Outcomes of end of range axilla splinting in children following burn injury

Rhianydd Thomas, B.App.Sci (Phty), MIPH

MACQUARIE University

Department of Health Professions
Macquarie University

Thesis presented for the degree of
Master of Research
Submitted 14 October 2018

Table of Contents

Preface ..... **v**

Thesis aims ..... **vi**

Abstract ..... **vii**

Candidate's Statement ..... **viii**

Supervisor's Statement ..... **ix**

Acknowledgements ..... **x**

List of Abbreviations ..... **xi**

Chapter One: Burns and the development of burn scar contracture **1**

1.1 Epidemiology of paediatric burn injury 2

1.2 Post burn hypertrophic scarring 3

1.2.1. Development of post burn hypertrophic scar tissue 3

1.2.2. Prevalence of post burn hypertrophic scarring 3

1.2.3. Predictors of hypertrophic scar development 8

1.2.4. Scar management 13

1.3 Burn scar contracture 14

1.3.1. Development of burn scar contracture 14

1.3.2. Prevalence of burn scar contracture 14

1.3.3. Predictors of burn scar contracture 16

1.3.4. Prevention and management of post burn contracture 19

Chapter Two: The shoulder joint and prevention of axilla contracture **22**

2.1 The shoulder joint 23

2.2 Postburn axilla splinting described in literature 25

2.3 Therapy management of axilla burns at The Children's Hospital at Westmead 30

Chapter Three: Outcomes of end of range axilla splinting in children following burn injury 32

Statement from co-authors confirming authorship contribution of the Master of Research candidate 33

Abstract 36

Introduction 37

Methods 40

Results 43

Discussion 55

References 59

Chapter Four: Discussion 62

Key Findings 63

Conclusion 79

References 81

Appendix 1: Axilla splint materials, design and fabrication 87

Appendix 2: Journal of Burn Care and Research manuscript preparation 90

Appendix 3: Sydney Children's Hospital Network ethics approval 95

List of Tables and Figures for Chapter One & Chapter Two

Table 1.1: Subjective burn scar scales 5

Table 1.2: Prevalence and predictors of post burn hypertrophic scarring 10

Table 1.3: Prevalence and predictors of burn scar contracture 17

Table 2.1: Prevalence of post burn shoulder contracture 24

Table 2.2: Outcomes of postburn axilla splinting described in literature 27

Figure 2.1: Shoulder positions which elicit nerve tension 29

List of Tables and Figures for Chapter Three

Figure 1: End of range axilla splint fabrication 39

Figure 2: Flowchart of patient inclusion 44

Table 1: Baseline and clinical characteristics of children splinted (categorical variables) 45

Figure 3: Frequency, mechanism and mean %TBSA of burn by age 46

Table 2: Characteristics of children according to length of time axilla splint used (continuous variables) 48

Table 3: Physiotherapy interventions for scar management in children splinted ≥60 days (n=49) 49

Figure 4: Hours end of range axilla splint worn in 24 hour period in children splinted ≥60 days (n=49) 50

Figure 5: Children treated with end of range axilla splint 51

Figure 6: Flowchart depicting numbers of children with early signs of contracture development in the first 9 months post burn 52

Table 4: Univariate analysis of characteristics at baseline and 1-month assessment associated with early signs of contracture development 53

Preface

This thesis is comprised of four chapters. **Chapter 1** is a synthesised literature review, providing in-depth background about the development, prevalence, predictors and current interventions for hypertrophic scarring and burns scar contracture following burn injury. **Chapter 2** investigates the prevalence of axilla contracture post burn and methods of axilla splinting described in literature. **Chapter 3** is a retrospective study exploring outcomes of end of range axilla splinting in children following burn injury. This chapter is presented in the format of the manuscript which has been submitted to Journal of Burn Care and Research. **Chapter 4** systematically explores the findings of the thesis in greater detail and considers the implications for clinical practice and research. This chapter discusses limitations of the research as well as key recommendations. The references for Chapters 1, 2, and 4 are presented together after Chapter 4, while the references for Chapter 3 are presented at the end of the submitted manuscript.

Thesis aims

This thesis aims to build upon the current knowledge regarding the prevalence and predictors of hypertrophic scarring and burns scar contracture following burn injury. Specifically, the outcomes associated with end of range splinting of the axilla post burn will be described and compared to current axilla splinting methods discussed in published literature.

To achieve this, the objectives of this thesis are to:

- Critically appraise the available literature regarding the prevalence and predictors of hypertrophic scarring and burns scar contracture following burn injury. Investigate the prevalence of axilla contracture post burn and current axilla splinting methods described in literature (Chapter 1 and 2).
- Describe outcomes resulting from splinting the axilla at end of range shoulder abduction with 15°-20° horizontal adduction over a 10 year period at one tertiary paediatric burn unit (Chapter 3).
- Evaluate and explore the outcomes of end of range axilla splinting in relation to previous research of axilla splinting methods. In addition, to discuss implications for clinical practice, future research, limitations and key recommendations (Chapter 4).

Abstract

This thesis explores the prevalence and predictors of hypertrophic scarring and burn scar contracture in adults and children. It builds upon the limited evidence base of axilla splinting as an intervention, which may be a valuable treatment strategy to prevent axilla contracture following burn injury to this area. To date, two randomised control trials have been completed into the effectiveness of axilla splinting at 90° abduction post burn in adult cohorts. In children, the only available evidence is a case series of 23 children splinted between 90° and 160° abduction post burn, published in 1985. Anecdotally, at the Children's Hospital at Westmead splinting the axilla at end of range post burn injury is well-tolerated with excellent range of movement outcomes.

Therefore, a retrospective study was completed, exploring outcomes from January 2006 to July 2016 in 76 children. No child developed contracture of the axilla for the duration of the 2 year study follow-up with no adverse events recorded. Children who required splinting ≥60 days to maintain full axilla range of movement had a higher frequency of deep burn, flame mechanism and burn distribution involving the anterior trunk, flank and arm compared to children who were splinted <60 days. Early signs of contracture, considered to be loss of full axilla range of movement or significant banding, developed in 9 children within the first 3 months post burn. All 9 children responded to intensive therapy with restoration of full axilla range by 9 months post burn.

End of range splinting may be a valuable intervention to maintain axilla range of movement in children following a burn to this area. To provide better evidence of the efficacy, feasibility and safety of end of range axilla splinting, comparison of this intervention to other types of axilla splinting practice or exercise only is recommended. Future research should also focus on improving reporting of the prevalence and predictors of burn scar contracture and hypertrophic scarring.

Candidate's Statement

I, Rhianydd Thomas, certify that the work in this thesis titled 'Outcomes of end of range axilla splinting in children following burn injury' has not been previously submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis. The research presented in this thesis was approved by Sydney Children's Hospital Network (LNR/18/SCHN/19) on 12 February 2018 and Macquarie University (reference number 5201800330).

Rhianydd Thomas (45045623)

Signed: 

Date: 13 October 2018

Supervisor's Statement

As the supervisor of Rhianydd Thomas' Master of Research work, I certify that I consider her thesis 'Outcomes of end of range axilla splinting in children following burn injury' to be suitable for examination.

Dr Verity Pacey
Department of Health Professions
Faculty of Medicine and Health Sciences
Macquarie University

Acknowledgements

I would like to thank my supervisor Verity, for her continuous support, guidance, knowledge and enthusiasm. I could not have asked for a better supervisor.

I would also like to thank my close friend and colleague Steph, for her invaluable help and constant encouragement with this project. Her passion for burns and research is inspiring, and I have really enjoyed our many discussions.

I would like to express my appreciation to my Mum and Mother-in-law for the countless hours of babysitting. I am so grateful for the opportunity to complete this project and your help has been invaluable.

To my husband Matt, your patience, support and encouragement mean the world to me. I could not have completed this without you.

To my 2 boys, I am so looking forward to some long overdue beach days together.

List of Abbreviations

ADLs	Activities of daily living
BSC	Burns scar contracture
CFUs	Cutaneous functional units
CHW	Children's Hospital at Westmead
CI	Confidence interval
CMC	Carpometacarpal
df	Degrees of freedom
ICC	Intraclass correlation coefficient
ICU	Intensive care unit
IP	Interphalangeal
ISBI	International Society of Burn Injuries
LOS	Length of stay
MCP	Metacarpophalangeal
mm	Millimetre
mVSS	Modified Vancouver Scar Scale
NSW	New South Wales
OR	Odds ratio
PICU	Paediatric Intensive Care Unit
POSAS	Patient and Observer Scar Scale
RCT	Randomised Control Trial
ROM	Range of movement
SBIS	Severe Burn Injury Service
SCHN	Sydney Children's Hospital Network
SD	Standard deviation
TBSA	Total Body Surface Area
VSS	Vancouver Scar Scale

Chapter One:
Burns and the development of burn scar contracture

1.1 Epidemiology of paediatric burn injury

Burns are a leading cause of childhood injury. In Australia, young children aged 0-4 years are significantly more likely to be hospitalised as a result of burn injury than any other age group.[1,2] In children aged 12 months or younger, nearly 85% of burn injuries occur between the ages of 7 and 12 months.[1] This is a reflection of the increasing mobility in this age group, the desire to explore their environment and their ability to reach and grasp.[1] In children younger than five years, a quarter of all burns involve the wrist and hand, followed by the trunk (21%).[2] In this age group, a scald injury is the most common mechanism of burn.[1-3] With increasing age, different patterns emerge and in males aged 10 through to 29 years, there is a sharp increase in the incidence of flame burns, with a larger proportion of burns to the trunk, hip and lower limb.[1,2] In all ages, there are greater numbers of hospitalised burn injury in males compared to females.[1,2] This begins in early childhood and peaks during the teenage to middle age years.[1,2]

Burn care has seen many advances over recent decades, with increasing survival rates resulting in an increased focus on quality of life and function post burn.[4,5] Poor scar quality and joint contracture are significant impediments to quality of life following burn injury.[6,7] Scarring remains an unavoidable result of deep dermal and full thickness burns and has wide ranging and significant long-term physical and functional implications. The development of fibrous, inextensible scar tissue across or in close proximity to a joint can result in joint contracture, defined as the inability of the joint to move through its full, expected range of movement (ROM).[7-12] Adults with at least one post burn contracture have significantly lower self-perceived physical functioning.[13] Individuals with moderate to severe contracture post burn have significantly poorer quality of life and an increased frequency of depression, compared to those without contracture.[14]

The development of burn scar contracture (BSC) commonly occurs in the presence of hypertrophic scarring. Consequently, the development and prevalence of hypertrophic scarring, and therapy interventions utilised to improve scar outcomes,

are essential to consider in the context of BSC. A retrospective review of adults treated through an outpatient burn unit found that 28% of patients post burn developed joint contracture in the presence of hypertrophic scarring.[5] Full joint movement requires skin mobility over a large area around a joint.[8] The development of thick, hypertrophic scar tissue in proximity to a joint can result in restricted joint ROM and therefore hypertrophic scarring and joint contracture are ultimately related.

1.2 Post burn hypertrophic scarring

1.2.1. Development of post burn hypertrophic scar tissue

Hypertrophic scars are considered highly vascular, thick and raised above the surrounding skin, while remaining within the margin of the original wound.[15,16] They develop as a result of a complex process of wound healing, activated by deep dermal fibroblasts, which proliferate and produce large amounts of collagen with low levels of collagenase synthesized to degrade the excess collagen.[15] The deep dermal fibroblasts create a scaffold for cell migration and vascularisation, which in combination with the overproduction of collagen and loss of elastin creates scar tissue that is highly vascular with an abundant and disorganised matrix.[15,17]

Scar tissue is considerably less extensible than normal skin. Its formation is an ongoing dynamic process, which generally reaches its peak around 6 months post burn.[18] After this period the process slows and scar hypertrophy shows a tendency to regress until complete maturation at 18 to 24 months post burn.[18,19] To achieve optimal outcomes, scar management with regular reassessment and modification should continue until maturation is complete and the scar is no longer amenable to therapy techniques.[20]

1.2.2. Prevalence of post burn hypertrophic scarring

Significant variation exists in the prevalence of post burn hypertrophic scarring, with published literature reporting prevalence data at varying time points during the scar maturation process. Current research reports the prevalence of hypertrophic scarring to be between 20% and 77% of adults following burn injury.[5,21-24] There is less

variation in children, with hypertrophic scar development reported between 16% and 41% of children following burn injury.[16,24-27] The majority of authors considered a hypertrophic scar to be present if the scar met criteria at any point during follow-up.[22-27] Other authors considered a scar to be hypertrophic if it met criteria at 12 months post burn.[16,21] Comparability of prevalence data cannot be explored without first considering variations in literature on the definition of a hypertrophic scar, based on different subjective burn scar assessment scales. Many subjective burn scar assessment scales have been described with varying levels of validity and reliability.[18,19,28-32] Currently, there is no consensus on the best subjective scale for burn scar assessment and as a result, the primary outcome measure to determine the presence of a hypertrophic scar is not consistent across research.[33] In clinical and research settings, the ability to obtain a measure of a scar is essential to monitor scar progress in terms of vascularity, pliability, height and pigmentation, to evaluate the effectiveness of intervention and report on the prevalence of hypertrophic scarring post burn.[34]

The two most commonly used validated subjective assessment scales are the Vancouver Scar Scale (VSS)[18] and the Patient and Observer Scar Scale (POSAS)[28]. These are presented in Table 1.1 along with other subjective scar scales, which are predominately modifications to the VSS.

Table 1.1: Subjective burn scar scales

Scar Scale	Study design	Subjects	Scar assessment and timing	Assessment parameters	Score*	Inter-rater and Intra-rater reliability
Vancouver Scar Scale (VSS) ***Sullivan et al***[18] **1990**	Cross sectional	n = 73 (Age 3-75 years) 73 burn scars assessed	Three occupational therapists (OT) assessed 4cm^2 burn scars up to 100 months post burn.	Pigmentation Vascularity Pliability Height	0-13	Inter-rater; Cohen's k 0.40 - 0.56 (SE 0.08-0.10) Intra-rater; not assessed
Modified Vancouver Scar scale (mVSS) ***Schwanholt et al***[29] **1994**	Prospective longitudinal	n = 63 (Age 6 months-16 years) 63 burn scars assessed	Two therapists (details not provided) independently assessed 1 inch^2 burn scars every 1-3 months until scar maturity, up to 19 months post burn.	VSS without pigmentation category	0-11	Inter-rater; not assessed Intra-rater; not assessed
mVSS ***Baryza and Baryza***[30] **1995**	Cross sectional	Not specified	PT's and OT's in the rehabilitation service assessed burn scars (number of assessors and details of assessment not provided).	VSS plus administration of plexiglass tool to assist measure of pigmentation and height	0-14	Inter-rater; ICC 0.81, k 0.56-0.73 Intra-rater; not assessed
mVSS ***Nedlec et al***[31] **2000**	Prospective longitudinal	n = 15 (Age 10-49 years) 18 burn scars assessed	Three observers; untrained multidisciplinary professionals (nurse, OT, physician) assessed burn scars monthly up to 7-9 months post burn.	VSS plus %TBSA, body chart and skin colour. Pigmentation assessed from normal to severe. Patient assessment of pain and itch.	0-14	Inter-rater; ICC 0.53 Intra-rater; not assessed

Scar Scale	Study design	Subjects	Scar assessment and timing	Assessment parameters	Score*	Inter-rater and Intra-rater reliability
mVSS ***Oliveira et al***[19] **2005**	Cross sectional	n = 62 (Age 2-17 years) 62 burn scars assessed	3 blinded observers (details about observers not provided) assessed photographs of burn scars 18-24 months post injury.	VSS plus mixed pigmentation category and pain and pruritis assessment	0-18	Inter-rater; not assessed Intra-rater; not assessed
mVSS ***Forbes- Duchart et al***[32] **2007**	Cross sectional	n = 14 (Age 1-16 years) 32 burn scars assessed	Three independent observers; OT with >10 years burn experience, OT with no scar experience, plastic surgeon experienced in burn care assessed 2 inch^2 burn scars ≤1 year post burn injury.	VSS plus two pictoral colour scales for Caucasian and Canadian Indigenous scars and the plexiglass tool by Baryza and Baryza[30]	0-15	Inter-rater; ICC 0.76-0.84, p <0.05 Intra-rater; not assessed
Patient and Observer Scar Scale (POSAS) ***Draaijers et al***[28] **2004**	Cross sectional	n = 20 (Age 15-73 years) 29 burn scars assessed	Four independent observers (all physicians) assessed 3cm^2 burn scars 3-360 months post burn. Each patient completed the Patient Scale for their scar area.	VSS plus patient assessments of pain, itch, colour, stiffness, thickness and relief	5-50	Inter-rater; Obs Scale ICC 0.92 95% CI 0.87-0.95 CV 18% SE_{meas} 3.14 Intra-rater; Obs Scale ICC 0.73 95% CI 0.62-0.82

Minimum age for testing in children where information available; VSS (Sullivan et al[18]) 3 years; mVSS (Baryza and Baryza[30]) 16 years; mVSS (Nedlec et al[31]) 10 years; mVSS (Oliveira et al[19]) 2 years; mVSS (Forbes-Duchart et al[32]) 1 year; POSAS (Draaijers et al[28]) 15 years.
*Higher score indicates a more hypertrophic scar
Abbreviations; CI, confidence interval; CV, coefficient of variation; ICC, intraclass correlation coefficient; k, kappa; mVSS, modified Vancouver Scar Scale; n, number; Obs, observer; OT, occupational therapist; POSAS, Patient and Observer Scar Assessment Scale; PT, physical therapist; SE_{meas}, standard error of measurement; SSS, split skin graft; TBSA, total body surface area; VSS, Vancouver Scar Scale.

The VSS was developed in 1990.[18] It was the first validated scar scale to be used extensively in clinical practice and has been widely used in research.[35,36] However, as demonstrated in Table 1.1, it has been found to have low internal consistency and low to moderate intraclass correlation coefficients (ICCs) with one observer and moderate ICC with four observers.[28] A systematic review also found the VSS to have indeterminate evidence of validity, reliability and responsiveness.[34] Further criticisms include the lack of focus on patient perception of the scar, the inability to capture variation across the whole scar surface and the limited sensitivity in detecting small changes as the scope of rating for each scar component is small.[18,31,37] To address the perceived limitations of the VSS, several authors developed their own versions, referred to as modified Vancouver Scar Scale's (mVSS).[29-31] Despite various modifications and perceived improvements to the VSS, a systematic review found that no mVSS had any advantage over the original VSS, with all modified scales having low, indeterminate or no evidence of validity or reliability.[34]

The POSAS was introduced in 2004 and includes patient assessment of scar quality, including perception of pain and itch.[28] The POSAS has demonstrated good internal consistency for the patient and observer scales.[28] Compared to the VSS, the POSAS has less variability and greater reliability for single observer assessments, making it more applicable to both the clinical and research settings.[28] At present, the POSAS has not been assessed for test-retest reliability, with evidence only to support use at a single timepoint.[34] It has also not been validated in children younger than 15 years and therefore is not a valid and reliable scar assessment for younger children.[28] The inclusion of self-reported components in the POSAS requires thorough assessment to demonstrate its applicability to paediatric clinical or research settings before its use within these environments.

