- Age (at time of injury in yrs/months), gender and self-reported ethnicity
• Setting: hospital (teaching, other and ward, operating theatre, other); general practice; dental practice; physiotherapy practice; other clinic.
• Brief description of incident
• Practitioner (doctor [specify grade and specialty if known], nurse, dentist, physiotherapist, midwife)
• Outcome/disability if known
• Cost to ACC of compensation if known

Common/serious types of error that we anticipate are:
- Nerve injury
- Bile duct injury after laparoscopic cholecystectomy
- Injuries secondary to misplaced cannulas and drains
- Wrong side surgery

Descriptive statistics will be used to report summary data. Andrew Gray, Biostatistician at the Department of Preventive and Social Medicine, Dunedin School of Medicine, has kindly agreed to be consulted if more complicated statistical analysis is required. Subsequent analysis will be aimed at identifying potentially avoidable anatomical errors.

Ethical approval
The study requires ethical approval from the ACC and from the University of Otago. Māori consultation will also be necessary. Any publication ensuing from this research will need to be approved by the ACC.

Dissemination of results
Results from this study will be included in Abigail Moore’s PhD thesis and John Zhang’s BMedSc dissertation. We also hope to publish summary data in an international peer-reviewed medical journal.

References
4. Insull P, Blyth P. Basic science confidence in senior medical students from the University of Auckland, New Zealand: results of the 2005 Senior Students Survey. NZ Med J 2006;119:U2364


Appendix C

ACC ethical approval
7 April 2010

Professor Mark Stringer
Department of Anatomy and Structural Biology
University of Otago
DUNEDIN

Dear Professor Stringer

**ACC Research Ethics Committee Decision Notification**

Re: *Anatomical-based errors in clinical practice* #178

Thank you for your resubmission which was considered by the ACC Research Ethics Committee at its meeting on 7 April 2010.

I am pleased to inform you that the committee has approved your research. Ethical approval for this study is given for one year at which time the Committee will ask you to complete a Monitoring Form. If for any reason the proposal is changed in any significant way the ACC Research Ethics Committee must be advised immediately.

Please do not hesitate to contact me if you have any queries.

The committee wishes you well with your research.

Yours sincerely

Fiona Conlon, Secretary

**PP Sharron Cole, Co-Chair**

**ACC Research Ethics Committee**
Appendix D

Māori consultation
Ngāi Tahu Research Consultation Committee
Te Komiti Rakahau ki Kai Tahu

23/02/2010 - 31
Tuesday, 23 February 2010

Professor Stringer
Anatomy and Structural Biology
Dunedin

Tētū Rētū Professor Stringer

Title: Anatomical-Based Errors In Clinical Practice.

The Ngāi Tahu Research Consultation Committee (The Committee) met on Tuesday, 23
February 2010 to discuss your research proposition.

By way of introduction, this response from the Committee is provided as part of the
Memorandum of Understanding between Te Runanga o Ngāi Tahu and the University. In the
statement of principles of the memorandum, it states "Ngāi Tahu acknowledges that the
consultation process outlined in this policy provides no power of veto by Ngāi Tahu to research
undertaken at the University of Otago". As such, this response is not "approval" or "mandate" for
the research, rather it is a mandated response from a Ngāi Tahu appointed committee. This
process is part of a number of requirements for researchers to undertake and does not cover other
issues relating to ethics, including methodology; they are separate requirements with other
committees, for example the Human Ethics Committee, etc.

Within the context of the Policy for Research Consultation with Māori, Consultation is defined
according to the definition of Justice McGechan:

"Consultation does not mean negotiation or agreement. It means: setting out a proposal
not fully decided upon, adequately informing a party about relevant information upon
which the proposal is based; listening to what the others have to say with an open mind
(in that there is room to be persuaded against the proposal) undertaking that task in a
genuine and not cosmetic manner. Reaching a decision that may or may not alter the
original proposal."

The Committee considers the research to be of importance to Māori health.

The Committee notes the researchers have identified that, "there is a possibility that Māori may
be more at risk of in-hospital adverse events".

The Committee suggests dissemination of the research findings to Māori health organisations
regarding this study.

We wish you every success in your research and the Committee also requests a copy of the
research findings.

The Ngāi Tahu Research Consultation Committee has membership from:
Te Runanga o Ōtāhuhu Incorporated
Kaitiaki Hauora Rākau ki Pūteaenski
Te Runanga o Moeroa
The recommendations and suggestions above are provided on your proposal submitted through the consultation website process. These recommendations and suggestions do not necessarily relate to ethical issues with the research, including methodology. Other committees may also provide feedback in these areas.

Mark Brunton
Kaiakauwhanga Rangahau Māori
Faciliator Research Māori
Research Division
Te Whare Wānanga o Otago
Ph: +64 3 479 8738
email: mark.brunton@otago.ac.nz
Web: www.otago.ac.nz

The Ngāi Tahu Research Consultation Committee has membership from:
Te Rūnanga o Ōtākou Incorporated
Kāi Whai Rūnanga ke Puketapu
Te Rūnanga o Mōrehu
Appendix E

Laterality of nerve injuries – full table
### Laterality of affected peripheral nerves n=122

