Fasciotomy wounds associated with acute compartment syndrome - a systematic review of effective management

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Abstract

Objectives: To systematically review the effectiveness of different treatment options for managing a fasciotomy wound on outcomes, including time to primary wound healing, percentage of patients who need skin grafts to effect closure of the wound and length of stay in hospital following the fasciotomies, in patients with acute compartment syndrome of the limb(s).

Methods: Published and unpublished English language papers about human subjects from January 1960 to June 2012 were identified using electronic searches of medical and nursing databases. Reference lists of relevant articles were also searched. A systematic review of the papers found was conducted.

Results: Thirty-two papers met the inclusion criteria and passed critical appraisal.

One randomised controlled trial (RCT) was analysed separately and four cohort studies were meta-analysed. The RCT favoured the use of shoelace technique over negative pressure wound therapy based on a range of indicators. The cohort studies favoured the use of negative pressure wound therapy over saline soaked gauze on a range of indicators.

Conclusion: The systematic review found limited evidence on which to base practice decisions. The single RCT needs to be replicated to confirm findings before practice change can be confidently recommended. The evidence provided some support for the use of vessel loop shoelace technique to improve the chances of achieving a primary wound closure without the need for a split thickness skin graft and to reduce length of stay when compared with negative pressure wound management. The use of negative pressure wound management appears to be associated with a higher rate of split thickness skin graft than vessel loop shoelace. Saline soaked gauze is not recommended for use with these wounds.

Keywords: Compartment syndrome, fasciotomy, systematic review, quantitative systematic review, wound management, wound care, wounds, wound dressings, VAC, vacuum assisted closure, split thickness skin graft

Student declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Margaret Walker and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Date

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I thank Beryl Sutton for helping me track down some papers when I failed.

Chapter 1: Introduction

1.1 Introduction

The introductory chapter explains the structure of the thesis and outlines the contents of each chapter. The context of the review is introduced and background information about the topic provided. The methodological basis for the thesis, including the use of the systematic review is explained. The systematic review question is presented. Finally key terms used throughout the thesis are presented and defined.

1.2 Structure

The thesis consists of four chapters.

Chapter one introduces the study and presents the background and context of the study. It describes the systematic review process and places the process in the context of developing and building a body of knowledge.

Chapter two explains the background to the formulation of the systematic review question and details the systematic review protocol which was developed and followed.

Chapter three presents the results of the systematic review and includes the meta-analysis and meta-analysis of results. This chapter details the methodology of the included papers, discusses the three different research study designs included in the systematic review results and explains the reasons for inclusion. The implications of the study designs on the results are discussed.

Chapter four discusses the results, and highlights the issues with the available research. This chapter includes the implications for clinical practice, proposes further research that may be required and concludes the thesis.

Appendices set out the included and excluded papers, additional references, the detailed search strategy and the tools used for extraction and critical appraisal.

1.3 Context of the review

The review was intended to identify the best available evidence for the management of fasciotomy wounds created to relieve acute compartment

syndrome in the limbs. Compartment syndrome can occur when a traumatic event causes tissue damage in an anatomical compartment. These compartments are essentially containers or enclosed areas within the body. They are usually formed by fibrous tissue but can also be formed by bone. They are filled with anatomical structures such as muscles, blood vessels, nerves, intestines, brain tissue, bone marrow and lungs. Tendons, blood and lymph vessels and nerves enter and exit from the compartment but the compartment itself is otherwise completely enclosed.[1] There are many anatomical compartments throughout the body. The skull is an example of a bony compartment which contains the brain. The abdomen has compartments enclosing the intestines and other abdominal anatomical structures. Each limb has a number of separate compartments enclosed in fascia. Fascia is a sheet of fibrous tissue which envelops the body under the skin. It also encloses muscles and groups of muscles.[1] The anatomical compartment creates a situation where increased pressure due to bleeding or swelling in the tissues is contained within the compartment and cannot escape naturally. This leads to reduced blood flow into and out of the compartment which, left unchecked, can result in life or limb threatening tissue necrosis. Fasciotomy wounds are surgical wounds created to relieve this pressure, and as such these wounds are essential and unavoidable.[2]

Compartment syndrome has been recognised since the late 19th century. It was first described by Volkmann in 1881 although he ascribed the condition to overly tight bandages.[3] Hildebrand described the limb contracture that can occur as Volkmann's contracture in 1906. Murphy described the first use of fasciotomy to relieve the symptoms in 1914. In the mid sixties, Seddon, Kelly and Whitesides described the four compartments of the leg, and developed a four incision approach to management of compartment syndrome in the leg.[4]

Research carried out during the next two decades focused on the best way to identify developing compartment syndrome early enough to avoid life and limb threatening complications.[5] This research did not examine the fasciotomy wounds themselves. This might be because at this juncture the fasciotomy wounds were viewed as a necessary result of treatment, and the treatment of the wounds themselves were not the primary concern. The treatment for fasciotomy wounds initially comprised of basic wound care

aimed at reducing the risk of infection and preventing the recurrence of the compartment syndrome. Saline soaked gauze combined with light bandages was commonly used. Definitive wound closure often required a split thickness skin graft. A case series conducted in 1976 found that 77% of patients who had a fasciotomy which was not closed immediately required a skin graft.[6] A study published in 2000 contributed to the growing understanding of the negative impact of skin grafts on long term functionality by identifying long term consequences associated with skin grafts.[7] These included physical effects such as reduced limb strength, nerve, tendon or muscle damage, pain, scarring and ulceration. In addition to the physical effects, psychological effects such as changes to behaviour and activity due to embarrassment about the physical appearance of the affected limb, were described.

The recognition of the negative consequences of spilt thickness skin grafts, coupled with the increased costs associated with longer lengths of stay, and the need for additional procedures, has led to the development of a range of techniques aimed at achieving wound closure with a reduced need for grafting. These techniques have not eliminated the need for split thickness skin grafts however, and even in 2011 the author has observed that skin grafts appear to be considered a common part of the treatment of fasciotomy wounds at a major tertiary public hospital in South Australia.

This quantitative systematic review was commenced with the intention of identifying the available evidence about the effectiveness of wound management techniques for fasciotomy wounds created to manage acute compartment syndrome due to any injury except burns. Burn wounds were excluded because burns fundamentally alter the structure of skin and underlying tissue. Comparison of these cases with surgically inflicted fasciotomy wounds on otherwise normal tissue was not possible, as burn cases require a series of interventions specific to burns. The purpose of this review was to identify the most effective method of wound management, as measured against a range of outcomes. These outcomes are detailed in chapter two.

1.4 Statement of the systematic review question

The systematic review question addressed the following: What was the effectiveness of different treatment options for managing a fasciotomy wound

on outcomes such as time to primary wound healing, percentage of patients who needed skin grafts to effect closure of the wound and length of stay in hospital following the fasciotomies, in patients with acute compartment syndrome of the limb(s).

1.5 Overview of the science of evidence synthesis

The research that contributes to the body of knowledge that supports evidence based medicine is rapidly evolving and developing. This evidence includes both qualitative and quantitative evidence, although only quantitative evidence has been considered in this review as the question to be addressed is about effectiveness. Hierarchies of evidence have been developed to guide the clinician faced with increasingly vast quantities of research. The National Health and Medical Research Council (NHMRC) published a hierarchy in 1999 as follows:[8]

Level 1: evidence obtained from a systematic review of all relevant randomised controlled trials

Level II: evidence obtained from at least one properly-designed randomised controlled trial

Level III-1: evidence obtained from well-designed pseudo-randomised controlled trials (alternate allocation or some other method)

Level III-2: evidence obtained from comparative studies (including systematic reviews of such studies) with concurrent controls and allocation not randomised, cohort studies, case-control studies, or interrupted time series with a control group

Level III-3: evidence obtained from comparative studies with historical control, two or more single arm studies, or interrupted time series without a parallel control group

Level IV: evidence obtained from case series, either post-test or pre-test/post-test

This hierarchy of evidence has been supplemented by a series of seven handbooks available on the NHMRC website which have refined and developed the hierarchy.[9] The handbooks help to explain the nature of the available evidence in terms of the likelihood that the evidence can be safely applied to the particular setting of the clinician.

The systematic review process as used in healthcare was developed by researchers based in the United Kingdom and was formalised when the Cochrane Collaboration commenced in 1992. The Cochrane Collaboration established a systematic review process which has been developed and refined over the intervening years as outlined below.[10]

Systematic reviews have been designed to apply a transparent and reproducible method to the search for evidence and the analysis of the evidence found. A systematic review follows a series of rules. The search strategy must be developed to ensure that all the available evidence is found based on a predetermined protocol. The search strategy is precisely defined and must be reproducible. The protocol sets out the population of interest and establishes the boundaries of the review. The timeframe is developed and the interventions of interest are precisely defined. The outcome measures are explained and the measurement instruments identified. The parameters and time frames of the search are defined and inclusions and exclusions stated and explained. Decisions about what level of evidence will be included in the review are made and the rationale for these decisions elucidated.

Once the search has identified all the papers of interest each paper is critically appraised by two researchers independently of each other, using predetermined critical appraisal instruments. The results of the critical appraisal are made available as part of the systematic review report. This is intended to ensure that only papers of sufficient methodological quality are included in the review. This is an important aspect of the systematic review process as this protects against the analysis of results that may be biased due to methodological flaws.

The results of each of the included papers are extracted and these results analysed and synthesised according to a predetermined set of rules. Where data can be analysised this is done according to statistical rules that consider the heterogeneity of the evidence and the effect size. The results of this meta-analysis provide evidence which can be used to assist with decision making in clinical practice.

The Joanna Briggs Institute is a major international agency for guiding evidence based healthcare. It has developed a Reviewers Manual to guide

the reviewer through this process.[11] In addition it has developed tools including Joanna Briggs Institute Meta Analysis of Statistic Assessment and Review Instrument (JBI-MAStARI),[12] System for the Unified Management, Assessment and Review of Information (SUMARI) and the Comprehensive Review Management System (CReMS).[13] These manuals and tools have been developed to assist and guide the reviewer through the systematic review process. These tools and guides were used throughout this systematic review to ensure that a transparent and reproducible process was followed.

1.6 Discussion of the methodological basis of the chosen approach

When preparing to undertake this systematic review, most of the available literature was found to be based on case series. A small number of cohorts were identified and only one randomised controlled trial. The decision to include all three research types in the systematic review was based on the premise that case series can provide useful information to guide future research, even if the case series themselves cannot provide definitive guides to treatment choices.[8] Excluding case series would have limited the usefulness of the thesis findings to clinicians as information about the many treatment options that had been described in the literature would not have been presented. The case series findings are presented in table form in the results section.

Data analysis using MASTARI could not be used on case series as these lacked a comparator. Data analysis could not be used on the RCT as it was a single study. The data analysis consequently used data only from the cohorts.

1.7 Key concepts and definitions of terms

Compartment: enclosed or confined anatomic space[14]

Compartment syndrome: a condition in which increased pressure in a confined anatomic space adversely affects the circulation and threatens the function and viability of the structures therein[14]

Dermotomy: incision through the dermis[14]

Decompression: removal of pressure[14]

Fascia: A sheet of fibrous tissue that envelops the body beneath the skin; it also encloses muscles and groups of muscles and separates their several layers or groups[14]

Fascial: pertaining to the sheet of fibrous tissue

Fasciotomy: incision through the fascia[14]

A surgical incision is made through the fascia to release pressure inside the compartment. A limb fasciotomy can involve between one and four incisions. The length of each incision will vary depending on the limb length but can be more than 30 cms long. Once the incision has been made the wounds usually bulge open due to swelling and oedema

Oedema: swelling from an accumulation of fluids in cells, tissues or cavities[14]

Quantitative research: research that can be measured using empirical data[10]

Systematic review: A systematic review that attempts to identify, appraise and analysise all the empirical evidence that meets pre-specified eligibility criteria to answer a given research question[10]

Tissue necrosis: death of skin or tissue[14]

Wound dehiscence: disruption of apposed surfaces of a wound[14]

Chapter 2: The systematic review protocol

2.1 Introduction

The chapter sets out the protocol for this systematic review. It describes compartment syndrome, fasciotomy and wound management options. It explains the reason for the systematic review and sets out the protocol that contains the review framework. This conceptual framework underpins the rigor of the review and adheres to the requirements of the Joanna Briggs Institute.

The chapter explains the search strategy and critical appraisal process, sets out the results of these and discusses the data analysis used.

2.2 Review question and objectives

The overall objective of this review was to identify the best available evidence on the effectiveness of treatment options for managing fasciotomy wounds acquired due to treatment for acute compartment syndrome in the limbs.

More specifically, the systematic review question was:

What is the effectiveness of different treatment options for managing a fasciotomy wound on outcomes such as time to primary wound healing, percentage of patients who need skin grafts to effect closure of the wound and length of stay in hospital following the fasciotomies, in patients with acute compartment syndrome of the limb(s)?

2.3 Background

Compartment syndrome of the limbs can occur in patients following limb trauma such as fractures or crush injuries, or following reperfusion after arterial blockage. Acute compartment syndrome occurs because tissue damage or bleeding in the limb results in increased pressure within the physically confined space or compartment.[15] The increase in local pressure reduces the blood flow into and out of the compartment, resulting in muscle ischaemia, and in the absence of treatment, muscle damage and tissue death. Once the pressures in the compartments rise within 30 mmhg of the diastolic blood pressure,[16, 17] the only definitive treatment is fasciotomy, cutting down into the compartments to relieve this pressure.[6] Fasciotomy must be performed without delay once the diagnosis of compartment

syndrome is made to prevent serious adverse events such as amputation and death. [6, 18] The fasciotomy wounds created must be left open until the swelling has reduced enough to allow for closure of the wounds.[2]

The resulting wounds can have a number of effects on the patient experience, both short and long term. The wounds are large, painful, may become infected, may be slow to heal or require skin grafting to heal and may have long term consequences.[7] Long term consequences include both physical effects such as reduced limb strength, nerve, tendon or muscle damage, pain, scarring and ulceration, and psychological effects such as changes to behaviour and activity due to embarrassment about the physical appearance of the affected limb.[7] ,[19] ,[20]

Fasciotomy is also used as one treatment option for chronic limb compartment syndrome. Chronic limb compartment syndrome typically develops slowly and is not related to trauma. This systematic review did not include fasciotomies performed as an elective treatment for chronic compartment syndrome. This was due to the fact that these wounds can be closed immediately, and as such are not subject to the same wound healing challenges as pertain with acute fasciotomies.[21, 22]

Compartment syndrome has been extensively studied and a number of systematic reviews have been undertaken,[23-26] the latest published in 2011.[27] These systematic reviews have focused on the best available overall management of compartment syndrome including early identification, use of pressure monitoring and surgery options. Methods of management of the fasciotomy wounds themselves have been described in the reviews but the effectiveness of the various wound management options has not been systematically examined. The only systematic review that looked at fasciotomies as a separate topic described the outcomes following fasciotomies but did not relate this to the wound management treatment.[25] There is an identified gap in the literature on the best available evidence for the treatment of acute fasciotomy wounds.

Fasciotomy wounds must be left open long enough to ensure that the compartment syndrome has resolved. This makes the wounds more difficult to treat because the skin edges retract and can become fixed to the underlying muscle.[28]

Treatment for fasciotomy wounds initially comprised of basic wound care aimed at reducing the risk of infection, wound desiccation and recurrence of the compartment syndrome. Saline soaked gauze combined with light bandages was commonly used. A case series conducted in 1976 found that 77% of patients who had a fasciotomy which was not closed immediately required a skin graft.[6] A growing understanding of the negative impact of skin grafts on long term functionality led to the development of a range of techniques aimed at achieving wound closure without the need for grafting. These techniques have focused on ways to improve the chances of the wounds healing without skin grafting by applying tension to the wound to pull the wound closed in a controlled fashion over a period of days.

First Cohn[29] then Harris[30] then Berman[28] described a delayed primary closure technique involving skin staples and a 'shoelace'. Skin staples were attached on each side of the wound running parallel to the incision. Vessel loops were attached to the end staples then threaded through the staples, crossing back and forth across the wound in a similar fashion to a shoelace (hence the name). The wound edges were gradually drawn together over a number of days by tightening the vessel loops. This was reported to result in improved patient outcomes, including reduced time to definitive closure and reduced need for split skin grafting. Variations and modifications of this technique followed.[31-33] Various proprietary products were developed.[34, 35] More recently, Govaert described the use of Ty-raps® (cable ties) to enable staged closure while avoiding some of the pitfalls of the commercially designed devices (including availability and cost) which had become available.[36] Chiverton described variation involving subcutaneous sutures.[37] Vacuum assisted closure of fasciotomy wounds started to be used either alone or in combination with other closure devices with good initial results.[38, 39]

To date systematic reviews [23, 24, 26, 27] of compartment syndrome management have not identified a definitive treatment for fasciotomy wound management. This was partly due to the lack of any randomised controlled trials comparing different treatment options. Most of the available literature described quasi experimental designs such as case series. None of the systematic reviews attempted to synthesis the evidence that was available. Therefore the aim of the present systematic review was to synthesis the best

available evidence on the effectiveness of treatment options for managing fasciotomy wounds acquired due to treatment for acute compartment syndrome in the limbs following any injury except burns. Burn wounds were excluded because burns fundamentally alter the structure of skin and underlying tissue. Comparison of these cases with surgically inflicted fasciotomy wounds on otherwise normal tissue is not possible, as burn cases require a series of interventions specific to burns.

A search of the JBI library of systematic reviews, Cochrane library and PubMed found no systematic reviews on this exact topic.

2.4 Criteria for considering studies for this review

2.4.1 Types of Studies

The review considered for inclusion studies that used a quantitative design including; randomised controlled trials, non-randomised controlled trials, quasi-experimental, before and after studies, prospective and retrospectivecohort studies, case control studies and analytical cross sectional studies. The review looked for randomised controlled trials and non-randomised controlled trials first but also considered the lower levels of evidence due to the lack of higher level trials available.