Subjective scar assessment scales are widely used clinically and in research to determine the presence of a hypertrophic scar. However, no scar assessment scale has a well-defined cut-off value to indicate hypertrophic scarring and there is a lack of consensus on what score or value on each scale constitutes or defines the presence of a hypertrophic scar.[36] A universally accepted definition based on a validated scar scale is essential to improve comparability of research, strengthen understanding of data and enable multi-unit trials.[36]

1.2.3. Predictors of hypertrophic scar development

The ability to predict patients at increased risk of hypertrophic scar development is essential to guide clinical decision making and determine optimal scar management. To study outcomes achieved by scar management interventions, it is essential to be able to account for known hypertrophic scarring risk factors in study design and analysis. Studies investigating predictive factors for hypertrophic scarring in adults and children are presented in Table 1.2.

Inconsistencies in the research methodologies employed within these studies result in difficulties when comparing the research findings and an inability to draw meaningful conclusions, due to the variations in defining a hypertrophic scar and the different population groups studied. The definition of a hypertrophic scar ranged from scars deemed to have increased elevation or thickness subjectively by the assessor,[24] to varying scores on modifications to the VSS. [16,21,22,25] Two studies by Wallace et al[16,21] selected scar height, a subscore of a mVSS, to determine the presence of a hypertrophic scar as this measure relates to the bulk of the scar above the level of unaffected skin. In these studies, a scar was considered hypertrophic if its height was deemed greater than 1mm by the assessor.[16,21] Three retrospective studies were limited to information available from medical records and used scar description or the presence of scar management to determine whether a hypertrophic scar had developed.[5,26,27] Consequently, it is likely that a scar could be considered hypertrophic in one study but not in another.

The research studies were also conducted in different population groups. Several authors focused on determining risk factors in children,[4,16,25-27] while others considered adults[5,21-23] or patients of all ages.[24] Clinical differences were also evident. Two studies excluded patients who required surgical management of the burn wound,[24,25] two recruited scald injuries only[26,27] while others included all mechanisms of injury and both conservative and surgical management of the wound.[4,16,21] The timing of scar assessment also varied considerably, with scars deemed hypertrophic at a minimum of 3 months post burn in one study[22] and up to 5 years post burn in another.[27] The effect of scar management on the prevalence of hypertrophic scarring was also often not considered. Treatment regimes were frequently poorly documented with either no specification of scar management or a

lack of detail regarding indications for commencement, interventions prescribed and patient adherence.[16,21,25,22-24,26]

Despite variation in the study populations, common predictors of hypertrophic scarring were evident in the research. Clinical features related to severity of the burn injury were found to be statistically significant with larger percent total body surface area (TBSA) burn[4,16,21,23] and longer time to heal[4,16,25] all associated with an increased risk of hypertrophic scarring in multivariate analysis in adults and children. Longer hospital stay[21] and wound complications such as graft loss or infection[21] were significant risk factors resulting from multivariate analysis in adults but not children. These findings suggest that factors directly influenced by both the injury and acute phase wound management are significant to future scar outcome, particularly in adult cohorts.

In comparison to factors related specifically to the burn injury, less consistency is clear when assessing the relationship between intrinsic patient characteristics and hypertrophic scar development. In multivariate analyses, age and sex were not statistically significant in several studies,[4,16,23] yet other studies reported a statistically significant association with female sex and younger aged adults.[5,21] Wallace et al,[21] who found that adult females were more likely develop hypertrophic scarring than adult males, hypothesised that this finding may be in contrast to what is reported by other authors due to differences in study populations, outcome measures and statistical approaches. Darker skin types, including American Indian,[23] Alaskan[23] and Fitzpatrick skin types 4-6[21] (brown to black skin) also demonstrated a statistically significant association with hypertrophic scarring within multivariate analyses. In univariate analysis in another study, African American and Asian race were also significantly associated with hypertrophic scarring.[22] In children, no significant relationship has been demonstrated between race and hypertrophic scar development.[16]

Table 1.2: Prevalence and predictors of post burn hypertrophic scarring

Study	Study design	Subjects	Therapy provided	Classification of HTS	Follow up	Results	
						Prevalence of HTS	Significant predictors of HTS*
Wallace et al [21] **2017**	Prospective case control Study period 2010-2015	n = 616 403 males >16y Inpatients/ outpatients Median TBSA 2.8%	Scar management provided, details not specified	SH >1mm as subscore of mVSS at 12 months post burn Cases = SH >1mm Controls = SH 0-1mm	Assessed at 3,6,12 months post burn	20.1%	**Multivariate analysis to predict SH >1mm OR (95% CI)**; **Female sex** OR 2.5 (1.6-3.8) **Age 45-60 years compared to <30 years** OR 0.2 (0.1-0.4) **Wound complications** OR 2.8 (1.8-4.4) **Fitzpatrick skin type 4-6**** OR 4.9 (3-8.1) **Hospital stay 30-60 days compared to 0 days** OR 5 (1.3-18.7) **Hospital stay >60 days compared to 0 days** OR 11.6 (1.1-124.7) **%TBSA >20% compared to 0-5%** OR 8.7 (3.2-23.7)
Wallace et al[16] **2017**	Prospective case control Study period 2011-2015	n = 186 108 males 0 - ≤16y Inpatients/ outpatients Median TBSA 3%	Scar management provided, details not specified	SH >1mm as a subscore of mVSS at 12 months post burn Cases = SH >1mm Controls = SH 0-1mm	Assessed at 3,6,12 months post burn	34.4%	**Multivariate analysis to predict SH >1mm OR (95% CI);** **Each 1% increase in %TBSA** OR 1.16 (1.0-1.3) **Healing time >14 days** OR 11.6 (3.7-36.2) **>1 Surgical procedure** OR 11.5 (2.0-66.6)
Chipp et al[25] **2017**	Prospective longitudinal observational Study period 2011-2013	n = 383 248 males 0-<16y Conservative management (Inpatients/ outpatients) Mean TBSA 2.33%	Not specified	SH >2mm and total score ≥5 on mVSS at any point during 2 year follow-up of the study	2 year study follow up.	17.2%	**Multivariate analysis to predict SH >2mm and total mVSS ≥5 OR (95% CI);** **Each additional day to heal after 8 days gives** OR 1.138, (1.1-1.17)

Study	Study design	Subjects	Therapy provided	Classification of HTS	Follow up	Results	
						Prevalence of HTS	Significant predictors of HTS*
Lonie et al[26] 2017	Retrospective Data inclusion 2011-2015	n = 322 sex not specified 0 - ≤17y Outpatients with scald injury Mean TBSA not specified	Not specified	HTS or never HTS determined by clinical documentation of scar hypertrophy or presence of scar management at any point during treatment.	Time of scar assessment not specified	16.1%	**Time to heal** 15-21 days to heal; HTS 9.3% 22-30 days to heal; HTS 63.6% >30 days to heal; HTS 86.2%
Sood et al[22] 2015	Prospective Study period not specified	n = 425 sex not specified ≥18y Inclusion criteria not specified Mean TBSA 7%	Not specified	VSS score >7 at any point during follow up (range 3-20 months post burn)	Follow-up range 3-20 months post burn	49%	**Univariate analysis for VSS score >7** **Prevalence ratio (95% CI);** **%TBSA** PR 1.1 (1.03-1.16) **≥1 operation** PR 1.3 (1.1-1.7) **Asian race** PR 1.5 (1.2-2.1) **African American race** PR 1.9 (1.4-2.5) Age (p=0.3) and female sex (p=0.7) did not demonstrate a statistically significant relationship with VSS >7
Thompson et al[23] 2013	Prospective observational Study period not specified	n = 300 206 males ≥18y Inclusion criteria not specified Median TBSA 7.1%	Not specified	VSS score >7 at either of the two follow up assessments	Assessment at 1-5 months post burn and 6-12 months post burn	42%	**Multivariate analysis for VSS score >7** **OR (95% CI);** **>20% TBSA** OR 2.0 (1.0-3.6) **Face** OR 9.7 (1.1-83.6) **American Indian/Alaskan** OR 12 (1.4-100.8) Age (p=0.8) and male sex (p=0.6) did not demonstrate a statistically significant relationship with VSS score >7
van der Wal et al[4] 2012	Prospective longitudinal observational Study period 2004-2009	n = 474 289 males Adults and children Inpatients Mean TBSA 11%	Silicone and compression garment prescribed depending on scar location and activity	Mean POSAS score by observer (HTS not defined, relationship between variables and mean POSAS score analysed)	Assessed at 3,6,12 months post burn	Not specified	**Multivariate analysis for higher mean POSAS score** **Regression Coefficient (95%CI);** **%TBSA** RC 0.02 (0.01-0.04) **Partial thickness depth** RC -1.0 (-1.4 to -0.7) **Time to heal** RC -0.05 (-0.1 to -0.002) Age (p>0.2) and aetiology (p=0.8) have no influence on HTS development in multivariate analysis

Study	Study design	Subjects	Therapy provided	Classification of HTS	Follow up	Results	
						Prevalence of HTS	Significant predictors of HTS*
Gangemi et al[5] 2008	Retrospective Data inclusion period 1994-2006	n = 703 412 males Adults Outpatients (2440 burn sites) Mean TBSA 20%	79% of scar locations were treated with medical and rehabilitative therapy.	Normotrophic scar*** or pathologic scar diagnosed on basis of typical signs and symptoms Timing of assessment not specified	Not specified	77%	**Univariate analysis for pathologic scar OR (95% CI);** **Full thickness burn %TBSA** OR 2.48 (1.8-3.4) **Burn site abdomen** OR 0.67 (0.48-0.94) **Number of surgical procedures** OR 1.74 (1.43-2.13) **Sheet graft** OR 0.44 (0.25-0.78) **Multivariate analysis for pathologic scar OR (95% CI);** **Older age** OR 0.64 (0.5-0.9) **Burn site abdomen** OR 0.35, (0.19-0.62)
Cubison et al[27] 2006	Retrospective Data inclusion period 1997-1999	n = 509 296 males ≤16y Inpatients with scald injury Mean TBSA 5.5%	Not specified	HTS or never HTS determined by clinical documentation of hypertrophy or presence of scar management at any point during follow up	Minimum follow up of 4 months post burn, up to 5 years post burn	35%	**Descriptive analysis (%);** **Time to heal** 10-14 days to heal; 8% developed HTS 22-30 days to heal; 52% developed HTS >30 days to heal; 92% developed HTS If time to heal 26-30 days; 75% managed conservatively developed HTS 64% who underwent skin grafting developed HTS
Deitch et al[24] 1983	Prospective Data inclusion period 1980-1981	n = 100 Sex not specified Adults and children Conservative management (Inpatients/ outpatients) (245 burn sites) Mean %TBSA not specified	Pressure garments used. Criteria for use not specified	Increased scar thickness or elevation at any point during 2-year study follow up Site of burn elevation must be >2cm diameter to be considered abnormal	Minimum 9 months post burn and up to 2 years post burn	38% of cohort (41% children 34% adults)	**Descriptive analysis (%);** **Time to heal** 14-21 days to heal; 33% developed HTS >21 days to heal; 78% developed HTS **Upper extremity distribution** 22% children developed HTS 22% adults developed HTS **Chest distribution** 33% children developed HTS 44% adults developed HTS

*Predictors of hypertrophic scarring significant if p<0.05

Fitzpatrick skin type 1-3; white skin. Fitzpatrick skin type 4-6; brown to black skin. * Normotrophic scar, scar which assumes thickness, colour and pliability similar to the surrounding healthy skin[5]

Abbreviations: CI, confidence interval; HTS, hypertrophic scar; mVSS, modified Vancouver Scar Scale; n, number; OR, odds ratio; POSAS, Patient and Observer Scar Assessment Scale; PR, prevalence ratio; RC, regression coefficient; SH, scar height; TBSA, total body surface area; VSS, Vancouver scar scale; y, years.

1.2.4. Scar management

Hypertrophic scarring following burn injury remains a significant challenge despite improvements in wound management. Optimal treatment of the burn wound, both conservative and surgical, is well documented in literature and is essential to achieve timely wound closure and therefore minimise hypertrophic scarring.[38] International Practice Guidelines for Burn Care recommend commencing scar management if conservative wound healing has taken more than 3 weeks or if surgical closure of the wound was required.[39] Literature to guide evidence-based scar management is limited. However, despite limited evidence to support all scar management strategies, burns therapists anecdotally report good outcomes when following best practice guidelines.[39]

The use of compression to minimise hypertrophic scarring is a widely accepted component of scar management, despite limited evidence.[38,40,41] Compression is frequently worn 23 hours per day until scar maturation and can be achieved through bandaging, tubular stocking and compression garments.[38,41] There has been one published meta-analysis on compression therapy post burn, which included 6 randomised control trials (RCT) involving 316 patients, predominately adults.[42] The authors reported that while use of compression garments showed a small but statistically significant reduction in scar height, the available data did not support compression garment use for the prevention of hypertrophic scarring.[42] They concluded that there is insufficient evidence to support the widespread use of compression garments post burn.[42] In children, there have been no RCTs to evaluate the effectiveness of compression garments in the management of burns scars.

Silicone is another widely used scar management intervention. Two RCTs have evaluated the effectiveness of silicone in the management of burn scars and found a significant reduction in pigmentation,[43] vascularity,[43] pliability[43,44] and itch[43,44] associated with its use. However, both RCTs assessed scar results up to 6 months only, which given the long term process of scarring is inadequate to provide conclusive results regarding the effectiveness of silicone.[43,44] Furthermore, a Cochrane analysis found weak evidence for the use of silicone in the prevention of

abnormal scarring in newly healed wounds, which included burn scars and post-surgical scars.[45] The authors found the studies to be highly susceptible to bias and concluded that there is a great amount of uncertainty around the effect of silicone on scar outcome.[45] In children, there have been no RCTs to evaluate the effectiveness of silicone in the management of burns scars.

1.3 Burn scar contracture

1.3.1. Development of burn scar contracture

The development of thick, hypertrophic burn scar tissue across or in close proximity to a joint can result in BSC. The potential for contracture begins almost immediately post burn where oedema, tight eschar and pain can cause a reduction in joint ROM, facilitating early shortening of soft tissue.[46,47] The tendency towards ROM loss continues with ongoing wound contraction, to reduce the surface area of the deficit and expedite its closure.[48,49] Overcoming these contractile forces is made more difficult by challenges associated with positioning. The patient seeks a position of comfort and shows a tendency to hold burned extremities in flexion and adduction, therefore facilitating the position of contracture.[13,50] Immobilisation to promote graft adherence can further contribute if the joint is not positioned with the graft in a lengthened position, as close to end of range as possible.[8,51] In the paediatric population, strategies to prevent BSC are particularly important, due to the years of growth ahead and the inability of scarred skin to accommodate growth likely to result in contracture development over time.

1.3.2. Prevalence of burn scar contracture

It is difficult to determine the prevalence of BSC due to variations in study methods and populations. The current published prevalence of BSC is presented in Table 1.3. There is variability in reported prevalence with a range of 28% to 39% of individuals post burn described in adult cohorts.[5,7,52,53] Only one study has analysed prevalence of BSC in children alone.[46] In this study, the reported prevalence was 23% of children, despite children reported to be receiving optimal therapy interventions of positioning and splinting.[46] Comparability of these studies is challenging for several

reasons. There is no consensus on the definition of BSC and therefore the criteria used to determine its development and categorise its severity is not consistent across the research.[5,46,52,53] There is also a notable lack of long-term contracture prevalence data with several studies reporting prevalence of BSC at hospital discharge.[7,46,53] Some have suggested that contracture rates are greatest at hospital discharge and therefore reporting at hospital discharge may in fact overestimate contracture prevalence.[54] Given that scar development and maturation continues up to 2 years post burn, reporting contracture prevalence at 2 years post burn is more reflective of outcomes.

In children, it is important to consider the effect of growth and development on the prevalence of BSC. Reporting outcomes at hospital discharge does not reflect the development of contracture associated with skeletal growth in the years following burn injury in children. Analysis of contracture prevalence in children at scar maturation 2 years post burn would provide valuable information regarding outcomes of post burn surgical management and therapy interventions. Additional analysis of contracture prevalence at skeletal maturity would provide more insight into the long-term effects of burn injury.

The prevalence of surgical release of BSC can be considered a surrogate for the prevalence of contracture post burn as it is likely to occur when there are limitations to joint ROM or function. Three studies have reported on the prevalence of surgical release of BSC.[51,55,56] Huang et al[51] reported the incidence to be 93% among adults who did not use splints and pressure for scar management post burn. Among those who had used splints and pressure for any length of time, the incidence was considerably reduced at 26.3%.[51] Two studies where prophylactic therapy interventions were implemented, including scar management and splinting, reported a 3.7%[55] incidence (7.8% in children, 2% in adults) and 13%[56] incidence of surgical release of BSC. All studies were retrospective and only one reported on time to surgical release post burn.[56] The inclusion criteria for all studies differed, ranging from all patients who presented to inpatient and outpatient settings for management of a burn injury[55] to inclusion of only patients with a burn to the axilla, elbow, wrist or knee.[51] Huang et al[51] who reported the greatest incidence of surgical release, included only patients with a burn to specific joints. This may explain the larger

incidence of surgical release they reported compared to other authors as they only included patients who were at risk of contracture.