<table>
<thead>
<tr>
<th>Affected nervous structure</th>
<th>Left</th>
<th>Right</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peripheral spinal nerve</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>6</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Anterior interosseous</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Common fibular</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Deep fibular</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Superficial fibular</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sciatic</td>
<td>6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Sural</td>
<td>-</td>
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</tr>
<tr>
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<tr>
<td>Superficial branch of radial</td>
<td>6</td>
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<tr>
<td>Ulnar</td>
<td>6</td>
<td>5</td>
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<tr>
<td>Lateral cutaneous nerve of thigh</td>
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</tr>
<tr>
<td>Digital</td>
<td>2</td>
<td>2</td>
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</tr>
<tr>
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<td>2</td>
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</tr>
<tr>
<td>Femoral</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Anterior cutaneous nerve of thigh</td>
<td>-</td>
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<td>1</td>
</tr>
<tr>
<td>Saphenous</td>
<td>1</td>
<td>-</td>
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</tr>
<tr>
<td>Obturator</td>
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<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Greater auricular</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Recurrent laryngeal</td>
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<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Lateral cutaneous nerve of forearm</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Genitofemoral</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Long thoracic</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Phrenic</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Intercostobrachial</td>
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### Peripheral nervous plexus

<table>
<thead>
<tr>
<th>Nerve Plexus</th>
<th>Left</th>
<th>Right</th>
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<tbody>
<tr>
<td>Brachial</td>
<td>3</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Lumbosacral</td>
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</table>

### Spinal nerve roots

<table>
<thead>
<tr>
<th>Nerve Root</th>
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<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7-T1</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>L3</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>L4</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>L5</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>L5-S1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sacral</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Presacral</td>
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<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Unspecified</td>
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</table>

### Laterality of affected cranial nerves n=20

<table>
<thead>
<tr>
<th>Affected Nerve Structure</th>
<th>Left</th>
<th>Right</th>
<th>Total</th>
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<tbody>
<tr>
<td>Inferior alveolar</td>
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<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Lingual</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Facial</td>
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<td>3</td>
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</tr>
<tr>
<td>Accessory</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Hypoglossal</td>
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</table>
Appendix F

2010 ANZACA conference poster
Iatrogenic Upper Limb Nerve Injuries under General Anaesthesia: Developing an Educational Poster

John Zhang*, Robyn Chirnside*, Mark D. Stringer
*Department of Anatomy & Structural Biology, Otago School of Medicine, University of Otago, Dunedin; Dunedin Hospital, Dunedin, New Zealand

Introduction

Analysis of more than 4000 adverse anaesthetic outcomes by the American Society of Anesthesiologists (ASA) identified damage to the ulnar nerve and brachial plexus from malpositioning as leading causes of claims, accounting for almost 10% of all cases.1 In 2009, there were 13 ulnar nerve and 11 brachial plexus injury claims from malpositioning under general anaesthesia accepted by the Accident Compensation Corporation in New Zealand. These treatment injuries accounted for 8.1% (24/298) of all iatrogenic nerve injuries recorded during this period. Internationally, ulnar nerve neuropathy has been shown to affect as many as 1 in 200 adult surgical patients.2 No current guidelines on correct positioning of the upper limbs are available from the New Zealand Society of Anaesthetists (NZSA).

Aim

To develop and produce an educational poster for operating theatre staff outlining the dos and don’ts of upper limb positioning under general anaesthesia.

Methods

The poster was developed using ASA recommendations.3

Common standard operating postures were selected to illustrate appropriate positioning of the upper limbs.

Comment

- The brachial plexus is particularly vulnerable to injury because it is tethered in the neck and runs within a confined space bordered by bony structures against which it may be compressed. Injury is more likely if the arms are abducted beyond 90°.4
- Most ulnar nerve malpositioning injuries occur behind the medial epicondyly, from external pressure and/or prolonged elbow flexion. Marked flexion of the elbow (<90°) shrinks the cubital tunnel and increases the risk of nerve compression.5
- Risk of injury is further compounded because anaesthetists patients are unable to respond to neurologic symptoms and muscle relaxants encourage limbs to be placed in unnatural and hazardous positions.6

Conclusion

This educational poster demonstrates how knowledge of clinical anatomy can be used to develop an educational resource that attempts to improve clinical practice.

References:


Results - The Poster

Major nerve injuries from incorrect positioning of the arms under general anaesthesia continue to be a problem worldwide in New Zealand. In 2009 alone, there were 24 such injuries.2

The two commonest injuries are:

1) Pressure on the ulnar nerve at the elbow (behind the medial epicondyly)
2) Compression of the brachial plexus

Anesthetised patients are unable to respond to neurologic symptoms and muscle relaxants encourage limbs to be placed in unnatural and hazardous positions. The following guidelines show how to safety position the arms in patients under general anaesthesia.

Dos:

- Arm on foam armboard below level of Table
- Shoulder abducted >90°
- Shoulder flexed >90°
- Head to neutral position or being abducted arm
- Arm on foam armboard above level of table
- Brachial plexus injury:
- Head to neutral position or being abducted arm
- Arm on foam armboard above level of Table
- Shoulder abducted >90°
- Head to neutral position
- Head turned to opposite side

Don’ts:

- Arm folded across chest
- Elbow supported with risk of padding
- Arm by side
- Palms facing up
- Elbow position is prone to prevent compression of upper arms

Proper (Belly Flox):

- Elbow flexed
- Forearm supported and supported with a armboard
- Antebrachial angle >90°

Lateral (armboard):

- Upper arm abducted
- Lower antebrachial angle >90°
- Shoulder abducted >90°
- Padding in lower arms

Lateral (pillows):

- Upper antebrachial angle >90°
- Shoulder abducted >90°
- Upper shoulder abducted >90°
- Lower antebrachial angle >90°
- Patient lying on lower arm

References:


John Zhang, Robyn Chirnside, Mark Stringer University of Otago, Dunedin Hospital, Dunedin, New Zealand

Safety No Pain