2.4.2 Types of Participants

The participants of interest were patients of any age who had acquired a fasciotomy wound as a result of treatment for acute compartment syndrome of the limb occurring as a result of injury (excluding compartment syndrome resulting from burns), regardless of co-morbidities or severity of injury.

2.4.3 Types of interventions/phenomenon of interest

The review considered any human studies that evaluated the effectiveness of different treatment options for managing fasciotomy wounds. Types of treatment included wound management aimed both at optimising the health of the open fasciotomy wound to prevent deterioration before the wound was closed, and at achieving wound closure, including staged closure.

2.4.4 Comparators

The review considered as a comparator the usual care of fasciotomy wound or other treatments of the fasciotomy wound as defined by the studies where

comparators are relevant to the study type. The case series did not have comparators.

2.4.5 Types of outcome measures

This review considered studies that included some or all of the following outcome measures:

- Time to wound closure without skin grafting, measured in days between fasciotomy operation and wound closure.
- Time to wound closure where skin grafts have been used, measured in days between fasciotomy operation and wound closure.
- Rate of wound healing without need for skin grafting. The numerator being all fasciotomy wounds that required skin grafts to effect wound closure and the denominator all fasciotomy wounds included in the study cohort
- Degree of scaring measured by the width of the scar at the widest part of the fasciotomy wound in all fasciotomy wounds in the study cohort.
- Length of stay following fasciotomy measured by the number of days between fasciotomy surgery and discharge home for the study cohort. Patients who were discharged to a rehabilitation facility or other healthcare facility were excluded from this measure because of the wide variation in availability of these facilities as well as the wide variation in need for ongoing care depending on the severity of the original injury.
- Wound infection rates. The numerator being the number of fasciotomy wounds reported as infected due to presence of signs of infection and/or with positive bacterial growth from wound swabs and the denominator the total number of fasciotomy wounds in the study cohort.
- Wound dehiscence rates. The numerator being all fasciotomy wounds assessed as having dehisced and the denominator being all fasciotomy wounds.
- Neurological deficit rates. The numerator being the neurological deficits in the affected limb reported by the patients and the denominator all patients who had a fasciotomy performed in the study cohort. It is acknowledged that neurological deficits may result from

the primary injury, the compartment syndrome or the fasciotomy or any combination.

- Pain experienced by the patient as a result of the wound management options chosen.

2.5 Search Strategy

2.5.1 Search strategy

The search strategy aimed to find both published and unpublished studies. A three-step search strategy was utilised in this review. An initial limited search of MEDLINE and CINAHL was undertaken followed by analysis of the text words contained in the title and abstract, and of the index terms used to describe the article. A second search using all identified keywords and index terms was undertaken across all included databases. Thirdly, the reference list of all identified reports and articles were searched for additional studies. Studies published in English, with human subjects, from January 1960 to June 2012 were considered for inclusion. The commencement date was chosen due to the absence of any studies that evaluated the effectiveness of wound management techniques on fasciotomy wounds published prior to 1960.

2.5.2 Databases searched

The databases searched include:

- Medline
- CINAHL
- EMBASE
- Cochrane Central Register of Controlled Trials (CENTRAL)
- Database of Abstracts of Reviews of Effects
- Scopus

The search for unpublished studies included:

- Mednar
- Australian Digital Theses Program, The Networked Digital Library of These and Dissertations (NDLTD)
- Proquest Dissertations
- Index to Theses

- Conference proceedings from major international Orthopaedic and Plastic Surgery conferences

Initial keywords used were:

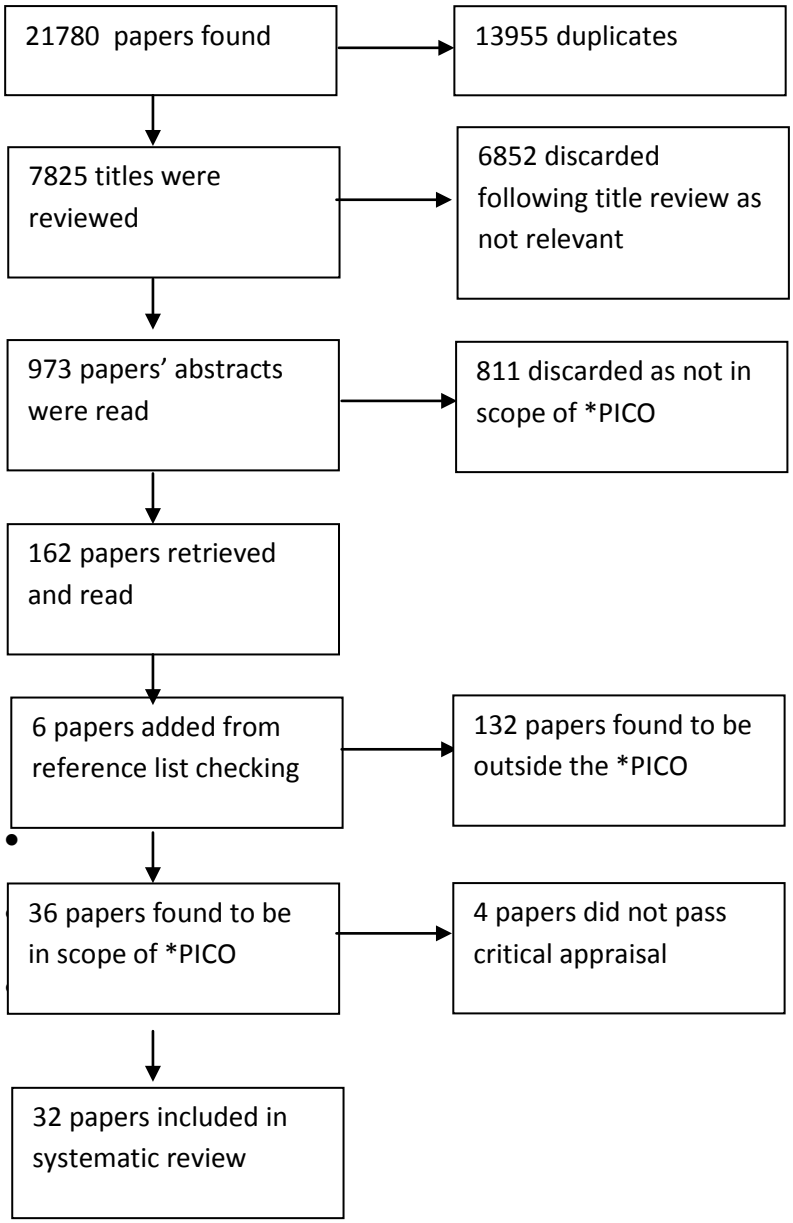
- anterior tibial syndrome
- compartment syndromes
- muscles
- muscular diseases
- ischemia
- fasciotomy
- fasciectomy
- Fascia and surgery
- Decompression surgery

The search strategy was developed with the assistance of an expert librarian. A grid of included terms was developed and used as the basis for the search in each of the included databases.

2.5.3 Search retrieval diagram

Figure 1 shows the search retrieval diagram.

Refer to the appendices for detailed information about the search.



*PICO: Population, Interventions, Comparators, Outcomes

Figure 1 Search retrieval flow diagram

2.6 Assessment of methodological quality/critical appraisal

Papers selected for retrieval were assessed by two independent reviewers for methodological validity prior to inclusion in the review using standardised critical appraisal instruments from the Joanna Briggs Institute Meta Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI). Refer to appendices for details. Disagreements that arose between the reviewers were resolved through discussion. In one case a third reviewer was consulted to assist with the resolution. As this systematic review was submitted towards the award of Master of Clinical Science, a secondary reviewer was used only for critical appraisal.

2.7 Data extraction

Data was extracted from papers included in the review using the standardised data extraction tool from JBI-MAStARI. Refer to appendices for details. The data extracted included specific details about the interventions, populations, study methods and outcomes of significance to the review question and objectives.

2.8 Data Analysis

Quantitative data was pooled where possible in statistical meta-analysis using JBI-MAStARI. All results were subject to double data entry. Effect sizes expressed as odds ratio (for categorical data) and their 95% confidence intervals were calculated for analysis. Heterogeneity was assessed statistically using the standard Chi-square and also explored using subgroup analyses based on the different study designs included in this review. Where statistical pooling was not possible the findings were presented in narrative form including tables and figures to aid in data presentation where appropriate.

Chapter 3: Results

3.1 Introduction

The chapter contains detailed descriptions of the studies included in the systematic review, the methodology used in the studies, the results and the meta-analysis undertaken. The chapter explains the characteristics of each of the three main types of methodologies used and details the specifics of each type, and the impact of each, on the rigor of the research results. The results of each study are presented in detail together with the methodological issues, including any flaws detected in each paper. Finally the meta-analysis of results from the suitable studies are presented and explained.

3.2 Description of studies

The section provides an overview of the studies found, when and where they were published and the study types. The three major study types found are introduced and an overview of the studies found in each presented.

3.2.1 Overview of studies

The systematic review found 32 studies that fit the protocol and that passed critical appraisal. The critical appraisal tool used and the details of each critical appraisal can be found in the appendices. The studies found consisted of:

1 randomised controlled trial.

8 cohort studies, 2 prospective and 6 retrospective.

23 case series, 19 prospective, 3 retrospective and 1 unclear.

Figure 1 below shows the spread of the years of publication of the papers included in the systematic review. This illustrates there has been an increase in papers published over the past 7 years, with half the included papers having been published since 2005. The overall number of papers however remains small, especially given the exponential increase in total research papers in general over the same time period.

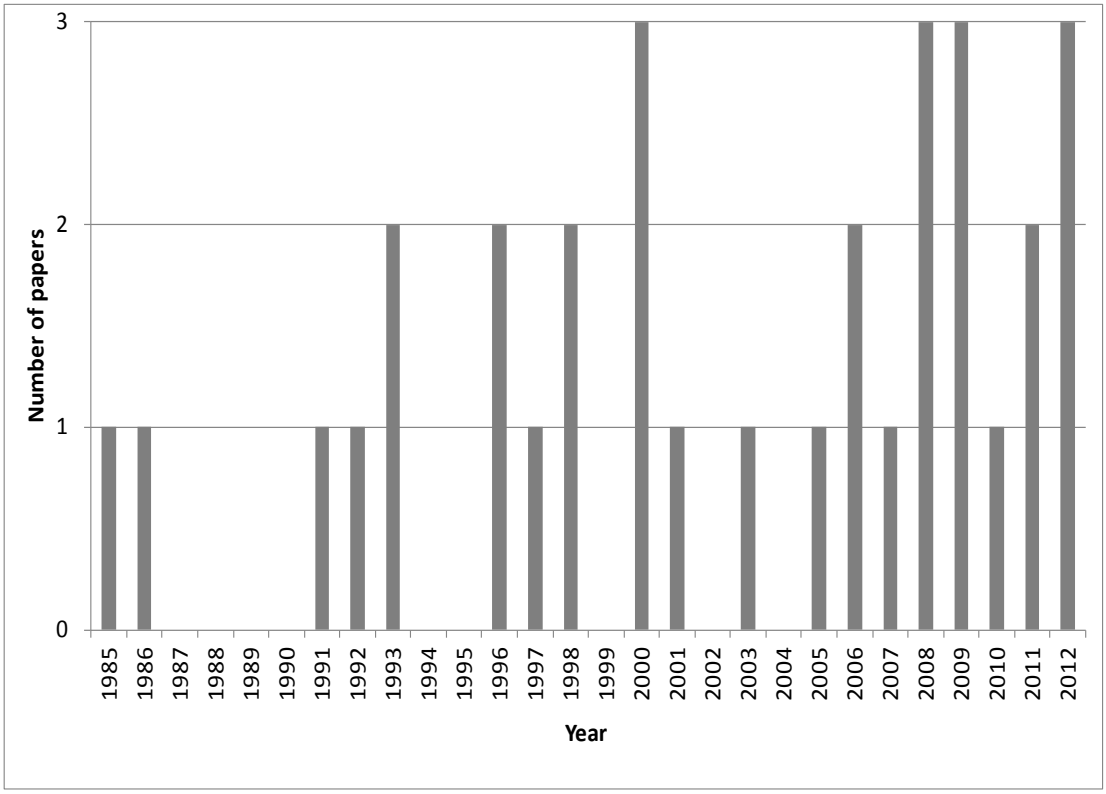


Figure 2: Spread of years of publication of papers included in systematic review

Table 1 below shows which journals published the papers included in the systematic review. This illustrates the variety of publications and sub specialties involved with the research including orthopaedic, vascular and plastic surgery. The significance of this with regard to the body of research is further explored in the discussion chapter.

Table 1: Journals that published papers included in systematic review

Journal	**Papers included in systematic review**
Injury	5
American Surgeon	3
Journal of Orthopaedic Trauma	3
American Journal of Surgery	2
Annals of Plastic Surgery	2
Journal of Trauma	2
Acta Orthopaedica Scandinavica	1
Annals of Vascular Surgery	1
Annals of the Royal College of Surgeons of England	1
Bone and Joint Research	1

Journal	Papers included in systematic review
Hand (New York)	1
International Wound Journal	1
Journal of the American College of Surgeons	1
Journal of Plastic, Reconstructive and Aesthetic Surgery	1
Journal of Surgical Orthopaedic Advances	1
Journal of Vascular Surgery	1
Journal of Cardiovascular Surgery	1
Journal of Trauma - Injury, Infection and Critical Care	1
Military Medicine	1
Orthopedics	1
Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery	1

Figure 3 below shows the worldwide distribution of research with Europe and USA accounting for close to 80% of the papers

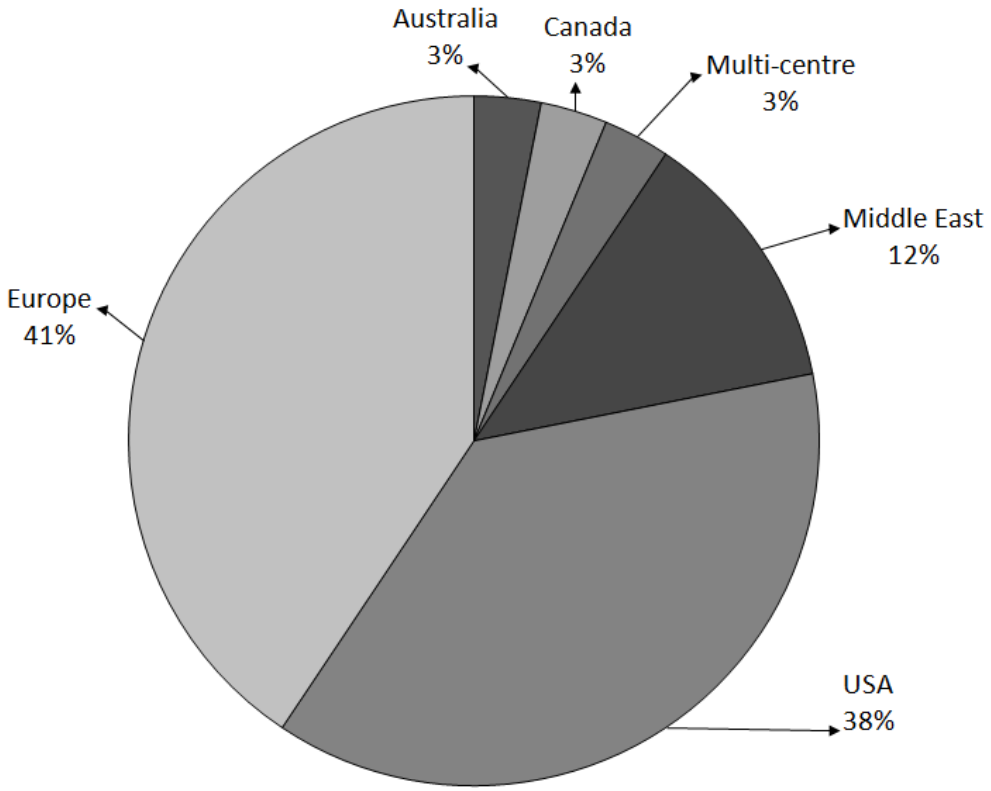


Figure 3: Worldwide distribution of research

Table 2 below shows the locations of the research covered in the papers included in the systematic review. This table illustrates the spread of the research and shows that there was no single place focused on researching this aspect of patient care.

Table 2: Location of research included in systematic review

Location	Research study locations
Baghdad, Iraq	1
Real, Spain	1
New York, USA	1
Athens, Greece	1
Plymouth, UK	1
Miami, USA	1
Tabuk, Saudi Arabia	1
California, USA	2
Maastricht, The Netherlands	1
Ohio, USA	1
Doncaster, UK	1
Odense, Denmark	1
Ottawa, Canada.	1
Connecticut, USA	1
Goteborg, Sweden	2
Arizona, USA	1
Beer-Sheva, Israel	1
Tel Aviv, Israel	1
Philadelphia, USA	2
London, UK	1
Geneva, Switzerland	1
Leuven, Belgium	1
Tubingen, Germany	1
Tuebingena and Stuttgart, Germany; and Chicago, USA	1
North Carolina, USA	2
Washington DC, USA	1
Canberra, Australia	1
Zurich, Switzerland	1

3.2.2 Randomised controlled trial study

This section describes the nature of the randomised controlled trial design in general and introduces the randomised controlled trial included in this review.