1.3.3. Predictors of burn scar contracture

The development of BSC is multifactorial. Predictors of 1 or more scar contractures post burn are presented in Table 1.3. Similar to hypertrophic scar development, factors related to injury severity and wound management were found to increase the risk of BSC with greater %TBSA burn,[7,53] greater %TBSA grafted[7,53] and greater number of surgical procedures[5] all significant in multivariate analysis in adults. In children, only older age and longer intensive care unit (ICU) stay had a significant association with the development of BSC.[46] In adult cohorts, intrinsic factors were not consistent across research with male sex statistically significant in multivariate analysis in one study,[53] not significant in others[5,7] or not assessed.[51,52] Similarly, younger age was statistically significant in multivariate analysis in one study[7], not significant in others[5,53] or not assessed.[51,52]

Table 1.3: Prevalence and predictors of burn scar contracture

Study	Study design	Subjects	Therapy provided	Classification of contracture and severity	Time of assessment	Results	
						Prevalence of BSC	Significant predictors of ≥1 BSC*
Goverman et al[46] **2017**	Retrospective Data inclusion period 1994-2003	n = 1031 681 males <18y Inpatients Mean TBSA 29.5%	Not specified	Active ROM at each joint measured using goniometer and inclinometer Severity determined by dividing normal ROM equally in thirds; mild, moderate, severe	At hospital discharge (mean LOS 24 days)	237 patients post burn injury (23%)	**Multivariate analysis OR (95% CI);** **Older age** OR 1.06 (1.04-1.09) **ICU LOS** OR 1.01 (1.0-1.03, *p*=0.013)
Goverman et al[53] **2017**	Retrospective Data inclusion period 1994-2003	n = 1865 1445 males ≥18y Inpatients Mean TBSA 18.3%	Not specified	Active ROM at each joint measured using goniometer and inclinometer Severity determined by dividing normal ROM equally in thirds; mild, moderate, severe	At hospital discharge (mean LOS 25 days)	620 patients post burn injury (33%)	**Multivariate analysis OR (95% CI);** **Female** OR 0.78 (0.67-0.91) **Black race** OR 2.17 (1.04-4.52) **Medical problems** OR 1.38 (1.12-1.69) **%TBSA burn** OR 1.06 (1.03-1.09) **%TBSA grafted** OR 1.07 (1.04-1.1) **Neuropathy** OR 1.7 (1.35-2.14)
Gangemi et al[5] **2008**	Retrospective Data inclusion period 1994-2006	n = 703 412 males Adults Outpatients (2440 burn sites) Mean TBSA 20%	79% of scar locations were treated with medical and rehabilitative therapy (type and timing of therapy not stated)	General ROM criteria applied to all joints to determine contracture; visible skin coarctation or deformity, reduced ROM, subjective sensation of constriction	Not specified	220 patients post burn injury (31%)	**Univariate analysis OR (95% CI);** **%TBSA burn** OR 1.53 (1.27-1.85) **Scald burn** OR 0.46 (0.27-0.8) **Number of surgical procedures** OR 2.46 (1.94-3.12) **Time to heal** OR 1.4 (1.16-1.68) **Abdomen** OR 0.07 (0.03-0.17) **Multivariate Analysis OR (95% CI);** **Abdomen** OR 0.02 (0.0-0.1) **Neck** OR 5.1 (1.5-17.7) **Number of surgical procedures** OR 1.39 (1.1-1.8)

Study	Study design	Subjects	Therapy provided	Classification of contracture and severity	Time of assessment	Results	
						Prevalence of BSC	Significant predictors of ≥1 BSC*
Schneider et al[7] 2006	Prospective Study period 1993-2002	n = 985 769 males ≥18y Inpatients Mean TBSA 25.1%	Specialised occupational and physical therapy services provided for all burn patients (type and timing of therapy not stated)	AROM at each joint measured using goniometer and inclinometer Severity determined by dividing normal ROM equally in thirds; mild, moderate, severe	At hospital discharge Mean LOS 21.7 (SD 22.9)	381 patients post burn injury (39%)	**Multivariate analysis OR (95% CI);** **Younger age** OR 0.99 (0.98-0.99) **LOS** OR 1.04 (1.02-1.07) **%TBSA burn** OR 1.03 (1.0-1.06) **%TBSA grafted** OR 1.07 (1.05-1.09)
Huang et al[51] 1978	Retrospective Data inclusion period 1964-1975	n = 625 Patient details not specified Only patients with burns to the axilla, elbow, wrist or knee included	Treatment with splint and pressure (S&P) used from 1968 on, not used prior to this Splinting** commenced on admission and remained in place all times except for exercise On discharge, patients instructed to wear continuously for 8-12 months	Severity classified into 4 categories; None; no limitation in ROM Mild; <25% limitation in ROM Moderate: 50% limitation in ROM Severe: less than 25% of normal ROM	Not specified	Prevalence data not specified Contracture developed in; -83% of joints with no S&P -73% of joints with <6m S&P -35% of joints with 6-12m S&P -22% of joints with >12m S&P	Not determined
Dobbs and Curreri[52] 1972	Retrospective Data inclusion period 1967-1968	n = 681 Patient details not specified	Program of PT, splinting and positioning commenced on admission and continued throughout hospitalisation	Criteria used to determine BSC not specified Acceptable; >50% ROM Functional: 50% ROM Severe: <50% ROM	>30 days after discharge	188 patients post burn injury (28%)	**Descriptive analysis (%)** Joint limitation developed in; 8% of patients with 0-10% TBSA burn 46% of patients 40%-50% TBSA burn 100% of patients with 70%-80% TBSA burn

*Predictors of ≥1 BSC significant if p<0.005

**Splint designs – Hand; custom isoprene splint positioning wrist in neutral, metacarpal joints in 30° flexion, interphalangeal joints in extension with extend thumb abducted across the palm. Elbow; 3-point extension splint. Axilla; 90° shoulder abduction via 'airplane' splint with layer of foam rubber around axilla. Knee; 3-point extension splint Abbreviations; BSC, burn scar contracture; CI, confidence interval; LOS, length of stay; m, months; n, number; NIDDR BMS, National Institute on Disability and Rehabilitation Research Burn Model System; OR, odds ratio; PT, physical therapy; ROM, range of movement; S&P, treatment with splint and pressure garment; TBSA, total body surface area; y, year

1.3.4. Prevention and management of post burn contracture

An important goal of post burn rehabilitation is prevention of BSC. It is paramount to recognise that long term outcomes begin to be established long before wound closure. Consequently, strategies to prevent BSC should begin as soon as possible following injury, to oppose the rapid and ongoing forces of contracture throughout wound healing and scar formation.[8,13,47,57] Expert opinion reported that aside from full thickness burns with tendon or joint involvement, no other factor was more likely to cause ROM loss than delay of therapy.[52] An early retrospective study reporting results of BSC management over 10 years found a relationship between contracture and length of time splints and pressure were used postburn.[51] Patients who used splints and pressure for more than 12 months post burn had the lowest incidence of contracture, while patients who did not use splints and pressure had the highest incidence of contracture.[51] Despite these early findings, the use of splinting to prevent BSC is yet to be universally implemented in clinical practice.

No research has described the length of time a splint should be worn each day to maintain ROM at a joint post burn and consequently, there is no consensus on length of time to splint in the 24 hour period.[58] In subjects with stiff proximal interphalangeal joints caused by orthopaedic conditions, a RCT comparing 3 and 6 days of total end range positioning, found that 6 days of positioning resulted in twice the increase in passive ROM compared to 3 days of positioning.[59] The increase in passive ROM was demonstrated to be directly proportional to the length of time the joint was held at end of range.[59] While the findings of this study do not directly relate to BSC, the concept of total end range time can be applied to this patient group. Intensive splinting, involving periods of the day and overnight may assist with maintaining ROM post burn and in cases of BSC, serial casting may be an intervention to consider to restore ROM. Furthermore, investigation into the effect of mechanical stress on healing wounds in rats suggests that scar tissue may be responsive to the application of stress, and that the response is determined by a balance between scar age and the amount of stress applied.[60] In the rat model, younger scars (<14 weeks old) were more responsive to stress remodelling than older scars.[60] Therefore, early serial casting in patients with BSC may be a useful intervention to improve ROM.

Splinting is considered to play a critical role in the prevention of BSC by burn experts.[13,20,47,49,58] International Practice Guidelines for Burn Care recommend splint use for at risk deep partial or full thickness burns, to aid oedema and pain reduction, protect new grafts and flaps, maintain ROM and correct joint deformity.[39] Despite the general consensus that splinting assists with maintaining ROM, there is limited knowledge and ongoing debate regarding splint fabrication and protocols of use.[20,47,51,55] A survey of splinting practice, completed by experienced burn therapists at 99 international burn centres in 1996, identified a trend of waiting until loss of ROM is identified before applying a splint.[58,61] A more recent survey has not been completed.

It has been suggested that static splinting is detrimental to maturing scar tissue as excessive mechanical tension theoretically increases hypertrophic scar formation and therefore increases the risk of BSC.[49,62] Currently, there is no evidence as to what level and form of therapy causes excessive skin tension on the developing scar.[49,54] However, early splinting may address the potential for BSC before it develops, eliminating the need for progressive serial casting and therefore, theoretically tension on the maturing scar should not be as great. A letter to the editor written in response to the suggestion that static splinting has a detrimental effect on maturing scar tissue, shared the results of reanalysis of splinting outcomes originally reported by Huang et al[51] in 1978.[63] They reemphasized the significant reduction in rates of contracture with splint use and found that the incidence of BSC decreased with increasing lengths of time of splint use.[63] More specifically, axilla contracture was reported to occur in 90% of patients who used a splint for less than 6 months compared to 32% of patients who used a splint for more than 12 months.[63] These results were statistically significant.

In cases of severe BSC, particularly in mature scar tissue, surgical release to restore ROM and function may be required. Splinting is a valuable intervention following surgical release to prevent recurrence of contracture and interestingly, the survey of postburn splinting practice in 1996 found that therapists were more likely to splint following surgical release of contracture than after skin grafting of the initial injury.[58,61] It is worth considering that perhaps earlier and more intensive intervention

would eliminate the need for reconstructive surgery as post burn scar tissue is amenable to conservative intervention to improve ROM, with good prognosis for resolution while scar tissue remains malleable and immature.[64]

Chapter Two:
The shoulder joint and prevention of axilla contracture

2.1 The shoulder joint

The shoulder joint is the most mobile joint in the human body. It is a multidirectional joint with three angular degrees of freedom; flexion/extension, abduction/adduction and internal/external rotation.[65] The primary function of the shoulder joint is to provide mobility, in synergy with the elbow and wrist, to enable the hand to move through many different positions and orientations in space.[65,66] The shoulder's wide arc of movement, resting position in adduction and concavity of the axilla all contribute to the joint's uniqueness.[67,68] It is within these parameters that the burns therapist must work to achieve a prolonged, end of range stretch and maintain shoulder ROM post burn. This is a significant challenge and the clinical picture becomes even more complicated when the elbow and hand are also affected.[69]

The shoulder is the most frequent joint to develop contracture following burn injury, accounting for between 23% and 38% of all post burn contractures in adults and 28% of all post burn contractures in children.[5,7,46,51-53] This is outlined in Table 2.1, which expands on the scar contracture prevalence data presented in Table 1.3, as all but one of these studies reported on the prevalence of shoulder contracture post burn. As highlighted in Table 1.3, there is a notable lack of long term prevalence data with reported timing and inclusion of therapy to prevent and manage post burn contracture poorly reported. Huang et al[51] were the only authors to describe splint design, commencement and regime. Furthermore, the prevalence of post burn shoulder contracture is reported as a percentage of all post burn joint contractures in all studies except one. Dobbs and Curreri[52] were the only authors to report rates of shoulder contracture as a percentage of all shoulder burns. They reported that 19.4% of all shoulder burns developed some degree of contracture.[52] Despite prophylactic management with compression, positioning and exercise, the prevalence of surgical release required to improve BSC at the shoulder, reported as a percent of all post burn releases, was 17% in children and 27% in adults.[55] The time from burn to surgical release was not specified.

Table 2.1: Prevalence of post burn shoulder contracture

Study	Study design and subjects	Classification of shoulder contracture severity	Prevalence of shoulder contracture as percentage of all burn scar contractures
Governan et al[46] 2017	Retrospective n=1031 <18y Mean TBSA 29.5%	Shoulder flexion and abduction contracture classified as; Mild 120-180° Moderate 60-119° Severe <60°	Of 787 BSCs, there were 219 shoulder contractures (28%) - shoulder most frequently contracted joint Of 219 shoulder contractures; 40% mild, 35% moderate, 25% severe
Governan et al[53] 2017	Retrospective n=1865 ≥18y Mean TBSA 18.3%	Shoulder flexion and abduction contracture classified as; Mild 120-180° Moderate 60-119° Severe <60°	Of 2097 BSCs, there were 482 shoulder contractures (23%) - shoulder was the most frequently contracted joint Of 482 shoulder contractures; 48% mild, 39% moderate, 13% severe
Schneider et al[7] 2006	Prospective n=985 ≥18y Mean TBSA 25.1%	Shoulder flexion and abduction contracture classified as; Mild 120-180° Moderate 60-119° Severe <60°	Of 953 BSCs, there were 365 shoulder contractures (38%) - shoulder was most frequently contracted joint Of 365 patients who developed shoulder contracture; 54% mild, 40% moderate, 6% severe
Huang et al[51] 1978	Retrospective n=625 Patient details not specified	Shoulder flexion and abduction contracture classified as; None: 180° Mild: >135° Moderate: 90° Severe: <45°	Of 658 BSCs, there were 264 axilla contractures (40%) Of 358 axilla burns, 264 developed contracture (74%) Contracture developed in; 95% of axilla burns which did not use S&P 90% of axilla burns using S&P for <6months 32% of axilla burns using S&P for >12 months
Dobbs and Curreri[52] 1972	Retrospective n=681 Patient details not specified	Shoulder flexion and abduction contracture classified as; Acceptable: ROM > 90° Functional: ROM ~ 90° Severe: ROM <90°	Of 523 BSCs, there were 121 shoulder contractures (23%) Of 121 shoulder joints that developed contracture; 55%, acceptable, 23% functional, 22% severe 19.4% of all shoulder burns developed contracture* 10% considered acceptable 4.8% considered functional 4.6% considered severe

*Only study to report shoulder contracture as a percent of all shoulder burns
Abbreviations; BSCs, burn scar contractures; n, number; ROM, range of movement; S&P, treatment with splint and pressure garment; TBSA, total body surface area; y, years.

Prevention of BSC of the shoulder is essential as loss of ROM at the shoulder has been demonstrated to adversely affect upper limb function and an individual's ability to complete activities of daily living (ADLs).[70,71] Functionally, loss of shoulder abduction or flexion has been demonstrated to contribute to poor body mechanics when completing a task.[70] A prospective study by Palmieri et al[70] evaluated the impact of post burn axilla contractures on shoulder movement during ADLs in 11 children aged between 6 and 13 years, scheduled for surgical release of postburn axilla contracture. In comparison to normal controls, alterations in movement patterns during functional tasks were evident as a result of the BSC.[70] During high reach, elbow flexion increased to compensate for significant reductions in shoulder flexion.[70] Following surgical release of axilla contracture in children, the compensatory movements used to complete functional tasks before surgery decreased with increasing shoulder ROM.[71] Significant improvements in shoulder flexion were found during high reach compared to presurgical values.[71] However, there was still a significant reduction compared to normal subjects. Post release, shoulder abduction did not show a significant increase in comparison to pre-surgery measures.[71] The authors hypothesised this was due to the tasks assessed not needing considerable shoulder abduction to be completed.[71] The results of these studies give weight to the importance of contracture prevention as surgical release may not restore full function.

2.2 Postburn axilla splinting described in literature

The International Society of Burn Injuries (ISBI) Practice Guidelines for Burn Care recommend positioning the axilla post burn at 90° abduction.[39] However, there is limited high quality evidence available to support axilla splinting in this position, particularly in the paediatric population. Several authors have presented descriptions of splinting devices used to manage axilla burns.[67,72-75] These articles provide a description of splint design, materials used and fabrication. No data regarding timing of splint commencement, regime or patient outcomes were reported. Typically, these splints immobilise the shoulder at 90° abduction, however, Manigandan et al[67,72] described axilla splints that can be adjusted up to 160° abduction. Similarly, a splint

described by Gorka et al[73] can position the shoulder within an abduction range of 90°-130°. A high-density foam aeroplane splint for use in unconscious or sedated children post burn has also been described.[75]

Table 2.2 presents all available research of outcomes of splinting of individuals post axilla burn. All have reported short term results only, with the longest follow-up 12 weeks post hospital discharge. To date, two prospective RCTs,[76,77] a retrospective cohort study[50] and two prospective case series[78,79] have investigated outcomes of axilla splinting post burn. Mixed results have been reported, a RCT found no significant difference between subjects treated with and without an axilla splint, commencing on admission and continuing until 12 weeks postburn.[76] In comparison, a case series reported full axilla ROM at hospital discharge (mean 2 weeks postburn), following splinting between 90°-160° shoulder abduction in children.[78] All studies involved axilla splinting at 90° shoulder abduction in adults[50,76,77,79] except for a case series of children, which positioned the axilla at greater degrees of shoulder abduction (90°-160°).[78] All reported short term results, ranging from mean 2 weeks postburn[78] to 12 weeks post hospital discharge.[79] No longer term outcomes of any axilla splinting has been reported in the literature. Given the long-term nature of post burn scar development and maturation, the short-term outcomes reported in these studies do not provide insight into the effect of splinting on the prevalence of axilla contracture in these individuals at scar maturation.

Table 2.2: Outcomes of postburn axilla splinting described in literature

Splint	Study design	Subjects	Inclusion criteria	Splint position and use	Time of assessment	Results
Multi-axis shoulder abduction splint **Jang et al[77] 2015**	Prospective RCT, parallel assessor blinded Study period not specified	n = 24 19 males Adults (age not specified) Mean TBSA Splint group 32.9 % Mean TBSA Control group 38.4%	(a) Burn around the shoulder joint (b) TBSA burn >10% and <80% (c) Date of burn <30 days prior to study inclusion	**Position**: Shoulder abduction as close as possible to 90°, commenced on admission. **Regime (4 weeks)**: **Splint group**; splint removed for hygiene and medical procedures only, 30 minutes active and passive exercise, twice/day. **Control group**; no splint, 30 minutes active and passive exercise twice/day.	Baseline and every week for 4 weeks	**Mean (SD) shoulder ROM at 4 weeks**; **Abduction ROM**: splint group 94.8° (22), control group 87° (18.4) **Flexion ROM**: splint group 107.3° (27.2), control group 100° (100)
Foam abduction wedge **Godleski et al[50] 2013**	Retrospective cohort study Study period 2011-2012	n = 10 7 males >18y Mean TBSA 38.6%	Admitted with a burn requiring grafting, which crossed the shoulder joint or included the region adjacent to the axilla	**Position**: Shoulder: 90° abduction, 20°- 30° horizontal adduction Elbow: full extension, 90° pronation Wedge commenced immediately post skin graft to shoulder **Regime (duration of admission to BICU)**: 24 hours/day until commencement of ROM exercises (usually 5 days post grafting). Following this, wedge on 12 hours overnight and 4 hours on/off during day with 30-60 minutes of scheduled therapy/day.	Discharge from BICU (mean 41.5 days postburn)	**Mean shoulder ROM at discharge**; **Abduction ROM**: left 132° ± 38°, right 118° ± 22° **Flexion ROM**: left 132° ± 31°, right 123° ± 29° At discharge; 90% of subjects had >90 degrees shoulder abduction and shoulder flexion
90° Shoulder abduction splint **Kolmus et al[76] 2012**	Prospective RCT, single centre, assessor blinded Study period 2008-2010	n = 52 34 males >18y Mean TBSA Splint group 19.1% Mean TBSA Control group 18.6%	(a) Consecutive patients admitted with an axilla burn (b) <50% TBSA	**Position**: Shoulder immobilised at 90° abduction with shoulder splint commenced on admission. If grafting required, splint commenced after this time (typically 5 days). **Regime (12 weeks)**: **Splint group** First 6 weeks; splint removed for hygiene, dressing changes and daily exercise only. Final 6 weeks; splint worn overnight only. **Control group** No splint. Daily shoulder exercise.	Admission, week 6 and 12	**Mean (SD) shoulder ROM at end of week 12**; **Abduction ROM**: splint group 151.5° (7.77), control group 151.5° (7.77), *p*=0.5 **Flexion ROM**: splint group 153.8° (7.15), control group 156° (7.15), *p*=0.3 Splint adherence* week 1: 77% (n = 20) week 3: 50% (n = 13) week 6: 38% (n = 8) week 12:16% (n = 3)

Splint	Study design	Subjects	Inclusion criteria	Splint position and use	Time of assessment	Results
Shoulder abduction brace **Webb et al[79] 2011**	Prospective case series Study period 2006 -2007	n = 20 19 males >18y Median TBSA 20%	Admitted with a burn to the axilla region 10 patients classified as LCR** 10 patients classified as HCR**	**Position**: LCR**: Shoulder abduction pillow 45°- 60° abduction HCR**: Shoulder abduction brace 90° abduction Both commenced immediately **Regime**: LCR**: If ROM >90°; pillow overnight and 2 hours/day for first 3 weeks. After this time, if shoulder ROM >120°; pillow was ceased. If shoulder ROM <120°; pillow continued. If SSG required or ROM <90°; abduction brace commenced and exercise increased. Once ROM ≥90°, abduction pillow used. HCR**: Shoulder abduction brace fitted and worn 24 hours/day until 5 days after SSG, then worn overnight and 2x 3 hours/day until 7 weeks post injury, then overnight until 12 weeks post injury	Admission, hospital discharge and 12 weeks post hospital discharge	Mean shoulder abduction 12 weeks post hospital discharge (SD); LCR** group: 168° (22) HCR** group: 166° (28) Mean shoulder flexion 12 weeks post hospital discharge; LCR** group: 172° (20) HCR** group: 167° (31)
Papoose device **Macdonald et al[78] 1985**	Prospective case series Study period not specified	n = 23 Sex not specified Age ≤6 years Mean TBSA 15%	Not specified	**Position**: Shoulder: 90°-160° abduction, 20° horizontal adduction, commenced early during hospitalisation **Regime**: Post grafting, papoose used 24 hours/day for 5 days. ROM exercises commenced on day 5. When grafts healed, conventional 90° axilla splints used during day with papoose overnight for duration of admission. Papoose ceased on discharge	At hospital discharge (mean 2 weeks)	All patients had full axilla ROM at discharge

*Participants deemed adherent with splint use if they wore it ≥4 days/week for ≥6 hours and ≥4 nights/week for ≥4 hours.
**Participants deemed low contracture risk (LCR) if they had superficial, localised burn with ≤1 area needing grafting and deemed high contracture risk (HCR) if they had deep, extensive burn with ≥2 areas needing grafting
Abbreviations; BICU, Burn Intensive Care Unit; HCR, high contracture risk; LCR, low contracture risk; n, number; RCT, randomised control trial; ROM, range of movement; SD, Standard deviation SSG, split skin graft; TBSA, total body surface area; y, years.