The Joanna Briggs Institute Comprehensive Review Management System (CReMS) for conducting systematic reviews places randomised controlled

trials second on the hierarchy of scientific evidence after systematic reviews.[40] As noted in chapter one this accords with other hierarchies used by the Cochrane Collaboration[41] and the National Health and Medical Research Council.[42] The most rigorous randomised controlled trial (RCT) design includes a double blind component which blinds both the participants and the researchers to the intervention being studied. This blinding ensures that both the reaction to the treatment by the participant and the assessment of the treatment by the researcher is not affected by preconceived ideas about the likely effects of the intervention. RCT design is also intended to reduce the likelihood that participant selection might bias the outcomes by randomly assigning participants to either the treatment arm or the control arm of the experiment. There are several ways to randomise. These include the use of a random number generator, tossing a coin, using a computer program, block randomisation, among others.[43, 44]

The systematic review search found a single randomised controlled trial by Kakagia et al published in 2012.[45] The study compared two wound treatments with each other. It involved 25 participants in each treatment arm. All participants developed compartment syndrome of the lower leg following either leg fractures or blunt trauma and all required one or more fasciotomies. Patients were randomised into one or other group using a random number generator. A random number generator is viewed as a reliable method of randomisation by the Cochrane Handbook for Systematic Reviews of Interventions.[41]

The two treatment choices were Vacuum Assisted Closure® (VAC) or shoelace technique. The VAC group contained 25 patients with 42 fasciotomy wounds and the shoelace technique group had 25 patients with 40 fasciotomy wounds. VAC is a wound treatment which was originally developed to manage large exudative wounds in vascular and plastic surgery.[46] The wounds were covered with polyurethane foam, the wound edges sealed and a negative pressure maintained over the wound surface using a vacuum pump.[47]

The shoelace technique involved placing staples along both wound edges, threading silastic vessel loops through the staples and tying these in a shoelace fashion across the wound. Tension was applied across the wound using the vessel loops and the wound edges gradually drawn together. As

outlined in Chapter two, this technique was originally described by Cohn in 1986,[29] and variations and refinements have been described since.[31-33, 48] The technique is also referred to in the literature as vessel loop shoelace technique.

In Kakagia's paper the VAC treatment was applied between 3 and 6 days after the initial fasciotomy and the negative pressure was continuously maintained at 125 mmHg.[45] The shoelace technique treatment was applied on the day of the fasciotomy but no tension was applied until after the oedema had settled, between 4 and 6 days post operatively. Kakagia's paper does not state a reason for this delay but others have identified the potential problem of recurring compartment syndrome associated with applying tension before the oedema has settled.[28, 30, 49]

The detailed results of the RCT are outlined later in this results chapter.

3.2.3 Cohort studies

This section describes the nature of cohort study designs in general, explains the differences between prospective and retrospective designs and introduces the cohort studies included in this review.

Cohort studies are placed third on the hierarchy of evidence. Cohort studies do not involve a double blind randomisation process although cohort studies can endeavour to reduce selection bias in various ways, including by selecting all the patients presenting with a particular characteristic or illness during a specified time period. Cohort studies can be prospective or retrospective. Prospective studies may have a more rigorous methodology due to the greater ability to control for selection bias. Retrospective studies usually involve review of casenotes. No control can be exerted on the treatment decisions, and information about why treatment decisions were made may not be available.[8] This limits the opportunity to generalise results from the specific study population.

3.2.3.1 Prospective cohort studies

The systematic review included 2 prospective cohort studies, by Labler, et al[50] and Janzing and Broos.[32]

Labler's paper compared the use of VAC dressing and Epigard® dressing on soft tissue wounds. Epigard is a two-layer wound dressing which has

similar properties to human skin and is also known as synthetic skin substitute.[51] The upper layer is made of Teflon. This is permeable to air but waterproof and impermeable to bacteria. The lower layer is made from polyurethane. It adheres to the wound and therefore produces mechanical debridement of the wound when removed.

Thirty-two patients were divided between the two treatment arms. Only 13 of these patients had fasciotomy wounds resulting from treatment for compartment syndrome. As this systematic review is concerned only with the wound care of fasciotomy wounds information about the other patients involved in this study was excluded. Of these 13 patients, 6 were treated with VAC dressings and 7 with Epigard

Labler also examined the nature and constituents of the exudate generated by each wound dressing in order to determine the impact on local inflammation, to measure wound cytokine levels and assess for neovascularisation.[50]

The cohort study selected patients prospectively as they presented to the hospital with traumatic wounds. The selection of VAC or Epigard was made by the treating surgeon. The paper does not explain the reasoning behind the surgeon selection therefore selection bias cannot be excluded.

Janzing and Broos compared three techniques, the vessel loop technique, the Marburger Skin Approximation System® and the prepositioned intracutaneous suture. There were 5 patients in each treatment arm.[32]

The vessel loop technique used was the same as the shoelace technique previously described. The vessel loops and staples were placed at the time of the fasciotomy but no traction was applied until the initial oedema had reduced between 3 and 5 days following the operation. The vessel loops were progressively shortened until the wound edges were close enough together to allow for final suturing.

The Marburger Skin Approximation System involved plates which were fixed at each side of the wound with staples and connected with a Ticron® suture (Tyco, Mechelen, Belgium). In similar fashion to the vessel loop system above, traction was progressively applied to the suture after the

wound swelling had diminished, between 3 and 5 days after the fasciotomy. The skin approximation system plates and Ticron suture were removed and the wound sutured closed once the skin edges were close enough together.

The prepositioned intracutaneous suture was placed loosely without applying traction to the wound edges at the time of the fasciotomy. A Novafil 1® suture (Tyco, Mechelen, Belgium) was used with the addition of a Mepitel® wound dressing to protect the wound surface. As with the other two wound options, traction was applied between 3 and 5 days post fasciotomy. In most patients, a second operation was not necessary because the wounds could be closed using the prepositioned intracutaneous suture either alone or with the addition of Steri-strip® (3M, Diegem, Belgium).

In each of the three treatment arms the patients were checked regularly to ensure there was no recurrence of symptoms of compartment syndrome.

No information about the selection of patients into each of the three treatment arms was provided therefore selection bias cannot be excluded.

3.2.3.2 Retrospective cohort studies

There were 6 retrospective cohort studies included in this review. Saziye et al[52], Yang et al[38] and Zannis et al[39] all investigated the use of VAC dressings on fasciotomy wounds.

Saziye's paper described 15 patients who had a fasciotomy due to ischaemic reperfusion syndrome over 6 years. Seven were treated with VAC and 8 with wet to dry saline soaked gauze. No information was provided about how patients were selected for each treatment.

Yang's paper described 34 patients who developed compartment syndrome due to trauma and who were treated with VAC dressings. They were retrospectively identified and treatment was by surgeon preference. They were matched with 34 patients who received standard treatment with saline soaked gauze.

In Zannis's paper 458 patients were identified retrospectively over 10 years. Patients developed compartment syndrome due to multiple aetiologies including trauma and ischaemic injuries. The fasciotomy wounds were treated either with VAC dressings or wet to dry gauze dressings and selection was surgeon preference.

Matt et al[53] retrospectively reviewed 227 patients who had fasciotomies for compartment syndrome due to a mixture of trauma and vascular injuries. The wounds were treated either with wet to dry gauze (n = 148), VAC (n = 55) or dynamic wound closure (n = 24). Treatment was selected according to surgeon preference.

The specific technique of dynamic wound closure was not described in the paper. The paper included an example of a dynamic wound closure type as follows. "Dynamic tension, an example of which is the 'Jacob's ladder,' is a well described technique whereby elastic bands (Vessel loop, Bard, Crawley, England) are serially crossed over the wound in a manner similar to shoelaces and secured at one end. These bands are progressively tightened over the ensuing days until closure is achieved."[53](page 1656)

This paper included a graphical representation of how the wound management techniques chosen had changed at their institution between 2000 and 2009 with gauze dressings becoming less popular, dynamic wound closure gaining popularity in the middle years but becoming less popular as VAC dressings became increasingly used until 2008 at which point its use dropped off sharply. The paper did not provide any explanation for this decrease in use.

Medina et al[54] included all 14 patients over a 36 month period who had an upper extremity fasciotomy for compartment syndrome due to trauma or vascular injuries that could not be closed primarily. They were retrospectively identified. The Silver Bullet Wound Closure Device (SBWCD, Boehringer Laboratories, Norristown, PA, USA) was used to provide traction across the wound. This device consisted of a stainless steel cylinder which was sutured into the wounds using polypropylene sutures. Traction was applied by rotating the cylinder. In this paper, multiple devices were used in some

fasciotomy wounds. The paper compared the fasciotomy closure effectiveness between the Silver Bullet Wound Closure Device used in 8 patients and STSG used in 6 patients. Each patient decided on the treatment for themselves.

Fowler et al[55] retrospectively reviewed 56 patients who had fasciotomies for compartment syndrome due to a mixture of trauma and vascular injuries. The wounds were treated either with vessel loop shoelace dynamic wound closure (n = 49) or with VAC (n = 7). Treatment selection was by surgeon preference.

The detailed results of the cohort studies are outlined later in this results chapter.

3.2.4 Case series

This section describes the nature of the case series trial design in general and outlines the case series included in this review in particular.

Twenty three of the papers were case series. These varied in size from 2 patients to 53 patients. 19 of the case series were prospective, 3 were retrospective and 1 was unclear. Patient selection criteria were not clearly stated in 19 of the 23 cases. Case series usually do not set out to prove or disprove the effectiveness of a treatment option but they can contribute to the body of knowledge. They are rated as fourth in the hierarchy of scientific evidence but this varies depending on the scientific rigor of the case series design. Case series are typically used initially to test out new treatment modalities in a small patient population or to review the outcomes of usual practice or treatments in an existing patient population. Most of the case series included in this systematic review were small scale studies involving very few patients. As previously discussed, data from these studies cannot be accumulated into a meta-analysis due to the lack of a comparator.[8]

The case series papers included in this systematic review have a common purpose. The authors were all motivated by a shared understanding that management of compartment syndrome itself had improved but the life and limb saving treatment still left many patients with unsightly wounds. New wound management techniques that had been developed and reported did

not always result in outcomes that were acceptable to the patient and had not eliminated the need for split thickness skin grafts A study published in 2000 of the impact of fasciotomy wounds found that patients continued to suffer long term negative consequences, especially associated with the use of skin grafts to close wounds.[56] As discussed in chapter two, this study showed long term consequences included physical effects such as reduced limb strength, nerve, tendon or muscle damage, pain, scarring and ulceration, and psychological effects such as changes to behaviour and activity due to embarrassment about the physical appearance of the affected limb.

Most of the case series papers explicitly stated their intention was to reduce the rate of skin grafts required to close these wounds, and they expand on the negative consequences of their use including cosmetic problems, neurological deficits, psychological issues and negative impacts on lifestyle.

The detailed results of the case series are outlined later in this results chapter.

3.3 Methodological issues of included and excluded studies

This section considers the assessment of the methodological quality of included studies and explains the reasons for excluding studies that otherwise fit the protocol. This is an essential component of a systematic review because results should only be synthesised if the methodology is of sufficient rigor. The studies are considered separately, randomised controlled trial, cohorts, case series and the excluded studies.

3.3.1 Randomised controlled trial

Kakagia's[45] paper, as previously described, used a random number generator to randomise the patients into the treatment arms which is a reliable method. The paper did not state if participants were blinded to the treatment allocation, or if the allocation to treatment groups were concealed from the allocator, or if those assessing the outcomes were blind to the treatment allocation. Although this level of blinding is preferred at a theoretical level it is difficult to achieve in trials such as this where there is a physical difference between the two treatments that would be hard to conceal, if not impossible, in practical terms. In addition this level of blinding

is less important when the key outcomes can be objectively observed to occur such as the need for a split thickness skin graft to effect wound closure.[57]

There were no withdrawals from either treatment group. The characteristics of both groups were comparable at entry. The two groups were managed identically apart from the named interventions. The outcomes were measured reliably in both groups. Appropriate statistical tests were performed and analysed.

This paper was found to be methodologically sound and conclusions drawn from it as a result.

3.3.2 Cohort studies

Cohort studies are a less rigorous form of research than randomised controlled trials. The lack of randomisation into treatment arms means that selection bias cannot be ruled out and the findings have less reliability and validity than well planned RCTs. A prospective cohort study offers the potential to allocate patients randomly but neither of the papers included in this review did so. Janzing[32] provided no information about how allocation was decided and Labler[50] stated that the surgeon made the selection. This introduced the possibility of selection bias which reduced their reliability and validity. Both papers had small sample sizes, (15 for Janzing and 13 for Labler) which also limited the ability to generalise from them.

The 6 retrospective cohort studies could not make decisions about allocation as they were examining treatment cohorts that had already occurred. Medina's[54] paper introduced a new closure device called the Silver Bullet Wound Closure Device. The patients made the decision between two wound management options offered to them: the new device or a split thickness skin graft. The paper does not explain what information was provided to patients to assist them to make this decision. This, and the small sample size of 14 patients, limits the generalisability of the findings.

Saziye's[52] paper retrospectively identified 15 patients who were treated either with VAC dressings or with traditional gauze dressings. The characteristics of both groups were examined as part of the study to ascertain their homogeneity but no information about treatment selection decisions were included. This, and the small sample size, again limits the

generalisability of the results. However the two treatment types, VAC and gauze, are the same as in the papers by Matt, Yang, and Zannis and these results have therefore been included in the meta-analysis.

Fowler's[55] paper retrospectively identified 56 patients who were treated either with shoelace technique or with VAC dressings. Of the 56 patients, 49 were treated with shoelace technique and only 7 with VAC. The results of this study supported the findings in Kakagia's RCT. The small sample size in the VAC group also reduced the value of this study as a comparison.

Matt,[53] Yang[38] and Zannis[39] papers all used retrospective cohorts. In each case the retrospective study included all patients treated at their institutions over a long period of time. This reduced the danger of selection bias from an overall point of view although the selection of patients into the treatment arms remained at the discretion of the treating surgeon. The decision making process cannot be ascertained from these retrospective studies. The three studies included large cohorts of patients. Matt had 227, Yang had 68 and Zannis had 458 patients. These larger numbers increased the generalisability of their findings. All three papers have been included in the meta-analysis. The numbers used in the meta-analysis have included separate wounds where the data has been presented in this way. The issue of the variability in the way patients, wounds and outcomes have been counted is expanded later in this results chapter.

The data extraction from Zannis paper was complicated by the fact that Zannis described some wounds that were treated with both treatment options, (n = 96) and some wounds were not included in the paper's statistical analysis. The former group had to be excluded from the analysis as the outcomes could not be ascribed exclusively to one treatment. The latter group comprised of patients described as having a wound that closed by secondary intention. This was much more common in the gauze group than in the VAC group, (59 wounds versus 3 wounds). The problem with excluding these wounds from the analysis was that the treatment effect of the VAC versus the gauze appeared much higher as a result. Wounds that close by secondary intention typically granulate over the exposed wound surface then gradually shrink and pull together over time. Such wounds will result in scarring but closure may be achieved without the need for skin grafts.[58] Zannis's paper does not explain the outcomes of these wounds in this cohort

but appeared to make an assumption that the outcomes were not satisfactory by excluding them from the overall analysis. The author was contacted to request additional information about the secondary intention wounds but this data was not available.

3.3.3 Case series

Case series describe a single treatment and therefore cannot be statistically analysed to demonstrate validity or reliability and the results cannot be generalised. The 23 case series included in this systematic review do however provide information about treatment options and devices, and have been used to generate hypotheses that can then be tested in clinical trials. Kakagia's paper is an example of a trial that emerged from the observation that VAC dressings were being used to treat fasciotomy wounds without evidence about their effects on wound closure with or without the need for split thickness skin grafts.

Most of the 23 included case series papers had very small sample sizes. Only four papers had studied more than 20 patients. The average patient numbers were 16 and the median was 9. In some cases the case series included other wound types apart from fasciotomy wounds and these were excluded from the results. The results of the critical appraisal can be found in the appendices. The critical appraisal identified some methodological flaws in every paper but the flaws did not detract from the value of the data contained, within the limitations of case series.

The results of the case series appear later in the chapter.

3.3.4 Excluded studies

Four papers were excluded from the systematic review.

Boxer[58] was excluded because the criteria for inclusion in study was not defined and no length of stay recorded.

Harrah[33] was excluded because the paper described the technique but did not provide sufficient results data.

Heemskerk[51] was excluded because the outcomes of interest were not clearly defined.

Schwartz[59] was excluded because wound management was not the main focus of the paper and most outcomes of interest were not documented.

3.4 Review Findings/Results

This section discusses the outcomes of interest and the issues identified during the extraction of these outcomes. The wound management methods from each study are presented and categorised. The results from the randomised controlled trial and the cohort studies are presented individually and as a collation. The results of the case series are presented as a collation. The results from the RCT and the cohort studies were statistically analysed and where possible meta-analysised and these results presented.

3.4.1 Outcomes of interest

The protocol for the systematic review included nine possible outcomes of interest. None of the included papers provided information about all of these outcomes. Each of the outcomes provided a range of challenges when attempting to collate results. One of the biggest challenges was the variation between whether results were presented per patient or by individual fasciotomy wound. Compartment syndrome must be relieved by fasciotomy but the number of individual fasciotomy wounds created varies between one and four per limb. Some papers described closure in terms of the individual wounds, some by individual patients, some defined closure as the time to closure of the worst wound and some did not specifically state how this difficulty was addressed. The other details of the issues encountered are set out after each outcome below. In the detailed results, the number of individual wounds has been used where this information was provided. In all other cases the number of patients was used.

Time to wound closure without skin grafting, measured in days between fasciotomy operation and wound closure.

This outcome was recorded in 22 of the included papers. Where this outcome was recorded, some papers provided average length of time in days with standard deviation included, some provided average length of time in days with a range included and some only provided the average. The

definition of wound closure was not specifically stated in some papers. Some papers separated time to primary closure from time to closure involving split thickness skin graft but some papers rolled this data together. This outcome was either not recorded at all or could not be ascertained specifically for fasciotomy wounds in 10 of the 32 included papers.

Time to wound closure where skin grafts have been used, measured in days between fasciotomy operation and wound closure.

The outcome was recorded in 22 of the included papers. The way this was recorded varied between papers in the same way as in the days between fasciotomy and wound closure above. This outcome was either not recorded or could not be ascertained specifically for fasciotomy wounds in 10 of the 32 included papers.

Rate of wound healing without need for skin grafting. The numerator will be all fasciotomy wounds that require skin grafts to effect a definitive wound closure and the denominator will be all fasciotomy wounds included in the study cohort

The outcome was described in all papers. In two papers the calculation of the rate of wound healing did not include all the original cohort of patients.[39, 60] In both cases patients who healed by secondary intention were not included in their published analysis.

Degree of scaring measured by the width of the scar at the widest part of the fasciotomy wound in all fasciotomy wounds in the study cohort

This outcome was not well described. Most papers did not measure the scar. Many papers mentioned the scar in the discussion but did not include details about the scars in the actual results. Some papers included photos of some of the scars. Patients' responses to their scars were recorded in some papers. Imprecise terms were commonly used such as "subjectively satisfied with scar", "cosmetic closure", "good aesthetic outcome" and "completely healed". Some papers suggested that the scarring achieved by some wound management methods was acceptable but did not provide measures or

photos to support these assertions. The benefits of avoiding split thickness skin graft was mentioned in most papers and some papers suggested that successful avoidance of a skin graft equated to an acceptable scar without providing evidence of this.

Length of stay following fasciotomy measured by the number of days between fasciotomy surgery and discharge home for the study cohort. Patients who are discharged to a rehabilitation facility or other healthcare facility will be excluded from this measure because of the wide variation in availability of these facilities as well as the wide variation in need for ongoing care depending on the severity of the original injury

Total length of stay was recorded in 7 of the 32 papers. Length of stay following the fasciotomy was recorded in 4 of the 32 papers.

Wound infection rates. The numerator will be the number of fasciotomy wounds reported as infected due to presence of signs of infection and/or with positive bacterial growth from wound swabs and the denominator will be the total number of fasciotomy wounds in the study cohort

Wound infection rates were recorded in 24 of the included papers but the definition of wound infection was variable, and in some papers not provided at all.

Wound dehiscence rates. The numerator will be all fasciotomy wounds assessed as having dehisced and the denominator will be all fasciotomy wounds

Wound dehiscence rates was recorded in 7 papers, mentioned as a potential problem without providing data in 2 papers and not recorded in 23 papers.

Neurological deficit rates. The numerator will be the neurological deficits in the affected limb reported by the patients and the denominator will be all patients who had a fasciotomy performed in the study cohort. It is

acknowledged that neurological deficits may result from the primary injury, the compartment syndrome or the fasciotomy or any combination.

Neurological deficits were recorded in 9 papers. There was no standardised approach to how this was measured. Subjective patient statements were the most common method with terms used such as “numbness” of varying degrees, “impaired sensation” and “muscle weakness”. In some cases the papers stated that the aetiology of the neurological deficits could not be differentiated between the original injury and the fasciotomy for compartment syndrome. Neurological deficits were not recorded at all in 23 papers.

Pain experienced by the patient as a result of the wound management options chosen

Pain was mentioned in 11 papers. Only one paper used a pain assessment tool. Some papers mentioned reduced analgesia requirements as a measure of pain. Some referred to the need to change dressings under a general anaesthetic without specifying the reason for this. Pain was not recorded at all in 21 of the 32 papers.

Psychological impact

Psychological impact of the wound management technique was not recorded in any paper.

Additional outcome – wound necrosis

Some papers included information about wound necrosis. The protocol for this systematic review did not include this outcome as it was not anticipated, but it has been included in results as it was felt to be relevant to the effectiveness of some wound management techniques.

3.4.2 Categorising wound management methods

This section discusses various ways to categorise wound management methods and introduces the method used in the thesis.

When considering the wound management methods used on fasciotomy wounds, no standardised method of characterising the methods could be

identified. Different papers used different terms for the same method. For example Kakagia divides the wound methods into four types:[45]

- Dynamic dermatotraction devices including commercial products such as Sure-Closure, Suture Tension Adjustment Reel, Canica dynamic wound closure device and Wisebands.
- Static tension devices including Steri-Strips or plaster strips.
- VAC dressings for negative pressure therapy.
- Gradual suture approximation techniques including vessel loop shoelace techniques.

Kakagia did not explain this categorisation method. The categorisation also did not include the traditional saline soaked gauze.

Taylor et al[61] described how the biomechanical characteristics of skin had been exploited by many of the delayed primary closure devices developed to manage fasciotomy wounds. This paper called all these devices 'dynamic' closure devices.

Medina et al[54] used a similar characterisation to Kakagia with the addition of secondary intention closure.

In the absence of an established standard this analysis categorised wound management techniques into five types.

The first type was called 'dynamic' (DYN). This category included all the wound management techniques that used any kind of force to draw or pull the wound edges together, using the biomechanical characteristics of skin. This included various commercial dermotraction devices, sutures, plasters, steri-strips, vessel loops, subcutaneous sutures, Ty-raps and elastic bands.

The second type was called 'static' (STAT). This category included all the wound management techniques that aimed to protect the wound and wound surface but did not use any other force. These included saline soaked gauze.

The third type was called 'negative pressure wound management' (NPWM). This included the commercial product called Vacuum Assisted Closure system. Papers that use this commercial product typically use the abbreviation VAC and this abbreviation is commonly used to describe this technique regardless of the actual product used. However the term 'negative

pressure wound management' accurately describes the technique without the need to use a term which is a trademark. 'Negative pressure wound management' was categorised separately from both 'dynamic' and 'static'. This was due to the unique characteristics of the 'negative pressure wound management' system. The system did use force on the wound but the force was not intended to draw the wound together. The force was designed to draw exudate away from the wound. Categorising this method of wound management as a 'dynamic' type of technique described above would remove the opportunity to collate the results from these studies separately. It is also worth noting that the widespread use of the 'negative pressure wound management' system is relatively new, following the work of Argenta and Morykwas published in 1997.[46]

The fourth type was called 'miscellaneous' (MISC). The two main wound management methods included here are multiple relaxing skin incisions described by Distasio in 1993[62] and closure by secondary intention. The latter happens over a period of time when delayed primary closure has failed and skin grafting has not been used to achieve closure.

The fifth type was called 'split thickness skin graft' (STSG). STSG is usually used when the wound could not be closed by any other method. However some papers[54, 60] describe choosing STSG as a primary wound management technique therefore this needed to be included amongst the wound management techniques.

Table 3 below shows the wound management techniques used and the number of papers that included each technique. This table illustrates the high number and variety of different techniques. It also shows that many techniques have only had a single paper published about them for the cohort of patients with fasciotomy wounds following compartment syndrome.

Table 3: Wound management techniques studied

Wound management technique studied	Number of papers
Vacuum Assisted Closure®	8
Vessel loop shoelace	8
Saline soaked gauze	4
Canica dynamic wound closure device®	2
External Tissue Extension (ETE)® dermotraction	2
Split thickness skin graft applied at the time of fasciotomy	2

Wound management technique studied	Number of papers
Mesh skin graft applied at same time as fasciotomy	1
Epigard®	1
Silicon sheet over wound with drain	1
Vacuum Assisted Closure® and hyperbaric oxygen	1
Multiple small incisions in the skin, parallel with the primary wound	1
Intracutaneous suture	1
Marburger skin closure®	1
Metal rod and opsite wound closure device	1
Shoelace technique and other dynamic closure techniques	1
Silicone sheet combined with gradual tightening using a suture running the length of the wound	1
Silver Bullet Wound Closure Device®	1
STAR, (Suture Tension Adjustment Reel)® mechanical skin closure device	1
Subcuticular prolene® suture running the length of the wound	1
Ty-raps® to effect dynamic wound closure	1
Vessel loop shoelace varient	1
Wire sutures placed across the wound and tightened as the wound swelling reduced	1
Wiseband® skin and soft tissue stretching device	1

Table 4 below shows the wound management techniques as categorised in the thesis and the number of papers that included each technique.

Table 4: Wound management techniques as categorised in this thesis

Category	Count
DYN	24
NPWM	9
STAT	6
STSG	3
MISC	1

3.4.3 Results from the randomised controlled trial

Kakagia et al[45] randomly assigned patients into 2 groups with 25 patients in each group. All patients developed compartment syndrome in their lower limbs following lower limb fracture or a blunt trauma. All patients underwent a fasciotomy to release the compartment pressures.

In group one, 25 patients had a total of 42 fasciotomy wounds. Negative pressure wound management (NPWM) using VAC was applied 3-6 days

after fasciotomy, using a pressure of 125 mmhg. Dressings were changed at the bedside every 3 days. Split thickness skin grafts were used in cases where the wound remained wider than 5cm when granulation tissue had reached the level of the skin.

In group two, 25 patients had 40 fasciotomy wounds. Dynamic closure (DYN) was applied using the shoelace technique. Staples were attached to both sides of the fasciotomy wound at the time of fasciotomy. At the same time silastic vessel loops were tied in shoelace fashion across the wound but no pressure or pull was exerted on the wound until the oedema had reduced between 4 and 6 days post fasciotomy. Gradual tightening across the wound occurred at the bedside each day until closure was achieved. The wounds were protected using standard wet dressings. Once the skin edges were close enough together the staples and vessel loops were removed the wound allowed to epithialise over the next 2-3 days.

Table 5 below shows the detailed results

Table 5: Results from Kakagia's randomised controlled trial[(45)]

Outcome of interest	**Results NPWM**	**Results DYN**
Wound management	Vacuum assisted closure	Shoelace technique
Total wounds	42	40
Average days between fasciotomy and closure of wound	19.1	15.1 (P = 0.001)
Range in days	Not stated	Not stated
Standard deviation	6.1	3.8
Number of wounds healed without a graft	36	40
Number of wounds needed grafting	6	0 (P = 0.06)
Percentage healed without STSG	85.71%	100%
Pain as a result of wound management chosen	Not stated	Not stated
Length of stay in hospital total	Not stated	Not stated
Length of stay in hospital following fasciotomy	Not stated	Not stated
Degree of scarring at widest part	All 5 patients who had a STSG said they would consider scar	All patients with skin edge approximation evaluated the result as satisfactory

Outcome of interest	Results NPWM	Results DYN
	revision in future	
Wound infection	6	4
Wound dehiscence	None	None
Neurological symptoms	Not stated	Not stated
Psychological impact	Not stated	Not stated

The difference between time to closure was described as significantly longer in the VAC group than the shoelace group. (P = 0.001, CI 95%, 1.8 – 6.3). The difference between closure rates without the need for a STSG was 85.76% in the VAC group and 100% in the shoelace group. This difference was described as not reaching statistical significance (P = 0.06).

This paper also measured the relative costs of treatment between the two treatment groups and found the average daily costs of VAC was 135 Euros compared with 14 for the shoelace option. The authors concluded that VAC and the shoelace technique were both safe, reliable and effective methods for closure of leg fasciotomy wounds. They asserted that VAC required longer to achieve definitive wound closure and was considerably more expensive than the shoelace technique, especially when additional skin grafting was required.

The Kakagia paper was analysed for the thesis using on-line software.[63] Odds ratios and Fisher exact test were calculated. Table 6 below shows the 2 by 2 table used.

Table 6: Statistical 2 x 2 table for Kakagia's paper[45]

	STSG	Delayed primary closure	Total
Shoelace	0	40	40
VAC	6	36	42
Total	6	76	82

Only 6 participants in the Kakagia paper required a split thickness skin graft to achieve wound closure, but notably they all belonged to the VAC treatment group, a difference which was statistically significant (p = 0.026, two sided Fishers exact test). The odds ratio, estimated by adding 0.5 to

each cell, was 0.069 (95% CI 0.004, 1.274), and no longer reached statistical significance. The odds ratio for requiring a split thickness skin graft in the VAC group was 14.4 (95% CI 0.785 to 265.0744). Therefore the results of this small study are suggestive, rather than conclusive, that the risk of requiring a split thickness skin graft to achieve wound closure is substantially lower with shoelace treatment than with VAC treatment.

3.4.4 Results from the cohort studies

This section sets out the results of each of the cohort studies individually.

Janzing and Broos[32] compared the vessel loop shoelace technique, the Marburger Skin Approximation System® and the prepositioned intracutaneous suture with each other. There were 5 patients in each treatment arm.

The vessel loop shoelace technique used was the same described previously. The vessel loops and staples were placed at the time of the fasciotomy but no traction was applied until the initial oedema had reduced between 3 and 5 days following the operation. The vessel loops were progressively shortened until the wound edges are close enough together to allow for final suturing.

The Marburger skin approximation system involved plates which were fixed at each side of the wound with staples and connected with a Ticron® suture (Tyco, Mechelen, Belgium). In similar fashion to the vessel loop system above, traction was progressively applied to the suture after the wound swelling had diminished, between 3 and 5 days after the fasciotomy. The skin approximation system plates and Ticron suture were removed and the wound sutured closed once the skin edges were close enough together.

The prepositioned intracutaneous suture was placed loosely without applying traction to the wound edges at the time of the fasciotomy. A Novafil 1® suture (Tyco, Mechelen, Belgium) was used with the addition of a Mepitel® wound dressing to protect the wound surface. As with the other two wound options, traction was applied 3 to 5 days after the fasciotomy. In most patients, a second operation was not necessary because the wounds could

be closed using the prepositioned intracutaneous suture either alone or with the addition of Steri-strip® (3M, Diegem, Belgium) applied across the wound.

Table 7 below shows the detailed results.

Table 7: Results of Janzing's cohort paper[32]

The authors concluded that dermatotraction with vessel loop shoelace or with prepositioned intracutaneous suture provided good skin apposition without the necessity for skin grafting. They concluded that the Marburger technique could result in the need for STSG and in skin necrosis and they did not recommend its use. This paper also included a decision tree to guide decisions about fasciotomy wound closure.

Labler et al's[50] paper compared the use of VAC dressing and Epigard® dressing on soft tissue wounds. Both dressings have been described previously.

16 patients were included in each treatment arm. Of these, 6 patients who were treated with VAC dressings and 7 patients who treated with Epigard had had fasciotomies for compartment syndrome. As this systematic review is concerned only with the wound care of fasciotomy wounds information about the other patients was excluded.

Labler examined the nature and constituents of the exudate generated by each wound dressing in order to determine the impact on local inflammation, to measure wound cytokine levels and assess for neovascularisation.

This cohort study selected patients prospectively as they presented to the hospital with traumatic wounds. The selection of VAC or Epigard was made by the treating surgeon. The paper does not explain the reasoning behind the surgeons' selections therefore selection bias cannot be excluded.

Table 8 below shows the detailed results

Table 8: Results of Labler's cohort paper[50]

This paper compared VAC and Epigard temporary skin closure methods. The study intended to determine the impact of VAC on local inflammation and neovascularisation in traumatic wounds. The paper compared 32 patients but only 13 were included in the above data extraction as the rest

involved other wound types. The authors concluded that “VAC™ therapy of traumatic wounds leads to increased local interleukin-8 and vascular endothelial growth factor concentrations, which may trigger accumulation of neutrophils and angiogenesis and thus, accelerate neovascularisation."[50] (page 3) However the clinical outcomes were similar in both treatment groups. 67% of fasciotomy patients treated with VACs and 86% treated with Epigard had delayed primary closure without need for skin graft or flap, but the numbers were too small to demonstrate a statistically significant difference.

Matt et al[53] retrospectively reviewed 227 patients who had fasciotomies for compartment syndrome due to a mixture of trauma and vascular injuries. The wounds were treated either with wet to dry gauze (n = 148), VAC (n = 55) or dynamic wound closure (n = 24). Treatment was selected according to surgeon preference.

Table 9 below shows the detailed results

Table 9: Results from Matt’s cohort paper[53]

This paper retrospectively compared VAC, various dynamic skin closure methods and standard care with saline soaked gauze. Closure rates were 62%, 83% and 72% but the numbers were too small to demonstrate a statistically significant difference. The paper concluded that the "study found no statistical difference between outcomes of patients treated with DYN as opposed to the GAUZE or NPWM groups. This data showed a trend towards a higher rate of primary closure when the DYN dressing was used, followed by standard GAUZE dressing. The most STSGs were seen when the VAC was used. However, due to sample size, these trends did not reach statistical significance." [53] (page 1656)

This paper included a graphical representation of how the wound management techniques chosen had changed at their institution between 2000 and 2009. Gauze dressings were commonly used across the time period. Dynamic wound closure gained popularity in the middle years but becoming less popular as VAC dressings became increasingly used between 2006 and 2008. However VAC use dropped off sharply after in 2009. The paper did not offer any explanation for these changes.

Medina et al[54] included all 14 patients over a 36 month period who had an upper extremity fasciotomy for compartment syndrome due to trauma or vascular injuries that could not be closed primarily. They were retrospectively identified. The Silver Bullet Wound Closure Device (SBWCD, Boehringer Laboratories, Norristown, PA, USA) was used to provide traction across the wound. The paper compared the fasciotomy closure efficacy between the Silver Bullet Wound Closure Device used in 8 patients and the application of a split thickness skin graft (STSG) used in 6 patients. The STSG was applied an average of 10.3 days after fasciotomy as a wound management choice once it was clear primary closure was not going to be achievable. Each patient chose between the SBWCD or the STSG for themselves. No information was provided to explain their decision making process.

Table 10 below shows the detailed results.

Table 10: Results from Medina's cohort paper[54]

Outcome of interest	Results DYN	Results STSG
Wound management	Silver Bullet Wound Closure Device	Split thickness skin graft
Total wounds/patients	8	6
Average days between fasciotomy and closure of wound	9.25	10.33
Range in days		
Standard deviation	3.24	3.77
Number of wounds/patients healed without a graft	8	Not applicable
Number of wounds/patients needed grafting	0	Not applicable
Percentage healed without STSG	100%	Not applicable
Pain as a result of wound management chosen	2 patients complained about persistent scar tenderness at follow up	3 patients complained about mild extremity pain at follow up
Length of stay in hospital total	20.87	34.83
Length of stay in hospital following fasciotomy	19	24.5
Degree of scarring at widest part	Not recorded but 5/8 were satisfied with the scar. 3/8 reported an extremity with an unsatisfactory cosmetic appearance but none requested a revision	Not recorded but 5/6 were not satisfied with the scar and subsequently underwent a revision
Wound infection	0	3
Wound dehiscence	Not stated	Not stated
Neurological symptoms	2 experienced mild numbness over extremity at follow up	5 patients experienced numbness over the extremity
Psychological impact	Not stated	Not stated

This paper concluded that the Silver Bullet device "may provide a more consistent and efficacious way to manage fasciotomy wounds because it starts approximating the edges at an earlier time. Furthermore, the device eliminates a second stage procedure reducing hospital costs." [54] (page 150) Patients treated with STSG had poorer outcomes including pain, reduced

sensation and poorer cosmetic results, as well as the need for additional procedures.