There is consensus among experts that splinting the upper limb above 90° abduction should be avoided to prevent tension on the brachial plexus and peripheral nerves.[47] There is no robust research evidence supporting this opinion, with all studies investigating axilla splinting in shoulder abduction ranges greater than 90° reporting results of a case series or splint description only, with no adverse events reported.[67,72,73] Research in healthy adults has demonstrated that specific positioning across multiple joints affects tension on the peripheral nerves.[68,80,81] There is increasing strain on the ulnar and median nerves as the upper limb is positioned in a specific and sequential way from the shoulder to the digits.[68,80] Shoulder abduction, extension and external rotation increase strain on the trunks of the brachial plexus.[81] Median nerve strain is increased when shoulder abduction and external rotation is combined with supination and extension at the elbow, wrist and digits (Figure 2.1.1).[81] In contrast, ulnar nerve strain is elicited with the addition of elbow flexion to shoulder abduction and external rotation (Figure 2.1.2).[68,80]

Figure 2.1: Shoulder positions which elicit nerve tension

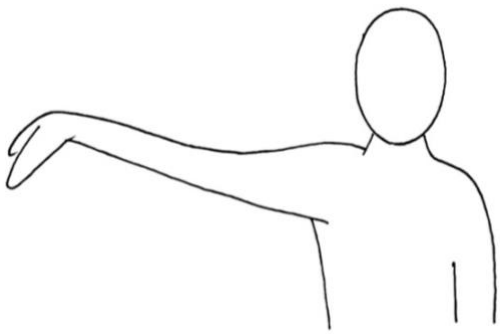


Figure 2.1.1 Median nerve tension

Figure 2.1.2 Ulnar nerve tension

To evaluate the safety of upper limb positioning, the occurrence of pain, paraesthesia and tolerance was evaluated in four shoulder abduction positions (90°,130°,150° and 170°) in healthy adults.[68] The elbow was extended in all positions except 130° abduction, where the elbow was at 110° flexion.[68] The study found that positioning the upper limb within normal physiologic range did not cause permanent damage to the peripheral nerves.[68] Paraesthesia occurred in all positions but was transient, lasting less than 3 minutes on cessation of positioning.[68] It occurred most frequently in the ulnar nerve distribution, followed by the median

nerve.[68] The greatest frequency of ulnar nerve paraesthesia occurred at 130° abduction with elbow flexion (27%).[68] In contrast only 3.3% of subjects reported symptoms in this distribution at 150° and 170° abduction, which suggests it was the combination of shoulder abduction and elbow flexion that significantly contributed to ulnar nerve symptoms.[68] Pain was frequently reported at 170° abduction and consequently the authors recommend positioning between 90° and 150° degrees in adults with regular repositioning.[68] It is important to note that horizontal adduction was not incorporated into any of the positions described. Previous literature, published as early as 1985, hypothesised that brachial plexus tension can be alleviated if the patient is positioned in a degree of horizontal adduction, therefore suggesting that it is not the degree of shoulder abduction that increases neural tension but instead, the lack of horizontal adduction.[49,78] Perhaps the four shoulder abduction positions described by Lester et al[68] may have been better tolerated if this had been incorporated. The effect of positioning children in varying degrees of shoulder abduction has not been evaluated and the extent to which the findings by Lester et al[68] can be applied to children, healthy or post burn, is unknown.

2.3 Therapy management of axilla burns at The Children's Hospital at Westmead

Standard clinical care at The Children's Hospital at Westmead (CHW) involves splinting all children with burns to the axilla joint surface or in close proximity to the joint at end of range shoulder abduction (160°-180°) with 20° horizontal adduction (Appendix 1). This splint is applied as a plaster cast on presentation to the burns unit and is reapplied at subsequent dressing changes. Burns which heal in >14 days or require skin grafting to achieve wound closure continue this intervention with a thermoplastic splint moulded in the above position. At this point the splint is usually worn 12 hours overnight and 2 hours on / 2 hours off during the day. This day regime may be modified to incorporate splint use during sleep or rest times and enable active play out of the splint when the child is awake. However, it is important that the splint is worn at least 6 hours during the day in addition to the 12 hours overnight.

Splint use is likely to continue for at least a year with time spent in the splint gradually reduced according to scar development and progression.

The ROM outcomes achieved with end of range splinting of the axilla in children has not yet been described in literature. Review of the outcomes of this splinting practice is therefore warranted.

Chapter Three:
Outcomes of end of range axilla splinting in children following burn injury

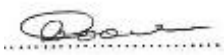
This chapter is presented in the format of the manuscript which has been submitted to the Journal of Burn Care and Research, with the exception of tables and figures embedded throughout the manuscript (rather than in a separate document) for ease of reading. See Appendix 2 for submission guidelines for the Journal of Burn Care and Research.

Statement from co-authors confirming authorship contribution of the Master of Research candidate

As co-authors of the paper 'Outcomes of end of range axilla splinting in children following burn injury', we confirm that Rhianydd Thomas has made the following contributions:

Conception and design of the research
Collection and extraction of data
Analysis and interpretation of the findings
Writing of the paper and critical appraisal of the content

Stephanie Wicks
Date: 25 September 2018



Claire Toose
Date: 27 September 2018

Dr Verity Pacey:
Date: 28 September 2018

Title

Outcomes of end of range axilla splinting in children following burn injury

Authors

Rhianydd Thomas[1,2]

Stephanie Wicks[2]

Claire Toose[2]

Verity Pacey[1]

Affiliations

[1] Macquarie University, New South Wales, Australia

[2] The Children's Hospital at Westmead, Australia

Correspondence

Rhianydd Thomas

Physiotherapy Department

The Children's Hospital at Westmead

Locked Bag 4001

Westmead NSW 2145

Phone: +61 2 9845 3369

Fax: +61 2 9845 3685

Email: rhianydd.thomas@health.nsw.gov.au

Author Disclosures

Conflicting interests

Nil

Financial benefits to the authors

Nil

Funding

Rhianydd Thomas received a Commonwealth Government funded Research Training Program Scholarship (RTP-MRES).

Details of any previous presentation of the research, manuscript, or abstract in any form

Abstract accepted for Impact Poster Presentation at the Australian and New Zealand Burn Association Annual Scientific Meeting, 16-19 October 2018.

Abstract

Scar contracture is a significant complication of burn injury. This study aimed to describe outcomes of early splinting of the axilla at end of range abduction in children, following a burn to the axilla region. A retrospective review of 76 children (mean age 3.9 years (SD 3.6)) treated at a tertiary children's hospital from 2006-2016 was conducted. No child developed axilla contracture for the duration of the 2-year study follow-up with no adverse events recorded. If splinting was ceased <60 days post burn it was considered not an essential intervention to maintain range of movement, leaving 49 children receiving splinting ≥60 days. Compared to the children who ceased splinting in <60 days, children who were splinted ≥60 days had a significantly higher frequency of deep dermal burn (59% vs 25%, *p*=0.01), flame mechanism (25% vs 5%, *p*=0.03) and burn injury distribution involving the anterior trunk, flank and arm (18% vs 3%, *p*=0.03). Early signs of contracture, considered loss of full axilla range or significant banding, developed in 9 children within 3 months post burn and with intensive therapy all returned to full axilla range by 9 months post burn. Children with skin tension at end of range shoulder movement at the 1-month clinical assessment were 11 times more likely to develop early signs of contracture (95% CI 1.9-62.1, *p*=0.007). Intensive splinting at end of range shoulder abduction in children with axilla burns is well tolerated. When undertaken with ongoing burn therapist review, full axilla ROM can be maintained.
Key words: burn, splinting, axilla, contracture, children

Introduction

Significant advances in management of acute burn injuries have occurred over recent decades.[1,2] Consequently, survival rates have improved and there is an increasing focus on quality of life and function post burn.[1,2] Burn scar contracture, a significant complication of burn injury, can result in severe functional impairment.[3] The shoulder joint is the most frequently contracted joint post burn.[4-6] Its wide arc of movement, resting position in adduction and concavity of the axilla make maintaining shoulder range of movement (ROM) a unique and significant challenge for burns therapists and patients.[7]

Current burn care guidelines recommend positioning individuals with burns to the axilla region at 90° shoulder abduction with 15°-20° of shoulder horizontal adduction to minimise loss of axilla ROM.[8] There is consensus among experts that splinting the upper limb above 90° abduction should be avoided to prevent tension on the brachial plexus and peripheral nerves.[9] However it has been suggested that splinting outside a strict frontal plane can avoid brachial plexus tension if >90° shoulder abduction is combined with slight horizontal adduction.[9]

There is limited research regarding axilla splinting post burn, particularly in paediatric cohorts. There has been one case series in a small cohort of children, which reported that following burn injury to the axilla, children positioned between 90° and 160° shoulder abduction with 20° horizontal adduction had full axilla ROM at hospital discharge (mean 2 weeks post burn).[10] In adult cohorts, there have been three prospective studies[11-13] and one retrospective study[14] on axilla splinting. All studies, splinted the shoulder at 90° abduction as soon as possible following admission. Mixed results were reported, however loss of some degree of axilla ROM was reported in all studies. In light of these outcomes, it is important to consider whether ROM outcomes beyond the position of splinting can be expected. If the desired outcome is full abduction, consideration of a splint as close to this as possible is worthwhile.

There is ongoing debate amongst therapists regarding splinting protocols post burn. Some therapists advocate implementing strategies to maintain ROM immediately following injury, while others are in favour of delaying splinting until an observed loss of ROM.[15,16] At the Children's Hospital at Westmead (CHW), it has been standard clinical care for over 30 years, to splint all children presenting with a burn to the axilla joint surface or in close proximity to the area at end of range shoulder abduction with 20° horizontal adduction. End of range axilla positioning is commenced as a plaster cast on initial presentation to the tertiary centre and is reapplied at subsequent dressing changes (Figure 1A). Burns which heal in >14 days or require skin grafting to achieve wound closure continue this therapy with a thermoplastic splint moulded in the above position (Figure 1B). If the flexor surface of the elbow joint is involved, the upper limb will be included to the wrist, with the elbow positioned in full extension (Figure 1C). At this point, the splint is usually worn 12 hours overnight and 2 hours on / 2 hours off during the day. Time in the splint is gradually reduced according to scar development and progression. Therefore, the aim of this study is to describe the outcomes of this splinting practice and whether baseline and clinical characteristics can predict the need for axilla splinting for ≥60 days post burn and the development of early signs of axilla contracture.

Figure 1: End of range axilla splint fabrication

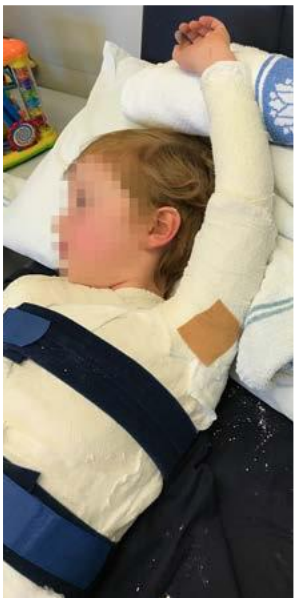


Figure 1A
Plaster axilla splint

Figure 1B
Thermoplastic axilla splint

Figure 1C
Thermoplastic axilla splint

Parent consent provided for use of these images

Methods

Study design, setting and participants

A retrospective study was conducted to review ROM outcomes following end range axilla splinting in children who had sustained a burn injury to the axilla region. To ensure all children managed with an axilla splint were captured, the New South Wales (NSW) Severe Burn Injury Service (SBIS) provided data on all children who presented to the burns unit at CHW between January 2006 and July 2016, with a burn involving any of the following areas in isolation or combination; left axilla, right axilla, anterior trunk, posterior trunk, left flank, right flank, right arm and left arm.

The NSW SBIS coordinates and provides treatment to severe burn injured patients who qualify for transfer to a tertiary level service. CHW forms the paediatric part of this service and all children in NSW who meet transfer criteria (involvement of major joints or burn >5% TBSA) are sent to this hospital. The SBIS collects and collates demographic, injury and management data on these children. As the only paediatric burn injury service in the state, physiotherapy management of children post burn injury is highly specialised. All physiotherapists working in the burns unit are trained to assess and treat burn injured children.

Every potentially eligible child's medical record was reviewed, to determine if they met the eligibility criteria. Children were included in this study if their burn involved the skin of the axilla surface or was in close proximity to that area, and therefore received management with an axilla splint. Children were excluded if their burn healed in less than 14 days and hence were deemed not at risk of scar development. Children with severe burns transferred from Pacific Island countries for acute management were also excluded as they returned home following wound closure and did not attend regular review and ongoing scar management at CHW. The remaining cohort were split into 2 groups; children who used an axilla splint <60 days and children who used an axilla splint ≥60 days. Based on clinical judgement, if splinting was ceased before 60 days it was considered not to have been an essential intervention to maintain ROM as it was no longer required in the period of high scar activity following wound closure.

Demographic and clinical data collected

The child's age at burn, sex, ethnicity, geographical location classified as metropolitan or non-metropolitan (based on postcode classification from Australian Standard Geographical Classification),[17] mechanism of burn, worst depth of burn, affected areas within the axilla region, % total body surface area (TBSA) and where applicable, the number of grafting and re-grafting procedures, were recorded from the NSW SBIS database. Review of each child's hospital medical record provided further clinical data; whether unilateral or bilateral axillae were affected (worst side used for analysis if bilateral), length of time to wound closure and if applicable, the length of hospital and paediatric intensive care unit (PICU) stay.

Physiotherapy assessment data was collected at seven time points as close as possible to the following months post burn; 1, 3, 6, 9, 12, 18 and 24. Axilla ROM was collected as full or not full. Skin tension was recorded to be present if there was any sign of skin blanching, pulling or banding at end of range shoulder abduction or flexion. A modified Vancouver Scar Scale (mVSS) was recorded at each time point and the scar was deemed hypertrophic if the scar height of the worst area, regardless of size, was >1mm.[18,19] Subjective reports of pain or tingling in the splint were recorded as positive signs of neural tension. Data collected on physiotherapy management included the number of days the splint was used, the number of hours the splint was used in a 24-hour period and if any modifications were required due to discomfort or signs of neural tension at each assessment point. Use of silicone products and compression garments were recorded as used or not used and where applicable, hours of silicone use in a 24-hour period was recorded at each assessment point.

Loss of ROM or significant banding around the axilla region, which resulted in altered management, was recorded and considered to be an early sign of axilla contracture. Additional data collected included, the number of days to development of early signs of contracture and initiation of serial casting (if required), number of serial casts applied and number of days of serial casting.

Data analysis

Data analysis was performed using SPSS statistics version 22.0.[20] Descriptive analysis of demographic and baseline clinical variables was performed to describe the population of children who used an axilla splint for any length of time and their physiotherapy management and outcomes at 1, 3, 6, 9, 12, 18 and 24 months post burn.

Univariate analyses using Pearson's chi square (categorical variables) and independent T-tests (continuous variables) were conducted to determine any significant differences in the demographic and baseline clinical characteristics between children who did and did not require an axilla splint ≥60 days to prevent contracture, and those with and without early signs of contracture development (if splinted ≥60 days).

Backward multiple regression was performed to determine the extent to which demographic and clinical characteristics can predict the number of days a child will wear the splint. Binary regression was performed to determine baseline variables and clinical characteristics at 1-month post burn that were significantly associated with the development of early signs of contracture in children splinted ≥60 days.

This study was approved by the Sydney Children's Hospital Network (SCHN) Human Research Ethics committee (LNR/18/SCHN/19) and Macquarie University (reference number 5201800330).

Results

Demographic and baseline clinical characteristics

Seventy-six children met inclusion criteria for this study. The flowchart of patient inclusion is shown in Figure 2. Demographic and baseline clinical characteristics of the cohort are displayed in Table 1. The mean age at burn was 3.9 years (SD 3.6), with burn injury occurring most frequently in children less than 2 years of age (43%). Characteristics of burn injury within the population varied across the age span. The mean overall %TBSA was 15.5% (SD 11.1), with a greater %TBSA in older children; 12% in children 0-<2 years compared to 25% in children 12-18 years (Figure 3). Scald burns were the most common cause of burn in younger children, while flame burns became more prevalent with increasing age. Figure 3 shows the decreasing frequency of burn injury with increasing age and the corresponding change in distribution of burn mechanism.