In Saziye et al's paper[52] 15 patients were identified who had a fasciotomy due to ischaemic reperfusion syndrome over 6 years. Seven were treated with VAC and 8 with wet to dry saline soaked gauze. No information was provided about how patients were selected for each treatment.

Table 11 below shows the detailed results.

Table 11: Results from Saziye's cohort paper[52]

Outcome of interest	Results NPWM	Results STAT
Wound management	Vacuum assisted closure	Saline soaked gauze
Total wounds/patients	7	8
Average days between fasciotomy and closure of wound	11	15
Range in days	Not stated	Not stated
Standard deviation	1.73	2.67
Number of wounds/patients healed without a graft	5	6
Number of wounds/patients needed grafting	2	2
Percentage healed without STSG	71.43%	75.00%
Pain as a result of wound management chosen	Not stated	Not stated
Length of stay in hospital total	Not stated	Not stated
Length of stay in hospital following fasciotomy	14	18.5
Standard deviation	2.16	3.25
Degree of scarring at widest part	Length of wound reduced by 58% and width by 56% Scarring itself not stated	Length of wound reduced by 40% and the width by 46% Scarring itself not stated
Wound infection	0	3
Wound dehiscence	Not stated	Not stated
Neurological symptoms	Not stated	Not stated
Psychological impact	Not stated	Not stated

The authors concluded that VAC showed significant reduction of the wound size, tissue oedema, duration of hospital days, evidence of

improvement of granulation tissue and reduced wound infection. The authors stated that the VAC therapy could be a new standard for treatment of fasciotomy wounds, but they also said the results were preliminary and needed further studies of long term trials.

The data presented supported these conclusions with regards to the wound benefits and reduced wound infection but the percentage achieving delayed primary closure without needing STSG was very similar in both groups (71% in VAC and 75% in gauze).

In Yang et al's paper[38] 34 patients who developed compartment syndrome due to trauma and who were treated with VAC dressings were retrospectively identified. Treatment was by surgeon preference. They were matched with 34 similar patients who received standard treatment with saline soaked gauze.

Table 12 shows the detailed results.

Table 12: Results from Yang's cohort paper[38]

The authors concluded that this study supported the use of VAC for the treatment of fasciotomy wounds due to the statistically significant reduction in the number of days until definitive closure.

There was no significant difference in the rate of healing, without requiring a STSG, between the two groups. The authors suggested a prospective randomised study comparing the two treatment modalities was required.

In Zannis et al's study[39] 458 patients were identified retrospectively over 10 years. Patients developed compartment syndrome due to multiple aetiologies including trauma and ischaemic injuries. The fasciotomy wounds were treated either with VAC dressings or wet to dry gauze dressings or a combination of the two and selection was surgeon preference.

Table 13 below shows the detailed results.

Table 13: Results from Zannis et al cohort paper[39]

As previously discussed the data extracted from this paper did not include wounds where a combination of VAC and saline soaked gauze was used

because the impact of either could not be assigned to either treatment. The data extracted above *does* include the patients with wounds identified as having closed by secondary intention.

The authors of the paper *did not* include these patients in their analysis. The published results therefore appeared much more favourable for VAC than they appear when these patients *are* included. The authors were contacted to request data for this group of patients but the data was no longer available. The paper stated that there was a statistically significant higher rate of primary closure using the VAC compared with traditional wet-to-dry dressings ($P < 0.05$ for lower extremities and $P < 0.03$ for upper extremities). Time to primary closure of wounds was found to be shorter in the VAC group. The paper concluded that "VAC used in the described settings decreases hospitalization time, allows for earlier rehabilitation, and ultimately leads to increased patient satisfaction." [39] (page 409)

The data extracted for the meta-analysis in this thesis included the wounds that healed by secondary intention. This reduced the apparent effectiveness of the treatment in preventing the need for a split thickness skin graft to an odds ratio of 1.49 (CI 1.04 – 2.12) from 5 as stated in the paper. This effect was however still statistically significant.

In Fowler et al's study[55] 56 patients were identified retrospectively over 6.5 years. Patients developed compartment syndrome due to multiple aetiologies including trauma and ischaemic injuries. The fasciotomy wounds were treated either with vessel loop shoelace or with VAC dressings. Selection was surgeon preference.

Table 14 below shows the detailed results

Table 14: Results from Fowler et al cohort paper[55]

Fowler's paper found the data showed an increased risk of skin grafts when VAC was used compared with vessel loop closure. They concluded vessel loop closure was protective against the need for skin grafts. They pointed out that the small number of VACs used make it hard to generalise from this study.

In the subset of forearm compartment syndrome, all 12 forearm fasciotomies were closed with vessel loops but the skin graft rate was 41.67% compared with an overall rate for vessel loops of 18.37%. They suggested a randomised controlled trial of exclusively forearm fasciotomy wound management was needed to determine if VAC has a place for management of these particular wounds.

3.4.5 Results from RCT and cohort studies

Table 15 below shows the results from the RCT and the cohort studies. This table includes the wound management technique used, the total number of patients or wounds included in the case series, the average time to closure, the number and percentage of wounds closed without need for a split thickness skin graft.

Table 15: Results from RCT and cohort papers – part 1

Citation	Number of pts/wounds	Type of study	Wound management technique	Wound closure categories	Total pts/wounds	Average time to closure (days)	Standard dev	Number of patients/wounds healed without a graft	Number of patients/wounds needed grafting	%age healed without STSG
Kakagia et al 2012[45]	50/**82**	RCT	VAC/Vessel loop	NPWM DYN	NPWM **42** DYN **40**	NPWM **19.1** DYN **15.1** (P 0.001)	NPWM **6.1** DYN **3.8**	NPWM **36** DYN **40**	NPWM **6** DYN **0**	NPWM **85.71%** DYN **100%**
Fowler et al 2012[55]	56	Cohort	VAC/Vessel loop	NPWM DYN	NPWM 7 DYN 49	Not stated		NPWM 3 DYN 40	NPWM 4 DYN 9	NPWM 42.86% DYN 81.63%
Janzing and Broos 2001[32]	15	Cohort	Vessel loop/Marburger/intracutaneous suture	DYN	Vessel loop 5 Marburger 5 Intracutaneous suture 5	9 (data not provided separately for each technique)	3.5 (data not provided separately for each technique)	Vessel loop 5 Marburger 3 Intracutaneous suture 5	Vessel loop 0 Marburger 2 Intracutaneous suture 0	Vessel loop 100% Marburger 60% Intracutaneous suture 100%
Labler et al 2009[50]	13	Cohort	VAC/Epigard	NPWM STAT	NPWM 6 STAT 7	NPWM 8.3 STAT 5.0	NPWM 8.36 STAT 15.23	NPWM 4 STAT 6	NPWM 2 STAT 1	NPWM 66.67% STAT 85.71%
Matt et al 2011[53]	227	Cohort	VAC/Gauze/ various dynamic	NPWM STAT DYN	NPWM 55 DYN 24 STAT 148	Not recorded		NPWM 34 DYN 20 STAT 106	NPWM 21 DYN 4 STAT 42	NPWM 61.82% DYN 83.33% STAT 71.62%

Citation	Number of pts/wounds	Type of study	Wound management technique	Wound closure categories	Total pts/wounds	Average time to closure (days)	Standard dev	Number of patients/wounds healed without a graft	Number of patients/wounds needed grafting	%age healed without STSG
			closure techniques							
Medina et al 2008[54]	14	Cohort	Silver Bullet Wound Closure Device/STSG	DYN STSG	DYN 8 STSG 6	DYN 9.25 STSG 10.33	DYN 3.24 STSG 3.77	DYN 8 STSG NA	DYN 0 STSG NA	DYN 100% STSG NA
Saziye et al 2011[52]	15	Cohort	VAC/Gauze	NPWM STAT	NPWM 7 STAT 8	NPWM 11 STAT 15	NPWM 1.73 STAT 2.67	NPWM 5 STAT 6	NPWM 2 STAT 2	NPWM 71.43% STAT 75.00%
Yang et al 2006[38]	68/**138**	Cohort	VAC/Gauze	NPWM STAT	NPWM **68** STAT **70**	NPWM **6.7** Gauze **16.1**	SD not stated but p value 0.0001	NPWM **49** STAT **45**	NPWM **19** STAT **25**	NPWM **72.06%** STAT **64.29%**
Zannis et al 2009[39]	458/**708**	Cohort	VAC/Gauze	NPWM STAT	NPWM **438** STAT **270**	NPWM **7.1** STAT **9.6**	Not recorded	NPWM **348** STAT **195**	NPWM **90** STAT **75**	NPWM **79.45%** STAT **72.22%**

Note that the use of bold within the tables indicates where the paper provided the results by number of wounds. As previously discussed, in most papers the results were presented by patient even though each patient will usually have more than one fasciotomy wound.

Table 16 below shows the other outcomes from the RCT and the cohorts including pain, length of stay in hospital, degree of scarring, wound infection, wound dehiscence and psychological impact.

Table 16: Results from RCT and cohort papers – part 2

Citation	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
Kakagia et al 2012[45]	Not stated	Not stated	Not stated	All pts with skin edge approximation evaluated the result as satisfactory while all 5 STSG pts said they would consider scar revision in future	NPWM 6 DYN 4	None	Not stated	Not stated
Fowler et al 2012[55]	Not stated	VAC 19.2 DYN 23.7	Not stated	Not stated	VAC 2 DYN 3	Not stated	Not stated	Not stated
Janzing and Broos 2001[32]	In one child, the traction on the prepositioned suture was painful, and the final part was closed by simple traction under mask anaesthesia	Not stated	Not stated	All patients were subjectively satisfied with the aspect of their scar, with the exception of one of the skin-grafted patients who complained of the vulnerability of the scar.	0	Not recorded	Two patients had subjective loss of power in foot dorsiflexion and plantarflexion without clinically objective loss of neuromuscular function; both	Not stated

Citation	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
							patients were in the Marburger skin approximation group.	
Labler et al 2009[50]	Not stated	NPWM 18.00 STAT 20.57	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Matt et al 2011[53]	Not stated	NPWM 25.8 sd 19.1 DYN 15.7 sd 15.0 STAT 21.7 sd 22.8	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Medina et al 2008[54]	Not stated but pain was evaluated and compared at follow up	DYN 20.87 STSG 34.83	DYN 19 STSG 24.5	Not stated but 5/8 SB were satisfied with the scar c/w 1/6 for the graft pts, all 5 underwent a revision subsequently	Not stated	Not stated	2/8 DYN had mild numbness at fu. 6/6 STSG had numbness of varying degrees	Not stated
Saziye et al 2011[52]	Not stated	Not stated	NPWM 14, sd 2.16 STAT 18.5, sd 3.25	NPWM length reduced by 58% and width by 56% STAT Length reduced by 40% and the width by 46%	NPWM 0 STAT 3	Not stated	Not stated	Not stated

Citation	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
				Scarring itself not stated				
Yang et al 2006[38]	Not stated	Not stated	Not stated	Not stated	1 in STAT group but related to skin graft	Not stated	Not stated	Not stated
Zannis et al 2009[39]	Not stated	Not stated	Not stated	Not stated although the paper mentions the benefits of avoiding a skin graft	Paper says this was looked at but no data	Mentioned as a potential problem but no data	Not stated	Not stated

3.4.6 Results of case series

Table 17 below shows the results from the case series papers. This table includes the wound management technique used, the total number of patients or wounds included in the case series, the average time to closure, the number and percentage of wounds closed without need for a split thickness skin graft.

Table 17 Results from case series papers – part 1

Citation	Primary wound management technique	Wound closure categories	Total patients included	Average time to closure in days	Range in days	Standard dev	Number of patients healed without a graft	Number of patients needed grafting	Percentage healed without STSG
Asgari et al[64]	Vessel loop shoelace	DYN	37	12		Not stated	37	0	100%
Bail et al[65]	Silicon sheet over wound with drain	STAT	7	10		4.69	6	1	86%
Barnea et al[34]	Wiseband skin and soft tissue stretching device	DYN	16	13		Not stated	14	2	88%
Bibi et al[66]	Mesh skin graft applied at same time as fasciotomy	STAT	2	Not stated		Not stated	0	2	0%
Bjarnesen et al[67]	External tissue stretching device	DYN	9	3		Not stated	9	0	100%
Bulstrode et al[68]	Metal rod and opsite wound closure device	DYN	8	Not stated	3 - 10	Not stated	8	0	100%
Chiverton & Redden[37]	Subcuticular prolene suture running the length of the wound	DYN	12	Not stated	3 - 8	Not stated	12	0	100%

Citation	Primary wound management technique	Wound closure categories	Total patients included	Average time to closure in days	Range in days	Standard dev	Number of patients healed without a graft	Number of patients needed grafting	Percentage healed without STSG
Cohn et al[29]	Vessel loop shoelace	DYN	2	5 days		0	2	0	100%
DiStasio et al[62]	Multiple small incisions in the skin, parallel with the primary wound	MISC	4	Not stated		Not stated	4	0	100%
Dodenhotf & Howell[69]	Vessel loop shoelace	DYN	2	10		0	2	0	100%
Gabriel et al[70]	VAC	NPWM	3	6.67	5 - 10		2	1	67%
Govaert & Van Helden[36]	Ty-raps to effect dynamic wound closure	DYN	23	6.3	1 - 14		22	1	96%
Harris[30]	Vessel loop shoelace	DYN	5	9	7 - 11		5	0	100%
McKenney et al[71]	STAR, (Suture Tension Adjustment Reel) mechanical skin closure device	DYN	13	2.9	2 - 4		13	0	100%
Singh et al[72]	Canica dynamic wound closure device	DYN	10	2.6	2 - 6		10	0	100%
Suliman & Aizaz[73]	Variant on vessel loop shoelace	DYN	5	8.6		3.85	5	0	100%
Taylor et al[61]	Canica dynamic wound closure	DYN	6	16.4		9.24	6	0	100%

Citation	Primary wound management technique	Wound closure categories	Total patients included	Average time to closure in days	Range in days	Standard dev	Number of patients healed without a graft	Number of patients needed grafting	Percentage healed without STSG
	device								
Walker et al[74]	Silicone sheet combined with gradual tightening using a suture running the length of the wound	DYN	53	11.9	5.9 – 17.9		36	17	68%
Weiland[75]	VAC and hyperbaric oxygen	NPWM	5	9.6		6.73	4	1	80%
Wiger et al[35]	External Tissue Extension (ETE) dermotraction	DYN	16	6.75		4.81	16	0	100%
Wiger et al[76]	Wire sutures placed across the wound and gradually tightened	DYN	12	Not stated			12	0	100%
Zorrilla et al[48]	Vessel loop shoelace	DYN	20	8.8	6 - 19	3.9	20	0	100%

Table 18 below shows other outcomes from the case series papers including pain, length of stay in hospital, degree of scarring, wound infection, wound dehiscence and psychological impact.

Table 18 Results from case series papers – part 2

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
Asgari et al[64]	Vessel loop shoelace	DYN	Not stated	Not stated	Not stated	"the vessel loop shoelace technique allowed for a more cosmetic closure" plus photos but no measure as such	0	Not stated	"intact sensation" is mentioned in the discussion as one advantage of the techniqu e	Not stated
Bail et al[65]	Silicon sheet over wound with drain	STAT	"Less pain when the wound dressing is changed" stated in paper and "dressing was changed painlessly" in the abstract but no measurement of pain otherwise	Not stated	Not stated	"our method leaves only a straight narrow scar" stated and photo but no measurement	1	Not stated	Not stated	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
Barnea et al[34]	Wiseband skin and soft tissue stretching device	DYN	One patient had intractable pain that required removal of the device. Otherwise not stated	Not stated	Not stated	"The treated area showed stable scarring with good aesthetic outcome and no functional deficit. One pt developed a hypertrophic scar that subsided considerably with silicone sheath dressing. None required scar revision.	1	Not stated	"no functional deficit	Not stated
Bibi et al[66]	Mesh skin graft applied at same time as fasciotomy	STAT	Not stated	8 days for case one, not stated for case 2	Not stated	The paper has photos of one of the wounds. The scars are large (3-5 cms wide approx and 20-25 cms long) and but not measured	0	0	At one year one leg fully healed, the other small amount of muscle	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
						in the paper. The other patient "scars present" at one year, no photo.			deficit	
Bjarnesen et al[67]	External tissue stretching device	DYN	Pain score measured using a 100 mm scale. Average pain was 30 mm	Not stated	Not stated	"all the patients were satisfied with the cosmetic result"	0	Not stated	Not stated	Not stated
Bulstrode et al[68]	Metal rod and opsite wound closure device	DYN	Not stated	Not stated	Not stated	"The resulting linear scar gives a much better cosmetic result, which is strong enough to tolerate cast bracing within 3 weeks of the injury"	Not stated	Not stated	"Normal sensation at the site of injury	Not stated
Chiverton & Redden[37]	Subcuticular prolene suture running the length of the wound	DYN	Not stated	Not stated	Not stated	"successfully closed" but no mention of scarring specifically	0	0	Not stated	Not stated
Cohn et	Vessel loop	DYN	Not stated	Not stated	Not	"the	0	Not	Not	Not