Figure 2: Flowchart of patient inclusion

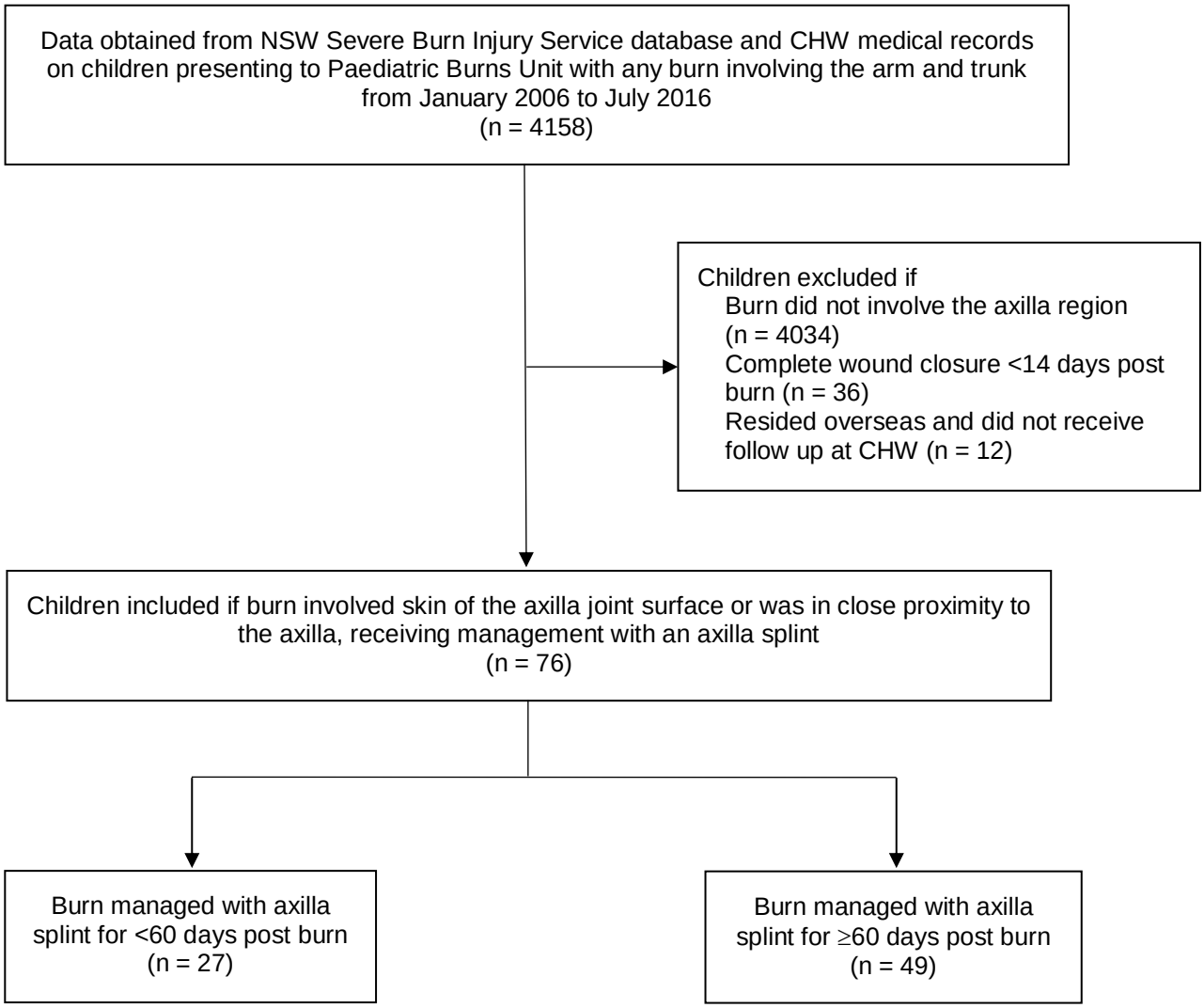
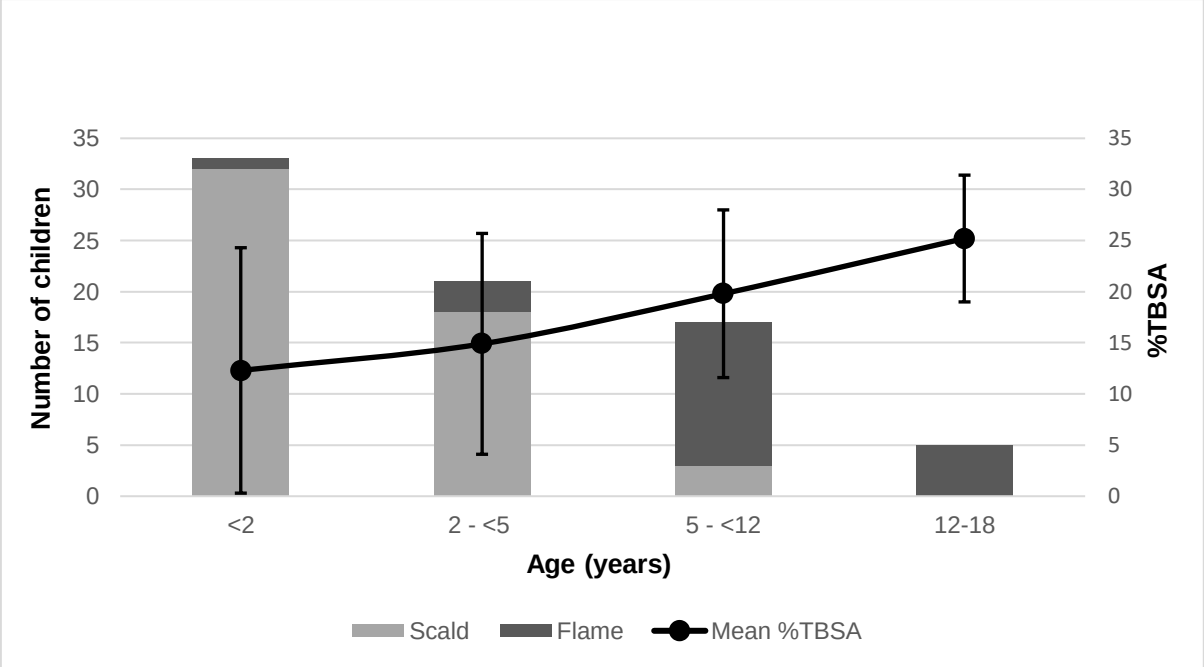


Table 1: Baseline and clinical characteristics of children splinted (categorical variables)

Categorical variable		All children splinted n=76 n (%)	All children splinted n (% of n=76)		*p*-value comparing children splinted <60 days to ≥60 days
			Splint <60 days n=27	Splint ≥60 days n=49	
Sex	Male	40 (53)	15 (20)	25 (33)	0.71
	Female	36 (47)	12 (16)	24 (31)	
Age (years)	<2	33 (43)	13 (17)	20 (26)	0.03*
	2 - <5	21 (28)	10 (13)	11 (15)	
	5 - <12	17 (22)	1 (1)	16 (21)	
	12 - 18	5 (7)	3 (4)	2 (3)	
Ethnicity	Caucasian	37 (49)	13 (17)	24 (32)	0.3
	Aboriginal	8 (10)	2 (3)	6 (8)	
	Asian	9 (12)	2 (3)	7 (9)	
	Arab and African	9 (12)	2 (3)	7 (9)	
	Mixed	9 (12)	5 (6)	4 (5)	
	Unknown	4 (5)	3 (4)	1 (1)	
Geographical location	Metropolitan	51 (67)	19 (25)	32 (42)	0.65
	Non-metropolitan	25 (33)	8 (11)	17 (22)	
Mechanism	Scald	53 (70)	23 (30)	30 (40)	0.03*
	Flame	23 (30)	4 (5)	19 (25)	
TBSA affected	<30%	68 (89)	27 (35)	41 (54)	0.03*
	≥30%	8 (11)	0	8 (11)	
Worst burn depth	Mid-dermal	12 (16)	8 (11)	4 (5)	0.01*
	Deep-dermal	64 (84)	19 (25)	45 (59)	
Distribution of deep burn areas**	Anterior trunk/ arm	19 (25)	5 (7)	14 (18)	0.33
	Anterior trunk/ flank/ arm	16 (21)	2 (3)	14 (18)	0.03*
	Posterior trunk/ arm	4 (5)	1 (1)	3 (4)	0.65
	Posterior trunk/ flank/ arm	6 (8)	1 (1)	5 (7)	0.32
Splinting required	Unilateral	68 (89)	26 (35)	42 (55)	0.15
	Bilateral	8 (11)	1 (1)	7 (9)	
Hospital admission	Admitted	66 (87)	22 (29)	44 (57)	0.31
	Not admitted	10 (13)	5 (7)	5 (7)	
PICU admission	Admitted	21 (28)	4 (5)	17 (23)	0.06
	Not admitted	55 (72)	23 (30)	32 (42)	
Infection	Infection	15 (20)	4 (5)	11 (15)	0.42
	No infection	61 (80)	23 (30)	38 (50)	

**p*-value <0.05 is significant
**% does not add up to 100 as children with distribution in other category (n=13) are not accounted for
Abbreviations; n, number; PICU, paediatric intensive care unit; TBSA, total body surface area

Figure 3: Frequency, mechanism and mean %TBSA of burn by age



Burn management

The mean time to wound closure for all children was 36 days (SD 21.9). Fifteen children (20%) developed infection. Eleven children (14%) did not require a skin graft, with all other children (86%) requiring one or more (mean 1.6, SD 1.0) skin grafting procedures to achieve wound closure. The mean time to axilla splint commencement was 6 days (SD 7.8). Sixty-six children (87%) required inpatient hospital admission for management of their burn injury. The mean length of stay (LOS) was 22 days (SD 23.8). Of these children, 21 (32%) were admitted to PICU due to burn severity (mean LOS 11 days, SD 10.1).

All 76 children were considered to be at risk of axilla contracture on presentation to the burns unit and had an axilla splint applied. Twenty-seven children (36%) did not require an axilla splint beyond 59 days post burn (mean 27 days post burn, SD 15.2). These children all had full axilla ROM for the duration of their follow up (mean 396 days post burn, SD 285.7).

Two children, both older males over 14 years old, reported symptoms while wearing the splint at 2 and 6 days post commencement of splinting. Symptoms were described as either pain or tingling in the upper limb and were indicative of neural tension. Symptoms were immediately resolved with removal and remoulding of the splint to increase horizontal adduction. Following remoulding, no further symptoms were reported and splinting was well tolerated. There were no other adverse events or long-term complications as a result of this splinting.

Univariate analyses of demographic and clinical characteristics of children splinted <60 days and ≥60 days are presented in Table 1 and Table 2. Children splinted for <60 days had significantly smaller %TBSA burns and less frequently sustained flame burns compared to children splinted ≥60 days. Children requiring ≥60 days splinting underwent significantly more grafting procedures, had greater healing time and longer PICU and hospital admissions.

Table 2: Characteristics of children according to length of time axilla splint used (continuous variables)

Continuous variable	Mean (SD) Splint <60 days n=27	Mean (SD) Splint ≥60 days n=49	Mean Difference	95% CI	*p*-value
Age (years)	3.5 (3.9)	4.1 (3.5)	-0.6	-2.3 – 1.2	0.52
TBSA (%)	12.1 (6.9)	17.5 (12.5)	-5.4	-9.9 – -1.0	0.02*
Hospital LOS (days)	12.1 (12.4)	26.5 (26.7)	-14.3	-26.3 – -2.3	0.02*
PICU LOS (days)	3.8 (1.5)	12.4 (10.5)	-8.7	-14.3 – -3.1	0.004*
Number of skin graft procedures	0.8 (0.7)	1.7 (1.2)	-0.8	-1.3 – -0.4	<0.001*
Time to wound closure (days)	27.4 (9.0)	40.2 (25.4)	-12.9	-20.9 – -4.8	0.002*

**p*-value <0.05 is significant
Abbreviations; CI, confidence interval; LOS, length of stay; n, number; PICU, paediatric intensive care unit; SD, standard deviation; TBSA, total body surface area

All baseline characteristics, which demonstrated significant differences between splint use <60 days and ≥60 days were entered into a backward multiple regression to predict the number of days a splint is required. Twenty-three percent of the variance (F=8.6, $p<0.001$) in the number of days a child wore a splint can be explained by the following equation;

Days splint worn = -67 - (14 x age) + (167 x mechanism) + (4 x %TBSA).

In this equation, age is the child's age in years at time of burn, mechanism is scald (1) or flame (2) and %TBSA is the burn %TBSA calculated on admission. Therefore, for every 1 year older, a child will wear a splint for 2 weeks less. A child who had a flame burn mechanism will wear a splint for 167 more days than a child who had a scald burn. For every 5% greater %TBSA they will wear a splint 20 more days. Worst burn depth and anterior trunk, flank, arm distribution was excluded from the final equation.

Ongoing end of range axilla splinting

Forty-nine children (64%) received axilla splinting ≥60 days post burn. The mean age of these children at burn was 4.1 years (SD 3.5) and mean %TBSA was 17.5% (SD 12.5). Within this group, scar management was prescribed and implemented by a burns physiotherapist and included use of compression garments and silicone

products. Table 3 outlines the frequency of hypertrophic scar (HTS) development and scar management interventions at multiple assessment points post burn. The peak use of compression garments and silicone products occurred between 3 and 9 months post burn. After 9 months, use of these interventions decreased as scars progressed towards maturation.

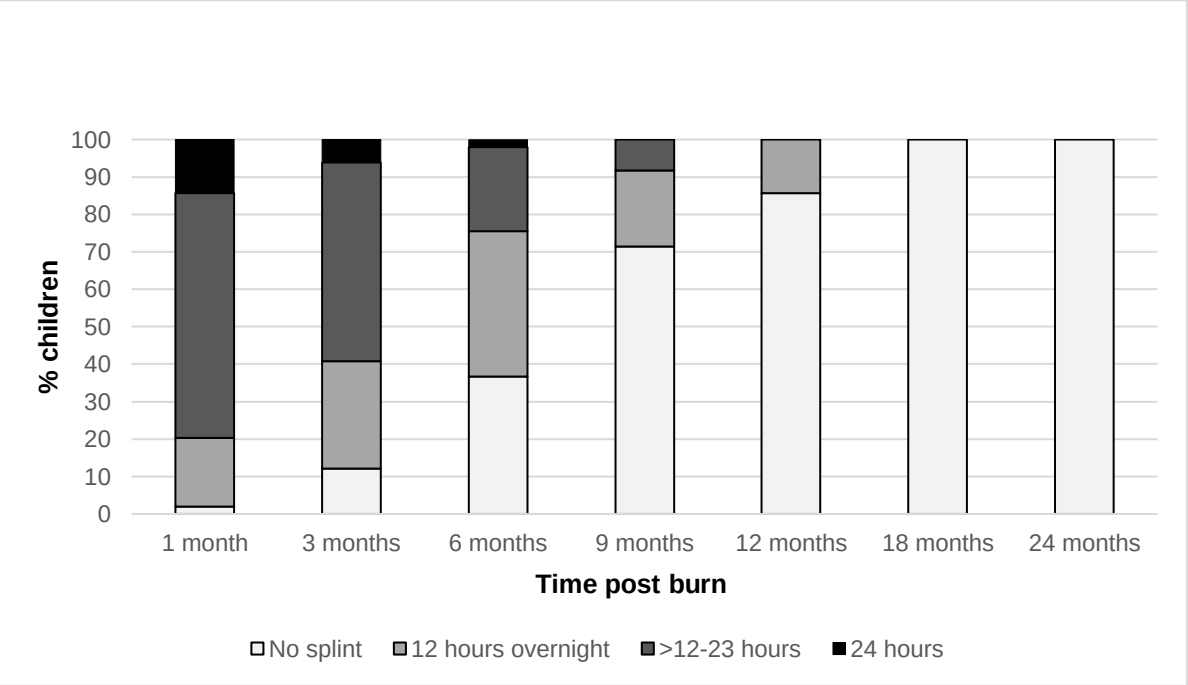
Table 3: Physiotherapy interventions for scar management in children splinted ≥60 days (n=49)

Months post burn	n (%) attending follow-up	n (%) HTS	n (%) splinted	Mean (SD) hours splint worn in 24 hour period	n (%) using compression garment	n (%) using silicone
1	49 (100)	19 (39)	48 (98)	18 (3.7)	25 (51)	11 (22)
3	49 (100)	45 (92)	43 (88)	16 (3.8)	47 (96)	38 (78)
6	49 (100)	44 (90)	31 (63)	14 (3.2)	47 (96)	38 (78)
9	47 (96)	41 (87)	14 (30)	14 (3.1)	38 (81)	35 (74)
12	42 (86)	33 (79)	7 (17)	12 (0)	24 (57)	21 (50)
18	33 (67)	21 (64)	0	0	9 (27)	9 (27)
24	26 (53)	18 (69)	0	0	4 (15)	4 (15)

Abbreviations; HTS, hypertrophic scar; n, number; SD, standard deviation

The mean time to axilla splint commencement in this group was 7 days post burn (SD 9.4) and the mean number of days of splint use was 221 (SD 111.7), with all children ceasing splinting by 18 months post burn. All were splinted prophylactically, except one child who commenced splinting when skin tension was identified at day 55 post burn. Forty-five percent of children commenced splinting within the first 3 days of injury. Figure 4 shows axilla splint use at multiple assessment points and demonstrates the changing frequency of splint regimes and the decline in splint use as the scar progresses towards maturation. Hours of axilla splint use in a 24-hour period are presented in Table 3. The mean duration of follow-up in these children was 612 days (SD 255.6).

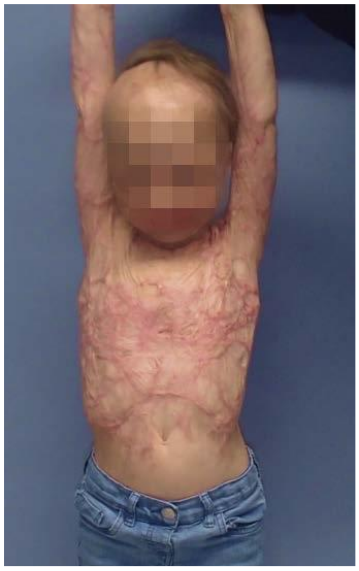
Figure 4: Hours end of range axilla splint worn in 24 hour period in children splinted ≥60 days (n=49)



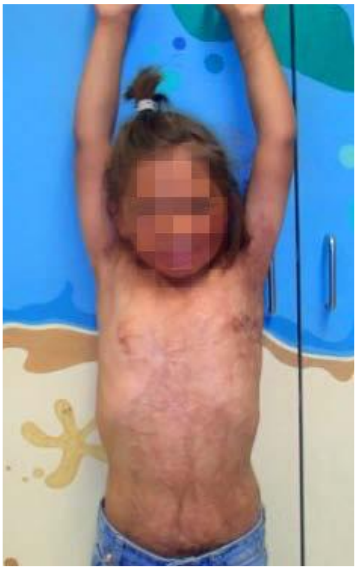
Outcomes of end of range axilla splinting

At 9 months post burn all children attending review had full ROM, with no further loss of ROM for the duration of their follow up in this study. Examples of outcomes of end of range axilla splinting at 12 and 18 months post burn are demonstrated in Figure 5. Early signs of contracture developed in 9 of the children (18%) who had received splinting ≥60 days post burn; 7 (14%) had loss of ROM and 2 (4%) had significant banding. Figure 6 illustrates the flow of children with early signs of contracture development in the first 9 months post burn. No child who received splinting <60 days demonstrated any early signs of contracture.

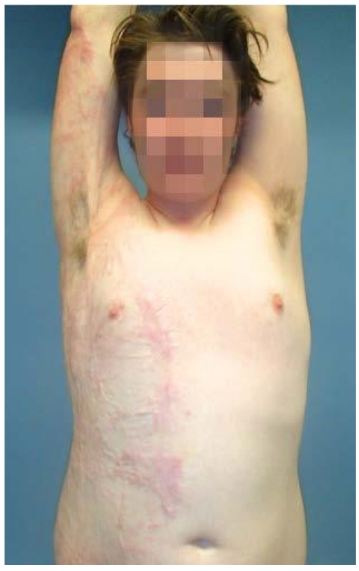
Figure 5: Children treated with end of range axilla splint



12 months post burn



12 months post burn



18 months post burn

Parent/Guardian consent provided for use of these images

In the first 6 months post burn, 6 of the children who developed early signs of contracture underwent serial casting at a mean of 76 days (SD 24.7) post burn. The mean age of these children at burn was 5.4 years (SD 2.5) with a mean %TBSA of 16.3% (SD 10.5) and a mean time to complete wound healing of 67.3 days (SD 47.7). Two of these children required only 1 serial cast; which was applied for up to 4 days. Three children required application of 2 serial casts, with a mean duration of casting of 8 days (SD 2.6). The remaining child had a daily serial cast applied for 3 days. This child had persistent scar tension at end of range abduction and flexion throughout the first 6 months post burn, which following casting was managed with ongoing and intensive splinting and exercise. All children were transitioned back to an axilla splint following casting with a mean length of splinting post burn of 311 days (SD 107.7).

The three other children who developed early signs of contracture (Figure 6) did not undergo serial casting. Two children improved axilla ROM with intensive exercises and ongoing axilla splinting. One child had loss of ROM and the axilla self-released

while participating in physical activity. In this case, re-grafting was required to achieve wound closure.

Figure 6: Flowchart depicting numbers of children with early signs of contracture development in the first 9 months post burn

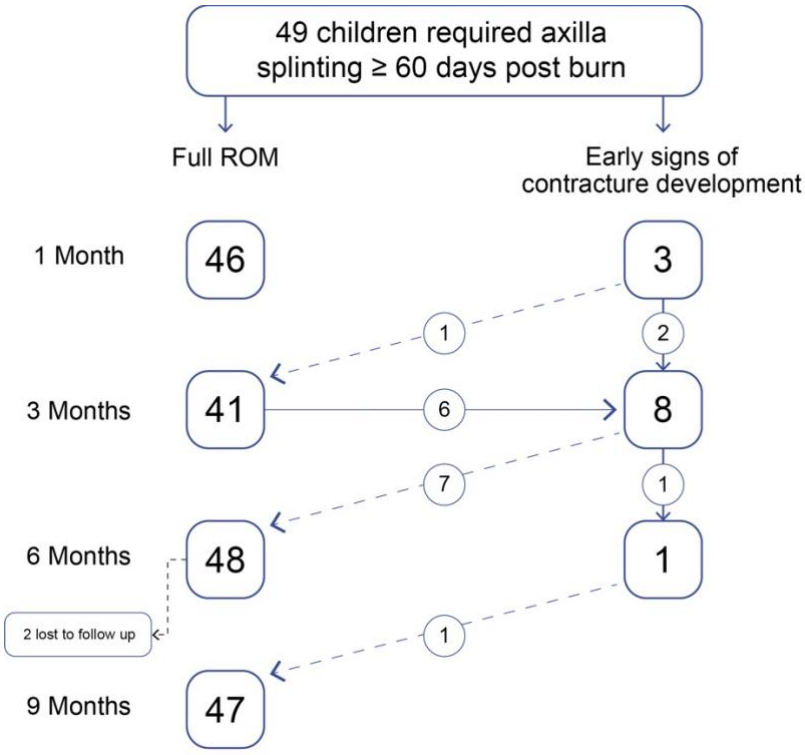


Table 4 presents characteristics associated with early sign of contracture development. Older children were significantly more represented with 7 of the 9 children who developed early signs of contracture between 5-<12 years old. In this age group, there were greater numbers of flame burns in the whole cohort and similarly, flame burns were also significantly more represented among those who developed early signs of contracture. Beyond baseline characteristics, children with skin tension at end of range shoulder abduction and flexion at 1-month post burn, were significantly more represented among those who developed early signs of contracture.

Table 4: Univariate analysis of characteristics at baseline and 1-month assessment associated with early signs of contracture development

Categorical variable		All children splinted ≥ 60 days n (% of n=49)		*p*-value comparing children who did and did not develop early signs of contracture
		Early signs of contracture development n=9	No early sign of contracture development n=40	
Sex	Male	6 (12)	19 (39)	0.30
	Female	3 (6)	21 (43)	
Age	<2	1 (2)	19 (39)	0.004*
	2 - <5	0	11 (23)	
	5 - <12	7 (14)	9 (18)	
	12-18	1 (2)	1 (2)	
Ethnicity	Caucasian	4 (8)	20 (41)	0.20
	Aboriginal	3 (6)	3 (6)	
	Asian	0	7 (14)	
	Arab and African	2 (4)	5 (10)	
	Mixed	0	4 (9)	
	Unknown	0	1 (2)	
Geographical location	Metropolitan	4 (8)	28 (57)	0.15
	Non-metropolitan	5 (10)	12 (25)	
Mechanism	Scald	1 (2)	29 (59)	0.001*
	Flame	8 (16)	11 (23)	
TBSA	<30%	8 (16)	33 (67)	0.64
	≥30%	1 (2)	7 (14)	
Worst burn depth	Mid-dermal	1 (2)	3 (6)	0.72
	Deep-dermal	8 (16)	37 (76)	
Distribution of deep burn areas**	Anterior trunk / arm	1 (2)	13 (27)	0.2
	Anterior trunk / flank / arm	4 (8)	10 (20)	0.24
	Posterior trunk / arm	1 (2)	2 (4)	0.49
	Posterior trunk / flank / arm	1 (2)	4 (8)	0.92
Side affected	Unilateral	9 (18)	33 (67)	0.18
	Bilateral	0	7 (14)	
Hospital admission	Admitted	9 (18)	35 (72)	0.26
	Not admitted	0	5 (10)	
PICU admission	Admitted	3 (6)	14 (29)	0.92
	Not admitted	6 (12)	26 (53)	
Wound closure at 1-month post burn	Incomplete	7 (14)	20 (41)	0.13
	Complete	2 (4)	20 (41)	
Skin tension at 1-month post burn	Present	5 (10)	4 (8)	0.001*
	Not present	4 (8)	36 (74)	

**p*-value <0.05 is significant
**% does not add up to 100 as children with distribution in other category (n=13) are not accounted for
Abbreviations; n, number; PICU, paediatric intensive care unit; ROM, range of movement; TBSA, total body surface area;

Predicting who will develop early signs of contracture

All baseline characteristics presented in Table 4 with *p*-value ≤0.15 demonstrating differences between children who did and did not develop early signs of contracture

were entered into a binary regression. The model contained 3 independent variables (mechanism, age at burn and geographical location). In this multivariate model (chi-square 12.8, df 3, Nagelkerke R squared 37.5%), no variables remained independently statistically significant; mechanism OR 12, 95% CI 0.9-158.3, *p*=0.06; age at burn OR 1, 95% CI 0.8-1.5, *p*=0.41; geographical location OR 0.9, 95% CI 0.1-5.7, *p*=0.9 and therefore baseline variables cannot predict who will develop early signs of contracture.

To determine if characteristics presenting at the 1-month postburn clinical assessment were better able to predict which children would develop early signs of contracture compared to baseline variables, variables related to clinical assessment with *p*-value $\leq$0.15 were entered into a binary regression. The subsequent model explained 31% of the variance (Nagelkerke R squared) and correctly classified 86% of patients. The presence of skin tension at end of range shoulder movement at the 1-month assessment made a unique statistically significant contribution to the model (OR 11, 95% CI 1.9-62.1, p=0.007), controlling for the absence of complete wound closure at 1-month (OR 3, 95% CI 0.5-21.5, *p*=0.2).

Discussion

This is the first study to report on ROM outcomes associated with end of range splinting of the axilla, demonstrating positive long-term ROM results in children with burns to the axilla region who have received this intervention. Furthermore, in this cohort of children, end of range splinting of the axilla was well tolerated. Only two children (3%) developed signs of neural tension, which was immediately addressed and resolved with splint remoulding. No further symptoms were reported and there were no adverse events in the long term.

Current literature reports contracture of the axilla accounts for 23%-40% of all postburn contracture, in all ages.[4-6,21,22] In a cohort of children only, axilla contracture accounted for 28% of postburn contractures at hospital discharge, despite intensive therapy, including positioning and splinting.[6] In our study, no child developed axilla contracture for the duration of their follow-up in the study. Development of early signs of contracture occurred in 9 children (18%) within the first three months of burn injury. These signs were amenable to early and intensive therapy and all children had restoration of full axilla ROM, which was retained for the remaining duration of their follow-up. Consequently, no child required surgical restoration of axilla ROM, however one child did require re-grafting as a result of an open wound from self-release. Previously published literature has demonstrated surgical release rates of 17% in children post axilla burn.[21] Our results from early, intensive, end of range splinting are therefore encouraging and could be a valuable therapy option in reducing axilla contracture rates.

Standard clinical practice at CHW is to splint all axilla burns on first presentation to the tertiary centre. A consequence of this model of care is that it will not be an essential intervention for all who receive it. One third of this cohort, ceased axilla splinting before 60 days postburn, when contracture was no longer considered a risk by the treating therapist. The 60-day cut off was selected as a defining timepoint as clinically we have noted this to be a time of highly active and dynamic scarring following complete wound closure, and if a splint was deemed not necessary at this time, then it is unlikely contracture would have ever resulted from the burn injury.

While prophylactic splinting requires considerable time and resources, prevention is an important aspect of our model of care and we believe that this approach, which captures and treats all children with any contracture risk, minimises the occurrence of poor outcomes as no one is missed. We acknowledge that this may not be suitable in settings where there is more demand on time and resources.

Current literature reports a greater prevalence of post burn contracture among individuals with larger %TBSA burns[2,4,5,23] and burns located in close proximity to a joint.[2] However, these findings are not specific to paediatric axilla burns. Therefore, due to the difficulty predicting at initial presentation who will develop early signs of contracture, the prophylactic splinting approach described within this study is recommended. While univariate analysis suggests that at initial presentation, older children with flame burns are more likely to develop early signs of contracture, the ability to predict who will develop these signs becomes much clearer at the 1-month post burn assessment with the presence of skin tension significant in a multivariate model. Identification of skin tension facilitates prompt intervention and we concur with Godleski et al[24] that early signs of contracture are amenable to intensive therapy without the need for surgical intervention. We found serial casting to be well tolerated and effective in restoring ROM and decreasing scar tension in the first 3 months post burn. This is in line with literature by Richard et al[25], who described a window of time of 2-months post burn, where contractures are amenable to therapy with good prognosis for resolution. Our findings highlight the importance of regular monitoring and clinical assessment, particularly in the first month post burn, to identify early warning signs of contracture development and facilitate prompt intervention.

In all children who developed early signs of contracture, poor compliance with splinting regimes was documented within the medical records. Compliance is a difficult variable to measure, particularly retrospectively. Consequently, the effect of poor compliance on the development of contracture could not be quantified and incorporated into statistical analysis. Interestingly, children aged 5-<12 years were represented in greater numbers among those who developed early signs of contracture. Our clinical experience suggests it is more challenging to maintain active older children in a splint, which restricts ROM for the long periods required,

particularly in the initial months post burn. However, based on the results of this study, encouraging parents and children to adhere to end of range splinting regimes may minimise the need for additional therapy interventions such as serial casting.

This study supports consideration of end of range splinting regimes well into the first-year post burn; over half of children required a splint for at least 6 months with all splinting ceased by 18 months postburn. To date, five studies[10-14] have reported results of axilla splinting post burn, however only one has reported outcomes in a cohort of children.[10] These children were splinted between 90° and 160° of shoulder abduction and while the authors reported full axilla ROM in all children, the study follow-up was very short-term (mean of 2 weeks post burn).[10] This does not account for scar development and subsequent contracture. The four studies with adult cohorts reported outcomes of axilla splinting at 90° shoulder abduction, also for short periods of time post burn only.[11-14] Follow-up of participants within these studies ranged from 4 weeks post burn[12] to 12 weeks post hospital discharge.[13] In comparison to the five studies, our cohort of children were splinted at a greater degree of abduction and for considerably longer periods of time postburn. This is a treatment approach we believe necessary to oppose the active and ongoing contractile properties of scar tissue.[9] This is in line with early work by Huang et al[22] who found contracture risk to be reduced if a splint was worn for at least six months. To date, we are not aware of any studies reporting longer term outcomes of any axilla splinting.

The optimal length of splint use in a 24-hour period to achieve scar elongation is unknown.[26,27] In this study, intensive splinting (12 hours overnight and 6 hours during the day), was highly prevalent in the first 3 months post burn but reduced markedly throughout follow-up. To facilitate intensive splinting well beyond hospital discharge, fabrication of a splint that allows ongoing ambulation is essential. Several axilla splint designs, which enable community ambulation are described in the literature.[7,28,29] Our end of range axilla splint allows mobility and physical activity to continue while the splint is worn. Where possible, splint use is incorporated into sleep or rest times to allow functional upper limb use during awake periods. This is particularly relevant in the periods of intense splinting early on.

There are several limitations to this study providing direction for future research. It is retrospective with a small sample size. A novel splinting method is described, which has not been previously documented and consequently, it is hard to verify the results with any other centre. Only dichotomous axilla ROM outcomes were recorded in the medical record, whereas ROM as a continuous variable may yield more detailed results. Functional outcomes as a result of splint use were not assessed, therefore unable to be collected and remain unknown. In future, a prospective study is needed with outcomes beyond 24 months post burn. A measure of upper limb function throughout the period of splinting and at cessation of splinting would also be useful. To study greater numbers, development of a standardised protocol and multicentre trial would be a valid consideration.

End of range axilla splinting is a well-tolerated and effective intervention to prevent contracture in children following a burn to the axilla region. In this study, no child developed contracture or required surgical restoration of axilla ROM for the duration of their follow-up. Early identification of children developing early signs of contracture, allows prompt and intensive intervention to restore full axilla ROM. Our findings suggest that the use of an end of range axilla splint is a valuable clinical tool to prevent axilla contracture and is worth consideration in settings where contracture rates are higher.

Acknowledgements

We thank Anne Darton from the NSW SBIS for providing data on all burn injured children managed at CHW.

We acknowledge Cheri Templeton for her contribution to burns physiotherapy and management of axilla burns at CHW.

References

1. van der Wal MB, Vloemans JF, Tuinebreijer WE, et al. Outcome after burns: an observational study on burn scar maturation and predictors for severe scarring. *Wound Repair Regen.* 2012;20(5):676-687.
2. Gangemi EN, Gregori D, Berchialla P, et al. Epidemiology and risk factors for pathologic scarring after burn wounds. *Arch Facial Plast Surg.* 2008;10(2):93-102.
3. Leblebici B, Adam M, Bagis S, et al. Quality of life after burn injury: the impact of joint contracture. *J Burn Care Res.* 2006;27(6):864-868.
4. Schneider JC, Holavanahalli R, Helm P, et al. Contractures in burn injury: defining the problem. *J Burn Care Res.* 2006;27(4):508-514.
5. Goverman J, Mathews K, Goldstein R, et al. Adult Contractures in Burn Injury: A Burn Model System National Database Study. *J Burn Care Res.* 2017;38(1):328-336.
6. Goverman J, Mathews K, Goldstein R, et al. Pediatric Contractures in Burn Injury: A Burn Model System National Database Study. *J Burn Care Res.* 2017;38(1):192-199.
7. Manigandan C, Bedford E, Ninan S, et al. Adjustable aesthetic aeroplane splint for axillary burn contractures. *Burns.* 2005;31(4):502-504.
8. ISBI Steering Committee. ISBI Practice Guidelines for Burn Care. *Burns.* 2016;42(5):953-1021.
9. Richard R, Ward RS. Splinting Strategies and Controversies. *J Burn Care Rehabil.* 2005;26(5):392-396.
10. Macdonald LB, Covey MH, Marvin JA. The papoose: device for positioning the burn child's axilla. *J Burn Care Rehabil.* 1985;6(1):62-63.
11. Kolmus AM, Holland AE, Byrne MJ, et al. The effects of splinting on shoulder function in adult burns. *Burns.* 2012;38(5):638-644.
12. Jang KU, Choi JS, Mun JH, et al. Multi-axis shoulder abduction splint in acute burn rehabilitation: a randomized controlled pilot trial. *Clin Rehabil.* 2015;29(5):439-446.
13. Webb DC, Byrne M, Kolmus A, et al. Outcomes of a shoulder treatment flowchart in patients with axillary burns. *J Burn Care Res.* 2011;32(2):224-230.

14. Godleski M, Holden MS, Luby D, et al. Clinical outcomes from a foam wedge splinting program for axillary contracture prevention in the intensive care unit. *J Burn Care Res.* 2014;35(6):379-386.
15. Richard R, Staley M, Miller S, et al. To splint or not to splint--past philosophy and present practice: Part I. *J Burn Care Rehabil.* 1996;17(5):444-453.
16. Richard R, Staley M, Miller S, et al. To splint or not to splint--past philosophy and present practice: part III. *J Burn Care Rehabil.* 1997;18(3):251-255.
17. Australian Bureau of Statistics. Australian Standard Geographical Classification (ASGC) Digital Boundaries, Australia. In: Statistics ABS. Vol 1259. Australia: Australian Bureau of Statistics; 2011.
18. Wallace HJ, Fear MW, Crowe MM, et al. Identification of factors predicting scar outcome after burn in adults: A prospective case-control study. *Burns.* 2017;43(6):1271-1283.
19. Wallace HJ, Fear MW, Crowe MM, et al. Identification of factors predicting scar outcome after burn injury in children: a prospective case-control study. *Burns & Trauma.* 2017;5(1):19.
20. *IBM SPSS statistics for windows, version 22.0* [computer program]. Armonk, NY: IBM Corp; 2013.
21. Kraemer MD, Jones T, Deitch EA. Burn contractures: incidence, predisposing factors, and results of surgical therapy. *J Burn Care Rehabil.* 1988;9(3):261-265.
22. Huang TT, Blackwell SJ, Lewis SR. Ten years of experience in managing patients with burn contractures of axilla, elbow, wrist, and knee joints. *Plast Reconstr Surg.* 1978;61(1):70-76.
23. Dobbs ER, Curreri PW. Burns: analysis of results of physical therapy in 681 patients. *J Trauma.* 1972;12(3):242-248.
24. Godleski M, Oeffling A, Bruflat AK, et al. Treating burn-associated joint contracture: results of an inpatient rehabilitation stretching protocol. *J Burn Care Res.* 2013;34(4):420-426.
25. Richard R, Miller S, Staley M, et al. Multimodal versus progressive treatment techniques to correct burn scar contractures. *J Burn Care Rehabil.* 2000;21(6):506-512.
26. Dewey WS, Richard RL, Parry IS. Positioning, splinting, and contracture management. *Phys Med Rehabil Clin N Am.* 2011;22(2):229-247.

27. Richard R, Baryza MJ, Carr JA, et al. Burn rehabilitation and research: proceedings of a consensus summit. *J Burn Care Res.* 2009;30(4):543-573.
28. Manigandan C, Gupta AK, Venugopal K, et al. A multi-purpose, self-adjustable aeroplane splint for the splinting of axillary burns. *Burns.* 2003;29(3):276-279.
29. Gorka R, Gupta AK, Prakash S, et al. Simple, self-adjustable airplane splint for axillary contractures. *Burns Open.* 2017;1(2):54-58.

Chapter Four:

Discussion

This thesis has explored the prevalence and predictors of burn scar contracture in adults and children and examined the methods and outcomes of current splinting techniques for axilla burns reported in published literature and in an original research study presented in Chapter 3. Early, end of range axilla splinting at The Children's Hospital at Westmead over a 10-year period demonstrated positive outcomes and has been submitted to the Journal of Burn Care and Research. This final chapter explores the findings of this thesis in greater depth than covered in the paper presented in Chapter 3.

Key Findings

1. Early, end of range axilla splinting is well tolerated with excellent ROM outcomes achieved in children following burn injury to the axilla region.
2. End of range splinting could be considered at other joints as an intervention to maintain joint ROM post burn injury.
3. Functional consequences and outcomes of prolonged splinting require further consideration.
4. There is limited evidence regarding the prevalence and predictors of burn scar contracture in published literature.
5. There is a need for clear, agreed upon definitions of hypertrophic scarring and contracture.

Finding 1: Early, end of range axilla splinting is well tolerated with excellent ROM outcomes achieved in children following burn injury to the axilla region.