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
al[29]	shoelace				stated	rubberband technique described here provides for a more cosmetic closure"		stated	stated	stated
DiStasio et al[62]	Multiple small incisions in the skin, parallel with the primary wound	MISC	Not stated	Not stated	Not stated	All pts agreed that their wound closure was preferable to other techniques such as flap or STSG. Also included photos of this technique versus STSG at 18 months	0	0	Not stated	Not stated
Dodenhoff & Howell[69]	Vessel loop shoelace	DYN	Not stated	Not stated	Not stated	Not stated	0	Not stated but implied "no problems with infection	Not stated	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
								of skin edge necrosis"		
Gabriel et al[70]	VAC	NPWM	Pain was mentioned but no data presented except to say the decreased frequency of dressings in kids is a good thing, and also no one needed a GA although other forms of pain management was provided	Not stated	6.67	Not stated	Not stated	Not stated	Not stated	Not stated
Govaert & Van Helden[36]	Ty-raps to effect dynamic wound closure	DYN	Procedure of tightening ty raps was described as 'well tolerated' but no pain measurements provided	Not stated	Not stated	The wounds were described as “completely healed” and “approximation of the skin edges” but the degree of scarring was not specifically	2	1	Not stated	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
						described				
Harris[30]	Vessel loop shoelace	DYN	After the first case was done in the OTS, in the next 4 cases tightening was performed on the ward with no anaesthesia or analgesia. No pain measures mentioned	Not stated	Not stated	Not specifically measured. The technique is stated to result in "normal skin coverage of the wound thus improving protection, sensation and cosmesis". There is a photo of a closed but not healed wound.	0	Not stated	Not stated	Not stated
McKenney et al[71]	STAR, (Suture Tension Adjustment Reel) mechanical skin closure device	DYN	"tightening was performed at the bedside and was associated with minimal discomfort. No sedation or pain medication was required."	Not stated	Not stated	Patients are left with "an acceptable sensate scar"	1	Not stated but implied "no problems with infection apart from one superfici	Not stated	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
								al infection"		
Singh et al[72]	Canica dynamic wound closure device	DYN	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Suliman & Aizaz[73]	Variant on vessel loop shoelace	DYN	Not stated	Not stated	Not stated	1 pt had a hypertrophic scar. The others were described as having good results	1	Not stated	Not stated	Not stated
Taylor et al[61]	Canica dynamic wound closure device	DYN	Not stated	Not stated	Not stated	All five patients reported being satisfied with the cosmetic result of their fasciotomy wound closure.	0	Not stated	Not stated	Not stated
Walker et al[74]	Silicone sheet combined with gradual tightening using a	DYN	"absolutely painless"	Not stated	Not stated	"may have a better cosmesis" but no evidence of this was presented	Not stated	Not stated	Not stated	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
	suture running the length of the wound									
Weiland[75]	VAC and hyperbaric oxygen	NPWM	NPWM dressings were done in OTS, pain not mentioned	Not stated	Not stated	Not stated	0	1	One pt had extensive muscle damage and therefore deficits	Not stated
Wiger et al[35]	External Tissue Extension (ETE) dermotraction	DYN	Not stated	Not stated	Not stated	None of the patients needed a skin graft - but scar not specifically mentioned	Not stated	Not stated	Not stated	Not stated
Wiger et al[76]	Wire sutures placed across the wound and gradually tightened	DYN	Not stated	Not stated	Not stated	"Patients were satisfied with the cosmetic results of the injured extremities". Scar width not measured	Not stated	Not stated	3 pts had impaired sensation and 1 had a stiff knee at long term follow up	Not stated

Citation	Wound management technique	Wound closure categories	Pain as a result of wound management chosen	LOS in hospital total	LOS in hospital following fasciotomy	Degree of scarring at widest part	Wound infection	Wound dehiscence	Neurological symptoms	Psychological impact
Zorrilla et al[48]	Vessel loop shoelace	DYN	"tightening is painless"	10 days, range 7-20	Not stated	Not stated although the paper mentions the benefits of avoiding a skin graft. Like many of the papers the implication is that the scar is narrow but this is not specifically stated	0	0	Papers says no problems except for one patient who had a retractile scar reducing flexion	Not stated

3.4.6.1 Case series not included in the preceding tables

A case series paper by Johnson et al[60] included in this systematic review was not included in the case series results tables. This paper has been reported separately because of significant differences between the patient populations included in this paper and the other case series patients. In addition to this, the paper was specifically concerned with identifying and analysing the contributing factors to wound complications, rather than looking at specific wound management techniques which were not reported.

This paper reported on seventy-three dermotomy-fasciotomies (DFs) performed on 68 patients from 1986 to 1991. The authors were primarily interested in identifying and analysing the contributing factors to wound complications experienced by the patients in the case series and they compiled a database of variables to that end. The variables included patient age, the injury that led to the initial fasciotomy as well as other injuries sustained, and method of initial wound closure. A multivariate stepwise logistic regression analysis was performed to determine which variables were associated with wound complications. The analysis found that overall 38% of patients who had a fasciotomy developed wound complications. In the patient group who developed wound complications, 51% were associated with closure by primary or secondary intention compared with 5% for patients who had their wound closed by skin graft.

This paper concluded that “this study suggests that closing dermotomy-fasciotomy wounds utilizing skin grafts allows for continued osteofascial decompression while concomitantly minimizing invasive sepsis.”[60] (page 286) This paper has been referred to 28 times since publication when this was checked via Google Scholar[77] on 13/10/12 and has been used to support the use of skin grafts for fasciotomy patients. This conclusion is problematic for two reasons. The study population included a very high number of limbs (58) with arterial injuries or occlusion and only 15 who had fasciotomies for more typical compartment syndrome due to simple fractures or blunt force trauma. The conclusions should therefore be limited to former patient population only.

In addition to these concerns, the paper included many wound complications of different aetiologies which it aggregated together, many of them not sepsis related at all. These included muscle necrosis and haemorrhage which related to the primary injury, not the fasciotomy for compartment syndrome. The paper did not include enough of the actual data to be able to analyse exactly what was meant by wound complications.

3.4.7 Meta-analysis

This section presents the results of the meta-analysis of four of the papers from the systematic review.

Four of the cohort studies compared the same wound management options. Matt[53], Saziye[52], Yang[38] and Zannis[39] all investigated the use of VAC dressings on fasciotomy wounds and compared the outcomes with the use of traditional gauze dressings. All four papers included the number of patients in each group who achieved wound closure without the need for a split thickness skin graft, and the number of patients overall. Matt et al (2011) compared 3 wound management options: VAC, saline soaked gauze and various types of dynamic closure. Data from that paper, comparing VAC and saline soaked gauze, is therefore also included in this meta-analysis. The four papers were analysed using the Joanna Briggs Institute meta-analysis software 'Mastari'. Meta Analysis of Statistics Assessment and Review Instrument and their results analysed where possible.

The analysis used the Mantel-Haenszel fixed effects odds ratio to create a forest plot of the results. The heterogeneity was calculated to be 5.22 with a P value of 0.15637. This level of heterogeneity is considered to be acceptable for this test.[10]

Figure 3 below shows the results of the meta-analysis.

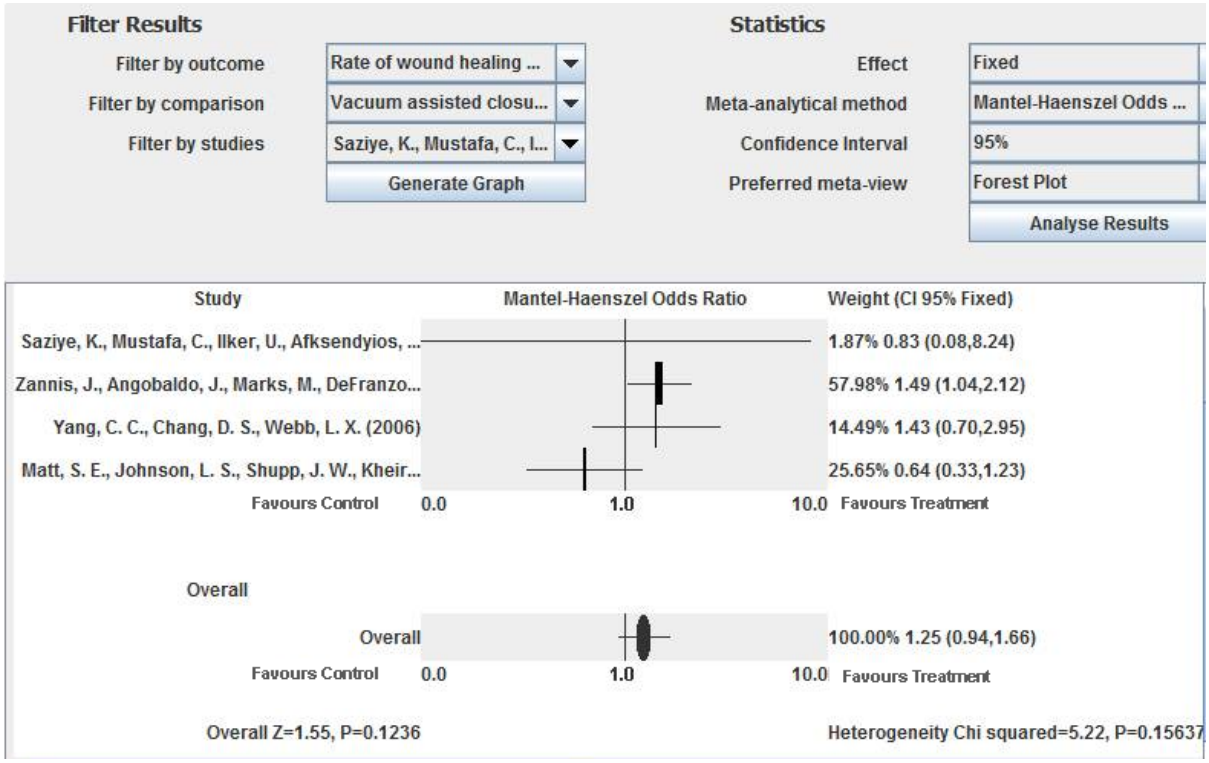


Figure 4: Results of the meta-analysis

The heterogeneity as mentions above is within acceptable limits for this test. The forest plot however shows that the four papers show variable results and are also variable in terms of the study size. The two larger studies, Matt and Zannis found different results. Matt found that more patients using VAC dressings required a split thickness skin graft for closure than those treated with gauze and Zannis found the reverse. Matt's result was not statistically significant while Zannis's was.

This meta-analysis showed that the Mantel-Haenszel odds ratio overall was 1.25 in favour of the VAC dressing. The confidence interval range was between 0.94 and 1.66. This result was not statistically significant although the data favours VAC over gauze overall.

3.5 Summary

This chapter set out the results of the papers and presented the details of these results. Chapter four discusses the overall findings and concludes the thesis.

Chapter 4: Discussion and Conclusions

4.1 Introduction

This chapter discusses the findings of the systematic review, the issues and limitations of the available research and the results of the meta-analysis. The chapter examines the nature of the research conducted to date, considers the implication for practice, makes recommendations for future research in this area and presents the overall conclusions.

4.2 Overview of the research identified by this systematic review

This overview examined the body of knowledge identified by the systematic review process, discussed this body of knowledge in the context of the broader world of research and considered the implications.

The systematic review set out to find and examine the research that had been conducted on the effectiveness of fasciotomy wound management between January 1960 and June 2012. The search identified no research on this specific topic before 1985. Compartment syndrome itself had been extensively studied with many hundred of papers including several systematic reviews available. These studies had initially focussed on the early recognition and appropriate management of compartment syndrome itself. They were aimed at avoiding the potentially catastrophic life and limb threatening consequences of poor management, and the wounds created were either not mentioned at all or mentioned in passing.[6, 78, 79]

It was only as compartment syndrome management itself started to improve that the problems associated with fasciotomy wounds started to be recognised and discussed as a separate issue. The percentage of fasciotomy wounds that required split thickness skin grafts to effect closure started to be mentioned regularly from the mid 1970s. Sheridan reported a split thickness skin graft closure rate of 77% in his 1976 paper, but it was not until 2000 that research was published examining the long term consequences for patients of fasciotomies performed for compartment syndrome.[56] Despite this information, a systematic review of the results of fasciotomy published in

2009 still did not include information about how the wounds were managed.[25]

Tables included in the results chapter showed the wide geographical distribution of the research undertaken, and the wide spread of journals that published the research. In addition, a search of the names of all the authors of the included papers found that most had published only once on this specific subject and there was little evidence of continued focus on the topic. The reasons for this might be due to a range of factors. The incidence of fasciotomy for compartment syndrome is relatively low which might reduce the likelihood of attracting funding for research from industry. Compartment syndrome can be managed by different sub specialties including orthopaedic, vascular and plastic surgeons. In some institutions the fasciotomy may be created by one sub specialty and the fasciotomy wound managed by another. This spread of specialties might reduce the focus of any single specialty on the problem. This idea is supported by the fact that the published research was found across a range of specialty journals.

Another factor affecting the research might also be the relative rarity of fasciotomies at an individual institution level. The author's own 530 bed tertiary hospital averages just 13 fasciotomies a year. A survey undertaken in England to ascertain the knowledge of fasciotomy amongst plastic and orthopaedic surgery trainees found that most trainees had little experience of watching, assisting or performing fasciotomies.[80]

These factors may have contributed to the relatively scanty body of research found by this review.

4.3 Meta-analysis finding

This section considers the findings of the meta-analysis.

The four cohort studies and the single randomised controlled trial study were analysed and the results presented in the results chapter. This section summarises and discussed these findings.

The meta-analysis findings set out in the results chapter showed that the pooled results from 4 papers comparing VAC wound management system with the traditional saline soaked gauze approach favour VAC over gauze for

reducing the risk of requiring split thickness skin graft to close the wounds. The length of stay data could not be pooled due to variations in the way this outcome was reported but the individual results showed a reduced length of stay and/or a reduced time between fasciotomy and closure for VAC over gauze. These findings favour the selection of VAC over gauze.

The randomised controlled trial compared shoelace with VAC. The analysis of the trial findings showed that shoelace technique was better than VAC for achieving delayed closure of the fasciotomy wound without STSG, and this difference was statistically significant. In addition this study showed shoelace achieved closure faster than VAC and this difference was also statistically significant. These findings together favour the use of shoelace over VAC and VAC over gauze.

4.4 Limitations of the available research

4.4.1 Types of research

This section examines the types of research included in the systematic review and discusses the implications of the research type on the resulting body of knowledge.

Systematic reviews in general are intended to find all the research that has been conducted on the population of interest, about the intervention of interest and including the comparators and outcomes as set out in the protocol. The decisions about which research type is included and which excluded are also set out in the protocol. This systematic review included all three levels of quantitative evidence; randomised controlled trials, cohorts and case series. This decision was made on the basis of the nature of the published research which had been conducted on this topic. The search found only one RCT and 8 cohort studies. All other research was case series only. These case series cannot be included in meta-analysis as they lack a comparator. The information contained in the case series cannot be generalised due to small sample sizes, lack of comparators and selection bias. In addition, it is well recognised that negative case series are seldom published.[81] This means that case series that are published usually

demonstrate a positive outcome related to an intervention. The results themselves may be genuine, but what is missing from the literature is the potentially large number of case series which found no positive outcome and therefore were of no interest to publishers. This factor is called publication bias and must be considered when examining available research. Similar publication bias occurs with all study types.[42, 82]

Despite these limitations, case series results still contribute to the body of knowledge providing they are read and interpreted within the limitations of their design. The fact that 17 of the 23 case series examined various methods of dynamic wound closure techniques indicated that the focus of these studies was on closing the fasciotomy wounds more effectively. The majority of the case series explicitly stated that the intention of the intervention was to reduce the need to use a split thickness skin graft to effect closure. The majority of the case series papers included this as a preferred outcome. The variety of the types of dynamic closure indicated that this preferred outcome remained elusive and the problem as articulated in these papers appeared to remain unsolved.

It is however always important that case series are carefully examined, their limitations understood and caution exercised when interpreting results. This can be illustrated with reference to Johnson's paper[60] as described in the results section. This paper has been referred to in a number of papers as providing evidence to support the use of primary STSGs on fasciotomy wounds to avoid sepsis. However the patient population in Johnson's paper is sufficiently different from the usual fasciotomy wound patient population to make this conclusion questionable.

The case series included in the systematic review covered a wide variety of wound management techniques. Some of these were proprietary devices all intended to harness the visco elastic properties of skin such as the Canica dynamic wound closure device®, External Tissue Extension (ETE)® dermotraction, STAR, (Suture Tension Adjustment Reel)® mechanical skin closure device and Wiseband® skin and soft tissue stretching device.

Other devices also intent on harnessing these properties included the vessel loop technique, the use of subcutaneous sutures, metal rod and opsite wound closure and the use of Ty-raps® to effect dynamic wound closure.

Other wound care options in the case series included mesh skin graft applied at same time as fasciotomy, multiple small incisions in the skin, parallel with the primary wound, use of a silicon sheet together with a wound drain or with a subcutaneous suture, split thickness skin graft as a primary treatment and the application of negative pressure to wounds using the VAC device.

The use of negative pressure wound therapy on fasciotomy wounds is an interesting example of the adoption of an intervention in advance of evidence of effectiveness. The success of this technique in other wounds such as chronic venous wounds and later larger traumatic wounds seemed to have been taken as sufficient evidence to spread the technique to other wounds. However fasciotomy wounds have unique characteristics which are well known to make them a challenge to close successfully without the need for split thickness skin graft. Fasciotomy wounds typically bulge open under pressure and some kind of pressure or tension is required to close them. Negative pressure wound management devices do exert some pressure but this pressure does not pull the wound edges together. Rather the pressure sucks exudates from the wound. This contributes to the gradual reduction in wound size as the wound heals and the wound edges begin to contract, but does not directly address the typical bulging nature of the fasciotomy wound. An evidence review of negative pressure wound management undertaken by the National Health Service of the United Kingdom in 2008 found that the methodological limitations of the available studies meant that firm conclusions could not be drawn and recommended further research.[83]

The evidence base related to compartment syndrome in general was found to be much larger than for fasciotomy wound management in particular. Many large studies, including systematic reviews, of compartment syndrome did not include information about how fasciotomy wounds were actually managed, or mentioned only traditional saline soaked gauze.[25-27, 84, 85]

4.4.2 Outcome measures

This section considers the outcome measures included in the systematic review papers and discusses the impact these have on the ability to compare results and draw conclusions from the included studies.

The results chapter detailed the outcomes of interest and the actual outcome measures as documented in the included papers. The substantial variation in the number of outcomes included in the papers, as well as variation in how the outcomes were measured was highlighted as a result. These factors have made comparing outcomes across papers more difficult and have reduced the opportunity for meta-analysis.