The study presented in Chapter 3 demonstrated that end of range splinting is a valuable intervention to maintain axilla ROM in children following a burn to this area. No child developed contracture of the axilla for the duration of their follow-up in the study. While 9 children developed early signs of contracture within the first 3 months post burn, these signs were amenable to early and intensive therapy and all children had full restoration of axilla ROM. This is in line with earlier work by Richard et al,[64]

who in a retrospective study found that scar contractures that developed within 2 months of burn injury had good prognosis for resolution. Several case studies have also reported positive ROM outcomes following serial casting of post burn contractures at the elbow, knee and foot and ankle.[82-84]

This study is the first to report 2-year outcomes of axilla splinting post burn. Previous research into the effectiveness of post burn axilla splinting assessed short-term outcomes only, with the longest study follow-up of 12 weeks post hospital discharge.[79] Given that scar maturation occurs up to 2 years post burn, the previously reported short term outcomes do not provide a clear measure of the long term results of splinting in the prevention and management of BSC. The outcomes of this current study suggest that intensive splinting, for up to 12 months post burn can result in excellent ROM outcomes at 2 years post burn. Future research needs to focus on the long-term efficacy of splinting post burn injury. To do this, ROM outcomes need to be analysed at scar maturation, at least 2 years post burn with minimal loss to follow-up.

It is important to acknowledge that there was considerable loss to follow up in the study presented in Chapter 3, particularly after 12 months post burn. Of the 49 children splinted ≥60 days, 100% were assessed at 6 months post burn, 86% at 1 year post burn and 53% at 2 years post burn. Consequently, there is a need for strategies to ensure greater rates of follow-up in future prospective research. In a study of orthopaedic patients, Sprague et al[85] outlined multiple strategies to limit loss to follow-up in a RCT. These strategies included, obtaining detailed contact information for participants including alternate contacts, excluding individuals uncertain about their willingness to complete follow-up, designing the study follow-up schedule to coincide with normal follow-up visits to minimise inconvenience to participants, fully informing participants of their role in the research and discussing expectations for personal benefit from participation as well as how the research will benefit future patients.[85] In future prospective research analysing the effectiveness of axilla splinting post burn, these strategies could be implemented to minimise loss to follow-up.

This study of end of range axilla splinting was retrospective, at one centre and involved one type of splinting practice only. To provide better evidence of the efficacy, feasibility and safety of end of range axilla splinting, this intervention should be compared to exercise only or other types of axilla splinting practice, through a prospective RCT. It is important to consider that a multicentre RCT may be unlikely to be agreed upon in centres where established clinical practice includes standard preventative splinting. This would certainly be the case at this tertiary children's hospital as end of range axilla splinting post burn has been standard practice for 30 years with excellent results. Consequently, while a multicentre RCT[86] to compare end of range splinting to a regime of exercise only or a 90° axilla splint, would provide higher level evidence into the effectiveness of this type of splinting, it may not be a feasible option in centres where there is already established practice. However, training therapists who are inexperienced in splinting methods or currently do not splint prophylactically due to lack of evidence regarding efficacy, may be an option to enable a multicentre trial to be conducted.

In a multicentre RCT, stratification of individuals according to known risk factors for contracture would be ideal. However, this remains a challenge, due to the lack of evidence regarding predictors of contracture in children. As presented in Table 1.3, Chapter 1, the only known risk factors for BSC in children, are older age and longer ICU length of stay.[46] Factors related to injury severity are more predictive of BSC in adult cohorts.[5,7,53] A recent development in the prediction of risk and extent of contracture post burn is the concept of cutaneous functional units (CFUs). This was first described by Richard et al[12] and refers to fields of skin associated with movement at a joint. In skin unaffected by burn injury the greatest amount of skin movement occurs in close proximity to the joint, however skin movement is also evident at significant distances from the axis of movement.[12] Parry et al[87] found that in children with post burn axilla contracture, the greater the percent of CFUs affected, the greater the loss of ROM at the shoulder. Further prospective research is needed, to demonstrate whether factors related to injury severity, such as the number of CFUs affected are associated with an increased risk of contracture in children. Consequently, a prospective longitudinal study[86] to enhance understanding of the tolerability and safety of end of range axilla splinting may be the first feasible

study design, until further knowledge regarding contracture predictors in children is gained.

A unique aspect of this study was the end of range splinting position in abduction ranges well beyond 90°. In this cohort of children, splinting in this position was not observed to cause any adverse events. Increased tension on the brachial plexus is a recognised concern of axilla splinting beyond 90° post burn to this area.[47] Two older males did report symptoms consistent with positive neural tension, however this ceased immediately on remoulding the splint in greater horizontal adduction. This therefore suggests, in line with hypotheses by other authors, that 15-20° of horizontal adduction is integral to the safety of end of range axilla splinting.[47,78] Future research could consider inclusion of nerve conduction studies if concerns regarding splinting the shoulder in >90° abduction continue to preclude use of this splint design in clinical practice.

Finding 2: End of range splinting could be considered at other joints as an intervention to maintain joint ROM post burn injury.

In light of the positive outcomes demonstrated in this study, end of range splinting to manage other joints post burn warrants further research and consideration in clinical practice. There is very limited evidence regarding the efficacy, feasibility and safety of any type of splinting practice, across any joint post burn. Consequently, as discussed in Chapter 1.2, implementation of splinting post burn and approaches to prevention and management of BSC vary considerably between therapists and burn units.[58,88] The potential role of end of range splinting across each limb joint will now be discussed.

At the elbow and knee joints, end of range splinting is recommended clinical practice in burn care guidelines.[39,89] To prevent contracture of the elbow and knee post burn, therapists are advised to position these joints in full extension, minus a few degrees to avoid joint trauma.[39,89] It is important to recognise that the elbow and knee differ from the shoulder as they are both hinge joints, which move within the sagittal plane

only.[90] In comparison, the shoulder is a multiplanar joint, moving within the frontal, transverse and sagittal planes.[90] Consequently, splinting at end of range to prevent flexion contracture of the elbow and knee is considerably easier compared to the shoulder, as extension can be comfortably maintained with a splint, which can be worn for prolonged periods of the day and overnight. Furthermore, the elbow and knee move frequently into end of range extension with normal daily activities. In comparison, the shoulder moves to end of range abduction and flexion considerably less frequently. A study assessing upper limb position during 8 hours of daily activity found that 96% of the time, humeral position was <120° of flexion and abduction.[91] Concern regarding nerve injury caused by isolated end of range splinting at the elbow and knee has also not been raised in any published literature. At present, there have been no published RCTs analysing the effectiveness of any elbow or knee splinting techniques. Lower quality evidence is available but limited. Two case series reported improvements in elbow and knee ROM following serial casting[83] and static progressive splinting.[92] One case study, involving an adult patient with bilateral post burn elbow flexion contractures, reported that elbow extension improved with use of a dynamic elbow splint.[93]

Prevention of contracture at the hip poses a similar challenge to the shoulder following burn injury as it is also a multiplanar, ball and socket joint.[90] Clinical practice guidelines recommend positioning the hip, particularly when the burn involves the anterior surface, in full extension with 15°-20° abduction and no rotation.[39,89] This is achievable when the patient is supine or prone post burn injury, however becomes more challenging when the patient is mobile as the hip cannot be immobilised in this position when the patient is upright and walking. Furthermore, when the patient is sitting, the hip is positioned in flexion, therefore promoting the position of contracture. Consequently, regular stretching in prone into end of range hip extension is a valuable adjunct to hip splinting. A fundamental difference between the hip and shoulder is that the hip moves into end of range extension with mobility, a daily activity. In comparison, end of range shoulder abduction and flexion is not required in the same frequency to complete regular ADLs.[91] This may explain why the shoulder accounts for 23%-40%[7,46,51-53] of all post burn contractures, while the hip accounts for 5%-8%[7,46,53] of all post burn contractures. Despite being similar

joints, the variation in contracture prevalence at the hip and shoulder suggest it is easier to maintain ROM at the hip post burn compared to the shoulder. At present, no prospective trials, splint descriptions or case studies regarding hip splinting techniques have been published.

Clinical practice guidelines recommend positioning the foot and ankle at plantargrade to prevent equinus deformity, a common contracture in adults following burn injury to the foot and ankle.[39,89] In children, burns to the feet commonly occur in the Australian population as a result of contact with a hot object, frequently campfire ash.[94] These burns often involve the plantar surface of the foot and are optimally positioned in plantargrade or neutral. However, when the dorsal surface of the foot and ankle are involved, splinting at end of range plantarflexion is an intervention to consider, as it may assist with prevention of dorsiflexion contractures. At present, no end of range plantarflexion splinting to prevent dorsiflexion contracture has been described in published literature. Two case studies involving children with bilateral plantarflexion contractures, reported improvements in ankle dorsiflexion ROM following serial casting.[82,84] At present, there have been no RCTs evaluating the effectiveness of one splint over another for burns involving the foot and ankle.

Contracture of the hand and wrist can result in less than optimal hand function following burn injury.[95] Similar to the effect of axilla contracture on upper limb function discussed in Chapter 2.1, BSC of the hand and wrist may impair an individual's ability to perform manual tasks. Clinical practice guidelines recommend positioning the hand and wrist post burn injury with the metacarpophalangeal (MCP) joints in 70°-90° flexion, the interphalangeal (IP) joints in full extension, the carpometacarpal (CMC) joint of the thumb in a combination of radial and palmar abduction and the wrist in neutral or slight extension.[39,89,96] This positioning reflects the functional position of the adult hand, with the MCP joints positioned in flexion to maintain length of the extensor tendons. In children, a different approach to splinting the hand and wrist may be warranted due to the large incidence of burns to the palmar surface of the hand and wrist, anecdotally reported in published literature.[97-99] Young children actively engage with their environment, seeking out new experiences and different objects to touch and explore. Consequently, burns to the palmar

surface of the hand frequently occur and in young children isolated burns to the hand and wrist account for a quarter of all burns in children aged 0-4 years.[2,100] The frequency of this distribution is not evident in adults.[2] To address the potential for palmar contracture in the growing hand, clinical practice at CHW is to splint the hand in full IP, MCP and CMC extension with the wrist in 30°-40° extension. This completely opens the palm and provides a sustained extension stretch to all joints of the hand and wrist, which may assist with the prevention of palmar contracture. This is particularly important in young children, due to the years of growth ahead and the potential for contracture development as a result of growth.

At present, literature involving splinting of the wrist and hand post burn is limited. Two RCTs have been published involving adult patients with flexion contractures restricting extension at the MCP joints post burn.[101,102] Choi et al[101] found greater improvements in active MCP flexion in patients treated with a dynamic splint for 8 weeks compared to no splint, while Kamal et al[102] found patients treated with a dynamic splint for 8 weeks had greater improvements in ROM and hand function compared to those treated with a static splint. The timing of splinting commencement post burn was not specified in either study, although all patients in the study by Choi et al[101] were within 6 months of burn injury. The only published literature to report outcomes of splinting paediatric palm burns is a case series published in 1992, which involved 11 children with palm burns splinted in MCP hyperextension with 30-40° of wrist extension.[103] The splint was worn continuously for the first 2-4 weeks post burn and reduced to overnight and day sleeps for an additional 3-6 months.[103] The authors reported that at 18 months post burn 75% of the cohort had normal ROM, while 25% were scheduled for reconstructive surgery.[103] Anecdotally, splinting burns involving the palmar surface of the hand and wrist in a similar position at this tertiary children's hospital, produces excellent ROM outcomes at scar maturation, which exceed those described in the case series above. Theoretically, this may be due continuous use of the splint throughout the day and night for greater periods of time than 2-4 weeks post burn.

There is very limited research into the effectiveness, feasibility and safety of splinting to prevent post burn contracture, particularly at end of range. This leaves very limited

evidence-based treatment pathways for burns therapists to prevent and manage contracture. While splinting post burn is accepted as a treatment to oppose the ongoing contractile forces of maturing scar tissue, the utilisation of splinting varies considerably among burn therapists.[9,58] In the proceedings of the Consensus Summit on Burn Rehabilitation, the authors hypothesised that this is due to a lack of objective data on intervention parameters and efficacy of splint use.[9] Despite many splint designs described in the literature, RCTs evaluating the effectiveness of one splint over another are extremely limited. Similar to the short time frames described in axilla splinting literature, the two RCTs involving the MCP joints of the hand analysed the effectiveness of splinting for 8 weeks only.[101,102] The timing of splint commencement post burn was not specified. Consequently, the long-term effect on ROM of these interventions remains unknown.

Future research should focus on determining the efficacy, feasibility and safety of postburn splinting at the axilla and other joints.[9] Outcomes should be analysed at least 2-years post burn with efforts to ensure minimal loss to follow up throughout the study period. This research will enable therapists to provide care to patients post burn, which is centred on solid evidence-based treatment instead of anecdotal evidence established from experience.

Finding 3: Functional consequences and outcomes of prolonged splinting require further consideration.

Post burn function needs improved evaluation, particularly following implementation of splinting interventions. In the study presented in Chapter 3, children were immobilised at end of range shoulder abduction for prolonged periods of time. While anecdotally no detrimental effects on upper limb function have been observed from this splinting practice at CHW, this is not definitively known. Although parents often subjectively report that upper limb use has returned to pre-burn level, no formal testing was conducted at this tertiary centre to substantiate this. Consequently, the functional outcomes of prolonged, end of range splinting could not be reported within the study presented in Chapter 3.

During childhood, children have acquisition of skills, which may be limited by a lack of task specific practice while immobilised in the axilla splint. To assess potential detrimental effects of intensive and prolonged end of range axilla splinting, standardised assessments of fine motor function at predetermined time points, during and post periods of intensive splinting and in the years following scar maturation, could be considered. Assessment using The Peabody Developmental Motor Scales-2,[104] the Nine-Hole Peg Test[105] or the Functional Dexterity Test[106] may be useful tools in these instances, to compare hand function of children splinted to normal values. If this demonstrated that during and following splinting, children performed poorly in comparison to normal, modification of splinting regimes or the addition of functional training when out of the splint, may be warranted. However, it is important to consider whether poor performance is solely attributed to splint use. To date, no research has been conducted analysing the effect of burn injury on children's gross or fine motor skill attainment. However, it seems plausible that following significant injury, there is potential for delay in the acquisition of new skills, or even regression of fine and gross motor skills. Incorporating a functional measure of upper limb use in a multicentre RCT would assist with determining this.

Another important area to explore is the perception of children and their families to prolonged and intensive splint use. Qualitative research methods to gauge the impact of splinting on families could provide useful information regarding the burden of care of intensive splinting regimes. Scar and contracture management post burn is invariably driven by the perspective of the burns therapist, which may not necessarily address what is important to the patient. Developing a greater understanding of the perception of post burn function and what is important to children and their families would assist with tailoring post burn therapy interventions to best meet patient goals. Reporting on patient reported outcomes is also increasingly recognised as important in clinical research, to inform a patient centred approach to care and clinical decision making.[107] In providing care to children and their families post burn, is important to consider their perception, as splinting is time intensive and potentially increases the burden of care on families.

Finding 4: There is limited evidence regarding the prevalence and predictors of burns scar contracture in published literature.

There is a need for a clear definition of BSC. Previous literature has defined contracture as loss of range of movement at a joint identified with goniometry or inclinometry[7,46,53] or subjective assessment of visible skin coarctation, reduced ROM or sensation of constriction.[5] Several studies presented in Table 1.3 provided additional classification of contracture according to severity, by dividing ROM equally into thirds[7,46,53] or quarters.[51] This current study of end of range splinting was retrospective and limited to information available in patient medical records. In contrast to other retrospective studies, where axilla ROM was measured with a goniometer and inclinometer,[7,46,53] axilla ROM in the medical records accessed for this study was recorded as either full or not full. In some cases of early signs of contracture, an approximate measure of end of range abduction was provided. However, no objective ROM measures were routinely recorded clinically. This is a limitation of this study, as the improvement in ROM gained from serial casting or intensive exercise with ongoing splinting could not be quantified in the children who developed early signs of contracture and underwent intensive therapy. Future prospective research must include an objective measure of axilla ROM, such as goniometry or inclinometry to provide more accurate ROM outcomes. To enable comparison of results between studies, there is a need for a clear, agreed upon definition of contracture post burn, obtained with objective measurement tools widely available in the clinical setting.

There is wide variation in the reported prevalence of postburn contracture. The study presented in Chapter 3 demonstrated no contracture at 2 years post burn. The children included in this study were all deemed on initial presentation to be at high risk of developing axilla contracture following a burn to this area. With the exception of Dobbs and Curreri,[52] who did not specify inclusion criteria, and Huang et al,[51] who included only individuals with burns involving specific joints, all other authors reported contracture prevalence in all individuals presenting to inpatient[7,46,53] or outpatient burn units[5] for management of a burn injury (Table 1.3, Chapter 1).[5,7,46,53] The prevalence of contracture reported in these studies therefore reflects the overall

risk of developing a contracture following a burn injury, as all individuals with a burn were assessed, including those without joint involvement.

To gain greater knowledge of the prevalence of contracture post burn, understanding the risk of developing contracture at a particular joint following a burn across or in close proximity to the joint is essential. Currently, evidence regarding the prevalence of BSC by burn anatomical location is limited.[9] Only one study, presented in Table 2.1, reported on the prevalence of axilla contracture as a percent of all axilla burns.[52] All other studies[5,7,46,51,53] reported the prevalence of axilla contracture in relation to all contracted joints. Consequently, it is unknown whether the risk of axilla contracture is the same as the risk of contracture at other joints post burn injury when the burn is across or in close proximity to that joint. In order to provide clearer prognostic information to patients and their families, more research into the risk of developing contracture at a specific joint following a burn across or in close proximity to that joint, is needed with prospective longitudinal studies. Clinically, this will enable better delivery of resources and aid prioritisation of patient care to target those most at risk.

To date, there have been no studies to analyse the prevalence of post burn contracture at the point of scar maturation. The only study to report on the prevalence of post burn contracture in children, assessed ROM outcomes at hospital discharge.[46] The lack of long-term prevalence data is particularly relevant in children, as there is an absence of knowledge regarding how contracture prevalence changes with normal growth and development. When normal skin is replaced with thick burn scar, which has decreased pliability and extensibility, the ability of the skin to accommodate growth is reduced.[15,16] In order to provide better information to children and their families on the effect of future growth and development following a burn to a specific joint, the prevalence of BSC needs to be studied, not only to the time of scar maturation, but also over longer periods of time, while a child continues to grow.

The ability to predict the development of BSC based on published literature is also limited. Understanding predictors of contracture is important, as knowing who is at risk of developing contracture can assist with guiding management and preventative

strategies. In children, only one study has analysed predictors of contracture.[46] These authors found that older children and increasing ICU length of stay were significantly associated with the development of 1 or more post burn joint contractures.[46] In the study presented in Chapter 3, predictors of splint use ≥60 days could be considered a proxy for predictors of contracture, as these children used a splint as a preventative intervention for contracture. In univariate analysis, younger children, flame mechanism, deep dermal burn, burn TBSA ≥30% and burn distribution involving the anterior trunk, flank and arm demonstrated a significant relationship with splint use ≥60 days. In multivariate analysis, younger children, flame mechanism and increasing %TBSA remained significantly related to longer splint use. In terms of age, this is in contrast to the finding reported by Goverman et al[46] as in their cohort, older children, not younger children were more likely to develop contracture. A possible explanation for this is that in the current study of end of range axilla splinting presented in Chapter 3, younger children were more tolerant of splint use and consequently continued to use a splint for longer periods of time. Clinically, it may be more difficult to maintain splint use over prolonged periods of time in older children, so compromise with regular exercise occurs earlier, hence excluding them from maintaining splinting ≥60 days. Another explanation for the greater prevalence of contracture in older children identified by Goverman et al,[46] is that, as discussed in Chapter 1.1, there is an increasing incidence of flame burns in older children,[1,2] which can result in more uniformly deep burns with larger distributions. In this current study of end of range axilla splinting, flame burns were identified as a predictive factor for longer splint use as well as development of early signs of contracture.