None of the included papers had information about all the outcomes of interest. The outcome measures that were included were measured in different ways across different papers. Some papers included wound numbers as well as patient numbers but some had data at patient level only. Some papers included the days to wound closure but did not include a standard deviation or a range. Some of the papers measured length of stay but others did not. Pain measurement is an example where there are many different pain scales in existence; however the majority of the papers did not use any pain scale, rendering the pain outcome useless as a potential contributor to wound management selection decisions. Measurement of the scars was another area where most papers did not include an objective measurement even though they frequently mentioned scarring as a concern. The appearance of scars were mentioned most often with regard to scars left after the use of split thickness skin grafts. The implication in many papers was that the scars were acceptable when the wounds could be closed without the use of split thickness skin grafts, but many of the papers did not state this explicitly, nor did they provide photographs, include patient statements or record scar measurements.

Information about wound infection, dehiscence or necrosis was not included in many papers. Where wound infection was recorded the definition of wound infection was not always stated, reducing the opportunity for comparisons.

Patient experience and viewpoints were not mentioned in most papers. The impact on neurological functioning and the psychological impact of the outcomes of the fasciotomies were generally not included.

4.4.3 Wound management modalities

This section considers the types of wound dressings and wound management techniques included in the systematic review papers, and discusses the possible reasons for these.

The five wound management categories used in this thesis were detailed in chapter three. These categories and the number of papers in each category were DYN (n = 24), NPWM (n = 9), STAT (n = 6), STSG (n = 3) and MISC (n = 1). See results chapter for the details. The wound management grouped under DYN covered all wound management techniques that used any kind of force to draw or pull the wound edges together. These included commercial dermotraction devices, sutures, plasters, steri-strips, vessel loops, subcutaneous sutures, Ty-raps and elastic bands. The variety of devices and techniques developed could indicate problems with existing devices and techniques. Commercially developed devices are expensive and this is one factor that has contributed to the search for alternatives.[36] Problems encountered using some of the devices also contributed to the search for alternatives. The papers included in this systematic review almost invariably commenced with an overview of the problems associated with the management of fasciotomy wounds and the lack of consensus about the best method to use.

The systematic review question examined a specific type of wound created for a specific purpose. This was necessary for the purposes of a systematic review but this did limit wider exploration of wound management techniques in other wound types. Many of the wound management techniques found in this review have been used in other wound types and the body of evidence is much more extensive when all wound types are considered. However this review has identified that using a wound management technique that appears to have good results with one wound type does not necessarily mean it is effective or appropriate in wounds of different aetiologies.

4.4.4 Building a body of knowledge

This section examines the body of knowledge that has been built in this area and discusses the identified gaps.

One of the limitations of the available evidence found in this systematic review was the small number of papers available that directly compared different techniques. Kakagia's paper[45], which was the only RCT found, compared vessel loop shoelace technique with negative pressure wound management. The cohort studies compared a variety of new wound management techniques with the traditional saline soaked gauze method, but did not compare new techniques with each other. It is not surprising that most modern wound management techniques studies are better that saline soaked gauze. Saline soaked gauze has been found to be detrimental to wound healing for many reasons including the drying effect on the wound, damage to the capillary bed during wound changes, desiccation of the wound surface as the saline dries out, and pain during dressing changes.[86] Modern wound management has moved away from saline soaked gauze as a result. The case series examined a wide variety of different wound management techniques and devices but the evidence from case series is limited as previously discussed.

More research is needed to compare modern wound management techniques with each other in the context of fasciotomy wound closure. Moran's 2003 paper described combining the vessel loop shoelace technique with the Vacuum Assisted Closure technique in abdominal fasciotomy wounds.[87] The paper described the technique but did not include data. The major benefit was stated to be that the combination of VAC with the vessel loop shoelace technique increased the tension and improved fascial and soft tissue approximation. This combination technique might be of great benefit to the limb fasciotomy wound management but research is needed.

4.4.5 Evidence into practice

This section considers the issues surrounding the translation of evidence into practice in the context of the fasciotomy wound management.

The meta-analysis results found in this systematic review indicated that the vessel loop shoelace technique was better than either saline soaked gauze

or negative pressure wound therapy in achieving closure of fasciotomy wounds without the need for a split thickness skin graft. This technique was first described more than twenty years ago and papers using the technique and modifying the technique with positive outcomes for wound closure have been published. (See chapter two for details.) Despite this, evidence suggests the technique is not in wide spread use. Wall's survey of 264 orthopaedic surgeons working in Australia in 2004-2005 found that, while this technique was rated as useful by the majority of respondents, it only rated slightly higher than either gauze or negative pressure wound therapy.[88] This finding indicates that considerable variation in practice exists and raises questions about the possible underlying factors.

One of these factors may be the lack of compelling evidence for the effectiveness of this technique due to the paucity of evidence previously described. Another factor might be lack of opportunity for the development of the shoelace technique as a skill. This technique is a skill that must be learnt and if surgeons do not see it used then they are unlikely to develop the necessary skills themselves. Anecdotal evidence obtained during personal communication with several orthopaedic surgeons at a major tertiary hospital in South Australia suggests that the technique can be a challenge to master and needs to be taught, then practiced, before the outcomes achieved in some of the published studies are possible. This can be illustrated by the variety of opinions that appeared in letters published in the British Medical Journal as part of the rapid response to an editorial on acute compartment syndrome.[89] The variety of opinions expressed in these 10 letters from expert orthopaedic surgeons indicated that there remained a lack of consensus about how best to manage fasciotomy wounds.

One of these letters also illustrated the relative lack of urgency in the viewpoint of orthopaedic surgeons to the problems associated with wounds managed using spilt thickness skin grafts as illustrated by the following quotation. "The possible cosmetic disadvantages occur only because the limb has been salvaged."[90] If this viewpoint is widespread and clinicians managing these patients feel that success is achieved if the limb has been saved then the impetus to strive for further improvement may be lacking. It is possible that the movement towards improved patient focus might provide

this impetus in the future. However this can only be achieved if patients are followed up for sufficient periods of time and their views sought on a range of outcome measures.[91]

The way individual clinicians practice is based on a range of interconnecting factors that include the body of evidence available, individual clinical expertise involving personal knowledge, skills and experience, patient factors, and local custom and practice. Sackett described individual clinical expertise as “the proficiency and judgment that individual clinicians acquire through clinical experience and clinical practice. Increased expertise is reflected in many ways, but especially in more effective and efficient diagnosis and in the more thoughtful identification and compassionate use of individual patients' predicaments, rights, and preferences in making clinical decisions about their care.”[92] (page71) The hierarchy of evidence discussed in chapter one of this thesis does not include expert opinion. However clinicians clearly *do* draw on their own expert opinion built up over many years to contribute to their decision making process. This is based on the patients they have interacted with and the good and bad outcomes they have experienced or heard about. A clinician who has seen a bad outcome as a result of a particular technique will take that into account when weighing up the evidence for and against an intervention. This is particularly so when the body of evidence is weak as is the case for the effective management of fasciotomy wounds created to relieve compartment syndrome in the limbs.

Even when evidence is strong the adoption of the evidence into practice is highly variable. McGlynn’s seminal paper on the quality of health care delivered to adults in the United States found that patients received only 54.9% of recommended care over a list of 30 acute and chronic conditions.[93] This study was recently repeated in the Australian context and the findings were almost identical even after ten years of increasing action in evidence based healthcare.[94] Further analysis published in response to criticism of this study showed that there was no difference in the percentage of adherence to recommended care between indicators supported by different grades of recommendations or levels of evidence.[95] Clearly there are many factors influencing clinician decision making and levels of evidence are just one element of these.

4.5 Implications for Practice

This section considers the implications for practice of the findings of this systematic review.

The major implication for practice comes from Kakagia's randomised controlled trial. This limits the strength of the evidence because a single trial can result in skewed results due to unknown local factors. The cornerstone of the scientific method is the ability to reproduce results and this study therefore needs to be replicated to strengthen its findings.

Within the limitations of this single study however the evidence does provide some support for the use of vessel loop shoelace technique to improve the chances of achieving a primary wound closure without the need for a split thickness skin graft when compared with VAC.

The use of negative pressure wound management is associated with a higher rate of split thickness skin graft than vessel loop shoelace and this should be taken into account when deciding whether this technique should be used on fasciotomy wounds.

Commercial devices that perform similar functions to vessel loop shoelace are more expensive but might be easier to use. This hypothesis needs to be tested through further research.

Saline soaked gauze is not recommended for use with fasciotomy wounds.

4.6 Implications for Research

4.6.1 Outcome measures to include in future research

This section outlines the outcome measures that should be included in future research and suggests measurement instruments and definitions that might enhance the data collection and therefore strengthen the research findings.

This systematic review found that there was a lack of consensus in the research undertaken to date around the outcomes measures included and

the methods of measurement. This limited the ability to compare data and pool data across studies. Future researchers should consider including the following outcomes measures in their research:

- Number of days between fasciotomy and wound closure including range and standard deviation. The definition of wound closure should be stated.
- Number of days between fasciotomy and discharge home including range and standard deviation. If the discharge destination is another hospital or rehabilitation facility this should be stated.
- Measurement of pain experienced at dressing changes using a validated pain measurement scale such as the Visual Analogue Scale.[96]
- Measurement of the scar at closure in millimetres with a statement of how the closure was effected. The measurements should include length, width at the widest point of the scar and average width across the entire scar. An option to measure the average scar width might be to measure the width at 3 points - quarter, half and three quarters - along the scar's length
- Measurement of the scar three months and six months after the fasciotomy. The measurements should include length, width at the widest point of the scar and average width across the entire scar. If the scar was revised in the interim this should be stated
- The total number of wounds, the number that could be closed by delayed primary closure and the number that required spilt thickness skin grafts to effect closure. The number of wounds should be recorded as well as the number of patients
- The location of the wounds divided into foot, lower limb excluding the foot, thigh, hand, below elbow excluding the hand and above elbow
- The wound aetiologies including the number due to trauma, including trauma type and the number due to vascular insults

- Wound infection rates with a definition of what constitutes an infection
- Wound necrosis and dehiscence rates with definitions

The following outcomes measures would also be useful to include in future research:

- Follow up at six months post the fasciotomy to include the patient's subjective assessment of the neurological function of the affected limb and their viewpoint on the cosmetic appearance of the scar(s)

Outcomes measures would also be of greater value if papers included patient level results in the published papers which would enable re-analysis and meta-analysis of results. Where this cannot be achieved due to lack of space, the de-identified data should be held by the original researcher and be made available to other researchers if requested. The ethical requirement is to hold data for at least 5-7 years, but ideally indefinitely.

4.6.2 Possible topics for future research

This systematic review has found evidence that vessel loop shoelace technique is better than negative pressure wound management in reducing the likelihood of a wound needing a split thickness skin graft to effect wound closure. However this conclusion is based on a small body of evidence. Larger RCTs are needed so that the available evidence can be strengthened. In addition, trials are needed to combine different techniques to ascertain if better results can be obtained, particularly in primary closure, length of hospital stay and overall cost.

One example of this is a paper that described combining negative pressure wound management with vessel loop shoelace technique in abdominal fasciotomy wounds.[87] A trial comparing DermaClose Continuous External Tissue Expander with vessel loop shoelace has already been registered with the US clinical trials registry and results database. This database covers publicly and privately supported clinical studies of human participants conducted around the world.[97]

4.7 Limitations

This systematic review has a range of limitations both intrinsic and extrinsic. This section explains these limitations.

The review excluded studies published in languages other than English which limited the overall scope of the review.

The studies included in this review had a range of methodological issues which have been explored in detail in other sections. The major limitation of this review is the difficulty with the multiple outcomes of interest. This variation in the types of outcomes included, and the way these were measured, has also been discussed in other sections. These problems also limit the opportunity within the review to balance all the outcomes measures when addressing the review question. There was not enough data available in a standardised fashion to allow a regression analysis of the contribution of the various wound management techniques to the outcome measures. As a result conclusions have been drawn about only two outcome measures out of a possible nine originally considered. This limitation means that clinicians making decisions about wound management techniques have access to only a small number of variables upon which to base their decisions. The other variables include pain experienced during dressings, overall appearance and strength of the scars and associated neurological deficits, length of stay in hospital and wound infection, dehiscence and necrosis risk. All of these variables have levels of importance to the individual patient and have the potential to interplay and influence each other in unknown ways. This makes it harder to make an informed decision at the clinical level and reduces the value of the systematic review to the clinician.

Conclusions

4.8 Future directions for practice

The systematic review found limited evidence on which to base practice decisions. The single RCT needs to be replicated to confirm findings before practice change can be confidently recommended. However clinicians should consider selecting a dynamic type of wound closure device to increase the chances of closing the fasciotomy wound without the need for split thickness

skin graft. There are a range of possible devices but the strongest available research supports the use of the shoelace technique.

The use of the shoelace technique might benefit from specific skills development, perhaps involving clinicians visiting centres where this technique is already performed successfully to improve their skills.

Care must be taken when using any type of dynamic closure device to leave the wound open and free of pressure for the first few days to avoid the risk of a recurrence of the compartment syndrome.

Commercial devices that perform similar functions to vessel loop shoelace are more expensive but might be easier to use. This hypothesis needs to be tested through further research.

Negative pressure wound therapy should be used with due consideration in fasciotomy wound management as the possible risk of requiring a split thickness skin graft to achieve wound closure is higher than with shoelace technique.

Saline soaked gauze is not recommended for use

4.9 Future directions for research

Further research is required to compare different wound management techniques with each other and to combine different techniques together. Outcome measures should be standardised in future research, both in terms of what is included and how these are measured. This will improve the possibilities for meta-analysis of study results in the future.

4.10 Conflict of Interest

The primary and secondary reviewers and the supervisors declare no conflict of interest.

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Appendices

Appendix I: Search Strategy

The search strategy was developed with the assistance of an expert librarian. A grid of included terms was developed and used as the basis for the search in each of the included databases.

A	B	C
anterior tibial syndrome*[tiab] compartment syndromes[mh] (compartment ti] AND syndrome*[ti]) compartment syndrome*[tw] muscles[mh] muscular diseases[mh] ischemia[mh]	fasciotom*[tw] fasciectom*[tw] (fascia[mh:noexp] AND surgery[tw]) (fascia[ti] AND surgery[ti]) (fascia[mh:noexp] AND surgical[tw]) (fascia[ti] AND surgical[ti]) (decompression AND surgery) (mesh term and all fields) 4/12/11	orbital[tw] abdominal[tw] abdomen[tw]

The searches included terms in column A AND the terms in column B NOT the terms in column C. The searches were made more challenging as the term fasciotomy was not used as a MESH term until 1984. For this reason the search included a simple search for the term fasciotomy in the title or abstract as well as the more complex search string set out below. The results of both searches added to Endnote for each database.

Pubmed search string

(((fasciotom*[tw] OR fasciectom*[tw] OR (fascia[mh:noexp] AND surgery[tw]) OR (fascia[ti] AND surgery[ti]) OR (decompression AND surgery) AND (("1960/01/01"[PDat] : "2012/06/30"[PDat])))) AND (anterior tibial syndrome*[tiab] OR compartment syndromes[mh] OR (compartment[ti] AND syndrome*[ti]) OR compartment syndrome*[tw] OR muscles[mh] OR ischemia[mh] OR muscular diseases[mh] AND (("1960/01/01"[PDat] : "2012/06/30"[PDat])))) NOT (orbital[tw] OR abdominal[tw] OR abdomen[tw] AND (("1960/01/01"[PDat] : "2012/06/30"[PDat]))) Filters: Humans; English

This returned 2796 papers

In addition the search string below was also used for each database due to identified problems with inconsistent use of MESH terms in some paper.

fasciotomy[All Fields] OR fasciectomy[All Fields] OR fasciotomies[All Fields] OR fasciectomies[All Fields] AND ("humans"[MeSH Terms] AND English[lang] AND ("1960/01/01"[PDAT] : "2012/06/30"[PDAT]))

This returned 1537 papers.

This search was repeated in each of the included databases with modifications depending on the database rules. The resulting papers were added to Endnote with the duplicates added to the duplicates library. This resulted in a total of 7825 papers and 13955 duplicates.

During the search the sole randomised controlled trial paper was published as an epublication in advance of appearing in the journal.[45] This paper fell within the PICO but the original search did not find this paper due to the use of the filter for human studies. This filter does not work until a paper has been published in a journal and the MESH terms added. This is a potential trap that searchers should be aware of. The search was re-run for the year 1/7/11 – 30/6/12 without the human filter to ensure that epublications were correctly identified. The numbers below include this expanded search.

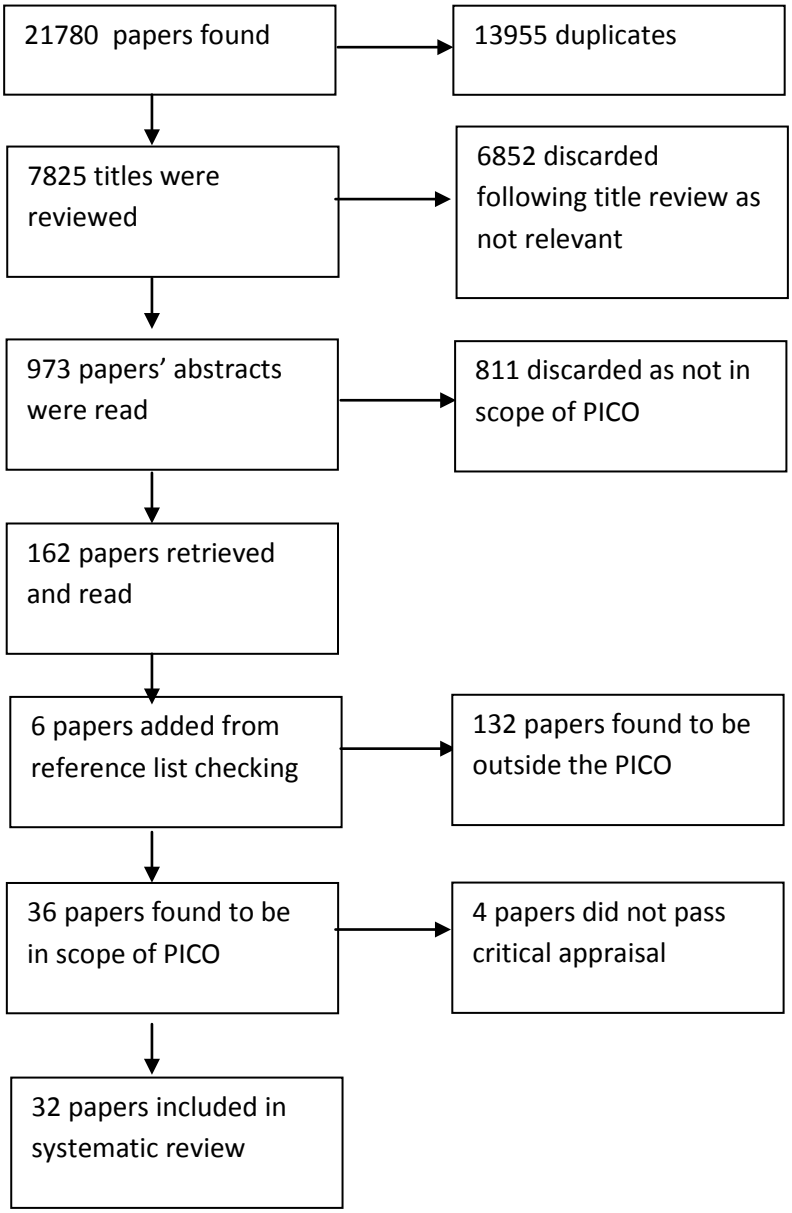

Figure 5 Search retrieval flow diagram

Appendix II: Critical Appraisal Instruments

MAStARI Appraisal instrument

Design: Descriptive / Case Series Studies

	Criteria	Yes	No	Unclear	Not Applicable
1)	Was study based on a random or pseudo-random sample?				
2)	Were the criteria for inclusion in the sample clearly defined?				
3)	Were confounding factors identified and strategies to deal with them stated?				
4)	Were outcomes assessed using objective criteria?				
5)	If comparisons are being made, was there sufficient descriptions of the groups?				
6)	Was follow up carried out over a sufficient time period?				
7)	Were the outcomes of people who withdrew described and included in the analysis?				
8)	Were outcomes measured in a reliable way?				
9)	Was appropriate statistical analysis used?				

Design: Randomised Control Trial / Pseudo-randomised Trial

	Criteria	Yes	No	Unclear	Not Applicable
1)	Was the assignment to treatment groups truly random?				
2)	Were participants blinded to treatment allocation?				
3)	Was allocation to treatment groups concealed from the allocator?				
4)	Were the outcomes of people who withdrew described and included in the analysis ?				
5)	Were those assessing outcomes blind to the treatment allocation?				
6)	Were the control and treatment groups comparable at entry?				
7)	Were groups treated identically other than for the named interventions?				
8)	Were outcomes measured in the same way for all groups?				
9)	Were outcomes measured in a reliable way?				
10)	Was appropriate statistical analysis used?				

Design: Comparable Cohort / Case Control Studies

	Criteria	Yes	No	Unclear	Not Applicable
1)	Is sample representative of patients in the population as a whole?				
2)	Are the patients at a similar point in the course of their condition/illness?				
3)	Has bias been minimised in relation to selection of cases and of controls?				
4)	Are confounding factors identified and strategies to deal with them stated?				
5)	Are outcomes assessed using objective criteria?				
6)	Was follow up carried out over a sufficient time period?				
7)	Were the outcomes of people who withdrew described and included in the analysis?				
8)	Were outcomes measured in a reliable way?				
9)	Was appropriate statistical analysis used?				

Appendix III - Data extraction instruments

MAStARI data extraction instrument

Extraction Details: Extraction - Name (2011) - Randomised Control Trial / Pseudo-randomised Trial Study Information

* denotes field which will appear in report appendix

Method *	
Setting	
Participants *	
# Participants	Group A: Group B:
Interventions	Interventions A: *
	Interventions B: *
Authors Conclusion	
Reviewers Comments *	
Complete	No

Extraction Details: Extraction - Name (2011) - Comparable Cohort / Case Control Studies Study Information

* denotes field which will appear in report appendix

Method *	
Setting	
Participants *	
# Participants	Group A: Group B:
Interventions	Interventions A: *
	Interventions B: *
Authors Conclusion	
Reviewers Comments *	
Complete	No

Extraction Details: Extraction - Name (2011) - Descriptive / Case Series Studies
Study Information

* denotes field which will appear in report appendix

Method *	
Setting	
Participants *	
# Participants	
Interventions *	
Authors Conclusion	
Reviewers Comments *	
Complete	No

Appendix VI: Data Extraction Instruments

JBI Data Extraction Form for Experimental / Observational Studies

Reviewer _____ Date _____

Author _____ Year _____

Journal _____ Record Number _____

Study Method

RCT ☐ Quasi-RCT ☐ Longitudinal ☐

Retrospective ☐ Observational ☐ Other ☐

Participants

Setting _____

Population _____

Sample size

Group A _____ Group B _____

Interventions

Intervention A _____

_____

Intervention B _____

_____

Authors Conclusions:

_____

_____

_____

Reviewers Conclusions:

_____

_____

_____

Appendix V-Critical appraisal details

Number of studies included and excluded

Number of studies included	Number of studies excluded
32	4

Critical appraisal - Randomised Control Trial / Pseudo-randomised Trial

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Kakagia, D., Karadimas, E. J., Drosos, G., Ververidis, A., Trypsiannis, G., Verettas, D., 2012	Y	N	U	N/A	U	Y	Y	Y	Y	Y
%	100.0	0.0	0.0	N/A	0.0	100.0	100.0	100.0	100.0	100.0

Critical appraisal - cohort / Case Control Studies

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Labler, L., Rancan, M., Mica, L., Harter, L., Mihic-Probst, D., Keel, M., 2009	Y	Y	N	N	Y	Y	N/A	Y	Y
Matt, S. E., Johnson, L. S., Shupp, J. W., Kheirbek, T., Sava, J. A., 2011	Y	Y	N	N	Y	Y	N/A	Y	Y
Medina, C., Spears, J., Mitra, A., 2008	Y	Y	N	N	Y	Y	N/A	Y	Y
Saziye, K., Mustafa, C., Ilker, U., Afksendyios, K., 2011	Y	Y	N	N	Y	Y	N/A	Y	Y
Yang, C. C., Chang, D. S., Webb, L. X., 2006	Y	Y	Y	N	Y	Y	Y	Y	Y
Zannis, J., Angobaldo, J., Marks, M., DeFranzo, A., David, L., Molnar, J., Argenta, L., 2009	Y	Y	Y	Y	Y	Y	Y	Y	Y
Janzing, H. M. & Broos, P. L., 2001	Y	Y	N	N	Y	Y	N/A	Y	N
Fowler, J. R., Kleiner, M. T., Das, R., Gaughan, J. P., Rehman, S., 2012	Y	Y	Y	Y	Y	Y	N/A	Y	Y
%	100.0	100.0	37.5	25.0	100.0	100.0	100.0	100.0	87.5

Critical appraisal - Descriptive / Case Series Studies

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Johnson, S. B., Weaver, F. A., Yellin, A. E., Kelly, R., Bauer, M., Baker, D., Ascer, E., Friedell, M., Ricotta, J., 1992	Y	Y	N	Y	Y	Y	N/A	Y	Y
Zorrilla, P., Marin, A., Gomez, L. A., Salido, J. A., 2005	N	Y	N	Y	N/A	Y	N/A	Y	Y

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Bail, D. H. L., Schneider, W., Khalighi, K., Seboldt, H., 1998	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Bjarnesen, J. P., Wester, J. U., Siemssen, S. S., Blomqvist, G., Jensen, N. K., 1996	N	N	N	Y	N/A	Y	N/A	Y	Y
Dodenhotf, R. M. & Howell, G. E. D., 1997	N	Y	N	Y	N/A	Y	N/A	Y	Y
Gabriel, A., Heinrich, C., Shores, J., Cho, D., Baqai, W., Moores, D., Miles, D., Gupta, S., 2009	N	Y	N	Y	N/A	Y	N/A	Y	Y
Govaert, G. A. M. & Van Helden, S., 2010	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Harris, I., 1993	N	Y	N	Y	N/A	Y	N/A	Y	N/A
McKenney, M. G., Nir, I., Fee, T., Martin, L., Lentz, K., 1996	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Singh, N., Bluman, E., Starnes, B., Andersen, C., 2008	N	Y	N	Y	N/A	Y	Y	Y	Y
Suliman, M. T. & Aizaz, S., 2008	N	Y	N	Y	N/A	Y	N/A	Y	Y
Taylor, R. C., Reitsma, B. J., Sarazin, S., Bell, M. G., 2003	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Weiland, D. E., 2007	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Wiger, P., Blomqvist, G., Styf, J., 2000	N	Y	N	Y	Y	Y	N/A	Y	Y
Wiger, P., Tkaczuk, P., Styf, J., 1998	N	Y	N	Y	N/A	Y	N/A	Y	Y
Bulstrode, C. J. K., King, J. B., Worpole, R., Ham, R. J., 1985	N	N	N	Y	N/A	Y	N/A	Y	N/A
Barnea, Y., Gur, E., Amir, A., Leshem, D., Zaretski, A., Miller, E., Shafir, R., Weiss, J., 2006	N	Y	N	Y	N/A	Y	Y	Y	N/A
Cohn, B. T., Shall, J., Berkowitz, M., 1986	N	N	N	Y	N/A	Y	N/A	Y	N/A
Chiverton, N. & Redden, J. F., 2000	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Asgari, M. M. & Spinelli, H. M., 2000	N	Y	N	Y	N/A	Y	N/A	Y	Y
Bibi, C., Nyska, M., Howard,	N	N	N/A	Y	N/A	Y	N/A	Y	N/A

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
C., Dekel, S., 1991									
DiStasio, A. J., 2nd, Dugdale, T. W., Deafenbaugh, M. K., 1993	N	Y	N	Y	N/A	Y	N/A	Y	N/A
Walker, T., Gruler, M., Ziemer, G., Bail, D. H., 2012	U	Y	N	Y	N/A	Y	Y	Y	Y
%	4.35	82.61	0.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix VI: Included Studies

Asgari, M. M. and Spinelli, H. M.. The vessel loop shoelace technique for closure of fasciotomy wounds. Ann Plast Surg.2000; 44(2): 225-9.

Bail, D. H. L., Schneider, W., Khalighi, K., Seboldt, H.. Temporary wound covering with a silicon sheet for the soft tissue defect following open fasciotomy. Journal of Cardiovascular Surgery.1998; 39(5): 587-591.

Barnea, Y., Gur, E., Amir, A., Leshem, D., Zaretski, A., Miller, E., Shafir, R., Weiss, J.. Delayed primary closure of fasciotomy wounds with Wisebands(registered trademark), a skin- and soft tissue-stretch device. Injury.2006; 37(6): 561-566.

Bibi, C., Nyska, M., Howard, C., Dekel, S.. Compartmental syndrome due to high velocity missile injury of the calf: use of immediate mesh skin grafting. Mil Med.1991; 156(8): 436-8.

Bjarnesen, J. P., Wester, J. U., Siemssen, S. S., Blomqvist, G., Jensen, N. K.. External tissue stretching for closing skin defects in 22 patients. Acta Orthopaedica Scandinavica.1996; 67(2): 182-184.

Bulstrode, C. J. K., King, J. B., Worpole, R., Ham, R. J.. A simple method for closing fasciotomies. Annals of the Royal College of Surgeons of England.1985; 67(2): 119-120.

Chiverton, N. and Redden, J. F.. A new technique for delayed primary closure of fasciotomy wounds. Injury.2000; 31(1): 21-4.

Cohn, B. T., Shall, J., Berkowitz, M.. Forearm fasciotomy for acute compartment syndrome: a new technique for delayed primary closure. Orthopedics.1986; 9(9): 1243-6.

DiStasio, A. J., 2nd, Dugdale, T. W., Deafenbaugh, M. K.. Multiple relaxing skin incisions in orthopaedic lower extremity trauma. Journal of Orthopaedic Trauma.1993; 7(3): 270-4.

Dodenhotf, R. M. and Howell, G. E. D.. The shoelace technique for wound closure in open fractures: Report of early experience. Injury.1997; 28(9-10): 593-595.

Fowler, J. R., Kleiner, M. T., Das, R., Gaughan, J. P., Rehman, S.. Assisted closure of fasciotomy wounds. Bone and Joint Research.2012; 1(3): 31-35.

Gabriel, A., Heinrich, C., Shores, J., Cho, D., Baqai, W., Moores, D., Miles, D., Gupta, S.. Outcomes of vacuum-assisted closure for the treatment of wounds in a paediatric population: case series of 58 patients. J Plast Reconstr Aesthet Surg.2009; 62(11): 1428-36.

Govaert, G. A. M. and Van Helden, S.. Ty-raps in trauma: A novel closing technique of extremity fasciotomy wounds. Journal of Trauma - Injury, Infection and Critical Care.2010; 69(4): 972-975.

Harris, I.. Gradual closure of fasciotomy wounds using a vessel loop shoelace. Injury.1993; 24(8): 565-6.

Janzing, H. M. and Broos, P. L.. Dermatotraction: an effective technique for the closure of fasciotomy wounds: a preliminary report of fifteen patients. J Orthop Trauma.2001; 15(6): 438-41.

Johnson, S. B., Weaver, F. A., Yellin, A. E., Kelly, R., Bauer, M., Baker, D., Ascer, E., Friedell, M., Ricotta, J.. Clinical results of decompressive dermotomy-fasciotomy. American Journal of Surgery.1992; 164(3): 286-290.

Kakagia, D., Karadimas, E. J., Drosos, G., Ververidis, A., Trypsiannis, G., Verettas, D.. Wound closure of leg fasciotomy: Comparison of vacuum-assisted closure versus shoelace technique. A randomised study. Injury.2012; ( ): .

Labler, L., Rancan, M., Mica, L., Harter, L., Mihic-Probst, D., Keel, M.. Vacuum-assisted closure therapy increases local interleukin-8 and vascular endothelial growth factor levels in traumatic wounds. J Trauma.2009; 66(3): 749-57.

Matt, S. E., Johnson, L. S., Shupp, J. W., Kheirbek, T., Sava, J. A.. Management of fasciotomy wounds-does the dressing matter?. American Surgeon.2011; 77(12): 1656-1660.

McKenney, M. G., Nir, I., Fee, T., Martin, L., Lentz, K.. A simple device for closure of fasciotomy wounds. Am J Surg.1996; 172(3): 275-7.

Medina, C., Spears, J., Mitra, A.. The use of an innovative device for wound closure after upper extremity fasciotomy. Hand (N Y).2008; 3(2): 146-51.

Saziye, K., Mustafa, C., Ilker, U., Afksendyios, K.. Comparison of vacuum-assisted closure device and conservative treatment for fasciotomy wound healing in ischaemia-reperfusion syndrome: preliminary results. Int Wound J.2011; 8(3): 229-36.

Singh, N., Bluman, E., Starnes, B., Andersen, C.. Dynamic wound closure for decompressive leg fasciotomy wounds. Am Surg.2008; 74(3): 217-20.

Suliman, M. T. and Aizaz, S.. Closing fasciotomy wounds using plastic bands: an alternative simple and cheap method. Ann Vasc Surg.2008; 22(5): 697-700.

Taylor, R. C., Reitsma, B. J., Sarazin, S., Bell, M. G.. Early results using a dynamic method for delayed primary closure of fasciotomy wounds. J Am Coll Surg.2003; 197(5): 872-8.

Walker, T., Gruler, M., Ziemer, G., Bail, D. H.. The use of a silicon sheet for gradual wound closure after fasciotomy. J Vasc Surg.2012; 55(6): 1826-8.

Weiland, D. E.. Fasciotomy closure using simultaneous vacuum-assisted closure and hyperbaric oxygen. Am Surg.2007; 73(3): 261-6.

Wiger, P., Blomqvist, G., Styf, J.. Wound closure by dermatotraction after fasciotomy for acute compartment syndrome. Scand J Plast Reconstr Surg Hand Surg.2000; 34(4): 315-20.

Wiger, P., Tkaczuk, P., Styf, J.. Secondary wound closure following fasciotomy for acute compartment syndrome increases intramuscular pressure. J Orthop Trauma.1998; 12(2): 117-21.

Yang, C. C., Chang, D. S., Webb, L. X.. Vacuum-assisted closure for fasciotomy wounds following compartment syndrome of the leg. J Surg Orthop Adv.2006; 15(1): 19-23.

Zannis, J., Angobaldo, J., Marks, M., DeFranzo, A., David, L., Molnar, J., Argenta, L.. Comparison of fasciotomy wound closures using traditional dressing changes and the vacuum-assisted closure device. Ann Plast Surg.2009; 62(4): 407-9.

Zorrilla, P., Marin, A., Gomez, L. A., Salido, J. A.. Shoelace technique for gradual closure of fasciotomy wounds. J Trauma.2005; 59(6): 1515-7.

Appendix VII: Excluded Studies

[1] Boxer, L.K. and Buchman, S.R., An alternative method of closure of fasciotomy wounds: healing by secondary intention

> Reason for exclusion: Methodology lacked rigor including criteria for inclusion in study not defined and no length of stay recorded.

[1] Harrah, J., Gates, R., Carl, J., Harrah, J. D., A simpler, less expensive technique for delayed primary closure of fasciotomies

> Reason for exclusion: Paper described a wound management technique but data about the patients the method was used on was not clearly enough described in the paper

[1] Heemskerk, J. and Kitslaar, P., Acute compartment syndrome of the lower leg: retrospective study on prevalence, technique, and outcome of fasciotomies

> Reason for exclusion: Outcomes of interest not clearly defined

[1] Schwartz Jr, J. T., Brumback, R. J., Lakatos, R., Poka, A., Bathon, G. H., Burgess, A. R., Acute compartment syndrome of the thigh. A spectrum of injury

> Reason for exclusion: This study reviewed patients who developed thigh compartment syndrome overall therefore wound management was not the main focus of the paper and most outcomes of interest were not documented