The study presented in Chapter 3 highlights the importance of closely monitoring children presenting with flame burns, as children with this mechanism of burn injury were significantly more likely to require splinting ≥60days and were also significantly more likely to develop early signs of contracture. These children should be identified at the outset and closely monitored throughout the scar maturation process. This is particularly important in the first 3 months post burn, as this was demonstrated as the time when early signs of contracture developed.

The importance of regular monitoring and good clinical assessment at 1-month post burn has been highlighted in this study. The presence of skin tension at end of range shoulder abduction and flexion at 1-month post burn was significantly more likely to be present in children who developed early signs of contracture. Multivariate analysis determined that identifying skin tension at 1-month post burn was more important in predicting early signs of contracture than demographic and baseline clinical variables. Therefore, to facilitate timely intervention to address warning signs of contracture, good clinical assessment at 1-month post burn is essential.

Nine children developed early signs of contracture in this current study. If prompt and intensive therapy intervention had not occurred, these early signs may have progressed to contracture and required surgical release to restore axilla ROM. Poor compliance with splinting was recorded in the medical record of all 9 children who developed early signs of contracture. Obtaining a measure of patient compliance can be difficult in both clinical and research settings. In this retrospective study, patient compliance was frequently not documented in the medical record, potentially due to poor compliance not being of concern to the therapist in most cases. Consequently, the study was unable to quantify the effect of poor compliance on the development of early signs of contracture. If compliance data had been available to incorporate into statistical analysis, it is hypothesised that this variable would have demonstrated a relationship with the development of early signs of contracture. In future prospective research, a record of daily compliance, kept by the parent or carer would provide valuable information regarding adherence to splint use. Other options could include use of pressure or temperature sensors in splints, to provide a more objective measure of compliance.[108,109]

Greater understanding of the predictors of BSC at specific joints is an important direction of future research. Improving understanding of skin movement around a specific joint may assist prediction of which burn distributions require more concentrated efforts to prevent contracture. The concept of CFUs builds upon %TBSA as a predictor of contracture post burn as %TBSA alone cannot account for the proximity and subsequent impact of the scar on the surrounding joints.[12] Applying the concept of CFUs to other joints post burn may help to provide more detailed information regarding who is at risk of developing contracture post burn.

Future prospective research on end of range axilla splinting could aim to measure burn distribution according to CFUs. Potentially, the greater the number of CFUs affected, the greater the length of time a child will require an axilla splint, both in the 24-hour period and months post burn. Additional information regarding contracture risk post burn may be gained by analysing hypertrophic scarring scores around the axilla within CFUs.

More research is needed into the predictors of BSC. It is essential to be able to account for known risk factors of contracture in studies determining the efficacy of therapy interventions. Currently, limitations in published literature regarding predictors of contracture mean that we do not conclusively know what the risk factors for contracture are, particularly in children. As a consequence, a prophylactic approach to splinting is recommended as we do not know definitively who will develop contracture. In order to better target children at risk of developing BSC and tailor therapy needs accordingly, better information regarding predictors of contracture is needed.

Improving evidence regarding therapy interventions will also enhance the clarity of reporting of therapy in the burn care setting. Currently, studies investigating the development of hypertrophic scarring and contracture post burn, presented in Table 1.2 and 1.3, Chapter 1, frequently do not account for the effect of therapy on these common burn sequelae. Providing quality evidence on the role of compression, silicone products and splinting in postburn care will enable therapy interventions to be standardised in burn research and improve clarity around reported prevalence and predictors of BSC. For example, we need to consider whether long term outcomes of post burn surgical intervention can be evaluated without standardising therapy interventions that patients in the cohort receive.

Finding 5: There is a need for clear, agreed upon definitions of hypertrophic scarring and contracture.

Significant variation exists in the reporting of post burn hypertrophic scarring in published literature. In adults, the reported prevalence of hypertrophic scar

development is between 20% and 77% of individuals post burn injury.[5,21-24] In children, the reported prevalence is between 16% and 41%[16,24-27] (Table 1.2, Chapter 1). The studies presented in Table 1.2, Chapter 1, demonstrate that at present, the prevalence of hypertrophic scarring post burn is determined subjectively, with use of subjective scar assessment scales. These scales enable burns therapists to measure scar severity, monitor scar progression and subjectively evaluate the effectiveness of scar management interventions. In children, research is yet to determine which subjective scar assessment scale, presented in Table 1.1, Chapter 1, has the greatest inter and intra rater reliability. Furthermore, there is no consensus on what score on any scale actually constitutes a hypertrophic scar. As a result, there is significant variation in the reported prevalence of hypertrophic scarring post burn.

In the study presented in Chapter 3, the mVSS was recorded at each assessment time point. The scar was deemed hypertrophic if the scar height of the worst area, regardless of size was >1mm. Consequently, a scar classified as hypertrophic may have only been small, with the remainder of the scar flat and pliable. This is a well-known limitation of subjective scar assessment scales as the scale does not capture variation across the whole surface area and therefore cannot provide a true representation of a scar if it is not completely homogenous.[18,31,37] The sub-score of scar height >1mm was considered by other authors to represent scar hypertrophy, as it demonstrates the presence of a raised scar.[16,21] Consequently, this criteria was selected for use in this study. However, this may have over-represented hypertrophic scarring in the cohort. Additionally, where the scar was hypertrophic it may not have been relevant to shoulder ROM.

This original research reported in Chapter 3, demonstrated a higher prevalence of hypertrophic scarring throughout the 2-year study period in comparison to the research presented in Table 1.2. The prevalence of hypertrophic scarring in this study, was recorded at each assessment throughout the 2-year study follow-up. The greatest prevalence of scar hypertrophy over the 2-year study follow-up was at 3 months post burn, with 92% of the cohort considered to have a hypertrophic scar (Table 3, Chapter 3). This large prevalence of hypertrophic scarring may be explained by the study population. The study presented in Chapter 3 involved only

children with a burn injury to axilla and the prevalence of hypertrophic scarring was analysed only in children who were splinted for 60 days or more. These children were deemed by an experienced burns therapist to have significant potential to develop axilla contracture. Therefore, this current study had a population of more severe burns, compared to those described in Table 1.2, Chapter 1. The mean %TBSA in this study was 17.5%. In comparison, 6 of the 8 studies presented in Table 1.2, Chapter 1, which reported a mean %TBSA, had a mean less than 10% TBSA,[16,21-23,25,27] the lowest of which was 2.33%.[25] In contrast, the study by Gangemi et al,[5] which reported a more similar 77% prevalence of hypertrophic scarring, had a mean %TBSA of 20%. Furthermore, other studies analysing the prevalence of hypertrophic scarring post burn, have reported wide variation in the timing of scar assessment (Table 1.2, Chapter 1) and broader inclusion criteria than the population presented in this current study. Several authors included all inpatients and outpatients,[16,21] others included conservative management only[24,25] or scald injury only[26,27]. In contrast, the study presented in Chapter 3 included only children with a burn to the axilla, deemed to have significant potential to contract by experienced burns therapists. The higher prevalence of hypertrophic scarring reported in the study presented in Chapter 3, is therefore likely to be explained by the greater severity of injury compared to the majority of studies presented in Table 1.2, Chapter 1.

Previous literature has theorised that static splinting has a detrimental effect on maturing scar tissue as the tension placed on the scar increases hypertrophic scar formation and therefore increases the potential for BSC.[49,62] The high rates of hypertrophic scarring presented in this current study could provide an opportunity for this method of splinting to be criticised as an intervention that potentially promotes hypertrophic scar development. However, as discussed above, this was a specific population of children post burn. In the children splinted for ≥60 days in this study, 92% had deep dermal burns, 90% required an inpatient hospital admission for management of their burn injury and 35% required admission to the paediatric intensive care unit. The mean time to complete wound closure in these children was 40 days with a mean number of skin grafting procedures of almost 2. These statistics provide evidence of the severity of the burn injuries of this cohort and are in line with

the predictors of hypertrophic scar development presented in Table 1.2, Chapter 1. In children, healing time >14 days and more than one surgical procedure were significant predictors of hypertrophic scar development in multivariate analysis.[16] Furthermore, two descriptive analyses in cohorts of children reported that burns which took >30 days to heal had a prevalence of hypertrophic scarring of 92%[27] and 86.2%[26]. Consequently, it is evident that the children included in this current study of end of range axilla splinting were at increased risk of hypertrophic scar development at the outset of injury. Therefore, maintaining axilla ROM in the presence of hypertrophic scarring around the axilla is a testament to the value of this intervention in contracture prevention.

Conclusion

This thesis has built upon the very limited evidence base of axilla splinting in children. It has demonstrated that splinting the axilla post burn at end of range shoulder abduction, for prolonged periods within both the 24-hour period and months post burn is well tolerated and can maintain full axilla ROM in children who are at risk of axilla contracture following a burn injury.

To maintain full ROM of the affected axilla, an intensive splinting regime should be considered, particularly in the first 3 months post burn. This requires the splint to be used 12 hours overnight and at least 6 hours during the day. Use of the splint during the day may be gradually reduced according to scar development and progression, however overnight use should continue at least 6 months.

On initial presentation to the burn unit, it is important to identify and subsequently closely monitor children with flame burns as this mechanism demonstrated a statistically significant association with splinting ≥60 days as well as the development of early signs contracture. Younger children with deep dermal burns, burn %TBSA ≥30% and burn distribution involving the anterior trunk, flank and arm should also be identified early as they may require splinting ≥60 days to maintain axilla ROM.

Early signs of contracture are amenable to intensive therapy. A thorough clinical assessment at 1-month post burn can identify children with skin tension at end of range shoulder abduction and flexion. Identification of skin tension is more predictive of imminent contracture development than baseline demographic and clinical factors.

Future research should focus on improving reporting of the prevalence and predictors of BSC and hypertrophic scarring. Reporting the prevalence of BSC at a specific joint as a percent of all burns at that joint, instead of a percent of all contractures, would be valuable, to improve prognostic information regarding risk of contracture to a specific joint. Longer term outcomes on the prevalence of BSC, particularly in children, would be useful to develop understanding of the effect of growth on contracture development. Clearer definitions of hypertrophic scarring through validated scar assessment scales, would facilitate more uniform scar assessment across burn units and increase comparability of findings.

The findings from this thesis provide valuable information to therapists managing axilla burns. It also identifies opportunities for future research.

References

1. Harrison J, Steel D. Burns and Scalds. South Australia: Australian Insitute of Health and Welfare; 2006:1-15.
2. Pointer S, Tovell A. Hospitalised burn injuries, Australia, 2013-14. Canberra: Australian institute of Health and Welfare; 2016: no.102.
3. Cronin KJ, Butler PE, McHugh M, et al. A 1-year prospective study of burns in an Irish paediatric burns unit. *Burns.* 1996;22(3):221-224.
4. van der Wal MB, Vloemans JF, Tuinebreijer WE, et al. Outcome after burns: an observational study on burn scar maturation and predictors for severe scarring. *Wound Repair Regen.* 2012;20(5):676-687.
5. Gangemi EN, Gregori D, Berchialla P, et al. Epidemiology and risk factors for pathologic scarring after burn wounds. *Arch Facial Plast Surg.* 2008;10(2):93-102.
6. Van Loey NE, Bremer M, Faber AW, et al. Itching following burns: epidemiology and predictors. *Br J Dermatol.* 2008;158(1):95-100.
7. Schneider JC, Holavanahalli R, Helm P, et al. Contractures in burn injury: defining the problem. *J Burn Care Res.* 2006;27(4):508-514.
8. Godleski M, Oeffling A, Bruflat AK, Craig E, Weitzenkamp D, Lindberg G. Treating burn-associated joint contracture: results of an inpatient rehabilitation stretching protocol. *J Burn Care Res.* 2013;34(4):420-426.
9. Richard R, Baryza MJ, Carr JA, et al. Burn rehabilitation and research: proceedings of a consensus summit. *J Burn Care Res.* 2009;30(4):543-573.
10. Richard R, Steinlage R, Staley M, et al. Mathematic model to estimate change in burn scar length required for joint range of motion. *J Burn Care Rehabil.* 1996;17(5):436-443.
11. Bartell TH, Monafo WW, Mustoe TA. A new instrument for serial measurements of elasticity in hypertrophic scar. *J Burn Care Rehabil.* 1988;9(6):657-660.
12. Richard RL, Lester ME, Miller SF, et al. Identification of cutaneous functional units related to burn scar contracture development. *J Burn Care Res.* 2009;30(4):625-631.
13. Leblebici B, Adam M, Bagis S, et al. Quality of life after burn injury: the impact of joint contracture. *J Burn Care Res.* 2006;27(6):864-868.
14. Pallua N, Kunsebeck HW, Noah EM. Psychosocial adjustments 5 years after burn injury. *Burns.* 2003;29(2):143-152.
15. Finnerty CC, Jeschke MG, Branski LK, et al. Hypertrophic scarring: the greatest unmet challenge after burn injury. *The Lancet.* 2016;388:1427-1436.
16. Wallace HJ, Fear MW, Crowe MM, et al. Identification of factors predicting scar outcome after burn injury in children: a prospective case-control study. *Burns & Trauma.* 2017;5(1):19.
17. Tredget EE, Levi B, Donelan MB. Biology and principles of scar management and burn reconstruction. *Surg Clin North Am.* 2014;94(4):793-815.
18. Sullivan T, Smith J, Kermode J, et al. Rating the burn scar. *J Burn Care Rehabil.* 1990;11(3):256-260.
19. Oliveira GV, Chinkes D, Mitchell C, et al. Objective assessment of burn scar vascularity, erythema, pliability, thickness, and planimetry. *Dermatol Surg.* 2005;31(1):48-58.

20. Dewey WS, Richard RL, Parry IS. Positioning, splinting, and contracture management. *Phys Med Rehabil Clin N Am.* 2011;22(2):229-247.
21. Wallace HJ, Fear MW, Crowe MM, et al. Identification of factors predicting scar outcome after burn in adults: A prospective case-control study. *Burns.* 2017;43(6):1271-1283.
22. Sood RF, Hocking AM, Muffley LA, et al. Race and Melanocortin 1 Receptor Polymorphism R163Q Are Associated with Post-Burn Hypertrophic Scarring: A Prospective Cohort Study. *J Invest Dermatol.* 2015;135(10):2394-2401.
23. Thompson CM, Hocking AM, Honari S, et al. Genetic risk factors for hypertrophic scar development. *J Burn Care Res.* 2013;34(5):477-482.
24. Deitch EA, Wheelahan TM, Rose MP, et al. Hypertrophic burn scars: analysis of variables. *J Trauma.* 1983;23(10):895-898.
25. Chipp E, Charles L, Thomas C, et al. A prospective study of time to healing and hypertrophic scarring in paediatric burns: every day counts. *Burns Trauma.* 2017;5:3.
26. Lonie S, Baker P, Teixeira RP. Healing time and incidence of hypertrophic scarring in paediatric scalds. *Burns.* 2017;43(3):509-513.
27. Cubison TC, Pape SA, Parkhouse N. Evidence for the link between healing time and the development of hypertrophic scars (HTS) in paediatric burns due to scald injury. *Burns.* 2006;32(8):992-999.
28. Draaijers LJ, Tempelman FR, Botman YA, et al. The patient and observer scar assessment scale: a reliable and feasible tool for scar evaluation. *Plast Reconstr Surg.* 2004;113(7):1960-1965.
29. Schwanholt CA, Ridgway CL, Greenhalgh DG, et al. A prospective study of burn scar maturation in pediatrics: does age matter? *J Burn Care Rehabil.* 1994;15(5):416-420.
30. Baryza MJ, Baryza GA. The Vancouver Scar Scale: an administration tool and its interrater reliability. *J Burn Care Rehabil.* 1995;16(5):535-538.
31. Nedelec B, Shankowsky HA, Tredget EE. Rating the resolving hypertrophic scar: comparison of the Vancouver Scar Scale and scar volume. *J Burn Care Rehabil.* 2000;21(3):205-212.
32. Forbes-Duchart L, Marshall S, Strock A, et al. Determination of inter-rater reliability in pediatric burn scar assessment using a modified version of the Vancouver Scar Scale. *J Burn Care Res.* 2007;28(3):460-467.
33. Fearmonti R, Bond J, Erdmann D, et al. A review of scar scales and scar measuring devices. *Eplasty.* 2010;10:354-363.
34. Tyack Z, Simons M, Spinks A, et al. A systematic review of the quality of burn scar rating scales for clinical and research use. *Burns.* 2012;38(1):6-18.
35. Nguyen TA, Feldstein SI, Shumaker PR, et al. A review of scar assessment scales. *Semin Cutan Med Surg.* 2015;34(1):28-36.
36. Thompson CM, Sood RF, Honari S, Carrougher GJ, Gibran NS. What score on the Vancouver Scar Scale constitutes a hypertrophic scar? Results from a survey of North American burn-care providers. *Burns.* 2015;41(7):1442-1448.
37. Brusselaers N, Pirayesh A, Hoeksema H, et al. Burn scar assessment: A systematic review of objective scar assessment tools. *Burns.* 2010;36(8):1157-1164.
38. Bloemen MC, van der Veer WM, Ulrich MM, et al. Prevention and curative management of hypertrophic scar formation. *Burns.* 2009;35(4):463-475.
39. ISBI Practice Guidelines Committee. ISBI Practice Guidelines for Burn Care. *Burns.* 2016;42(5):953-1021.

40. Atiyeh BS, El Khatib AM, Dibo SA. Pressure garment therapy (PGT) of burn scars: evidence-based efficacy. *Ann Burns Fire Disasters.* 2013;26(4):205-212.
41. Macintyre L, Baird M. Pressure garments for use in the treatment of hypertrophic scars--a review of the problems associated with their use. *Burns.* 2006;32(1):10-15.
42. Anzarut A, Olson J, Singh P, et al. The effectiveness of pressure garment therapy for the prevention of abnormal scarring after burn injury: a meta-analysis. *J Plast, Reconstr & Aesthet Surg.* 2009;62(1):77-84.
43. Momeni M, Hafezi F, Rahbar H, et al. Effects of silicone gel on burn scars. *Burns.* 2009;35(1):70-74.
44. van der Wal MB, van Zuijlen PP, van de Ven P, et al. Topical silicone gel versus placebo in promoting the maturation of burn scars: a randomized controlled trial. *Plast Reconstr Surg.* 2010;126(2):524-531.
45. O'Brien L, Jones DJ. Silicone gel sheeting for preventing and treating hypertrophic and keloid scars. *Cochrane Database Syst Rev.* 2013(9):CD003826.
46. Goverman J, Mathews K, Goldstein R, et al. Pediatric Contractures in Burn Injury: A Burn Model System National Database Study. *J Burn Care Res.* 2017;38(1):192-199.
47. Richard R, Ward RS. Splinting Strategies and Controversies. *J Burn Care Rehabil.* 2005;26(5):392-396.
48. Harrison CA, MacNeil S. The mechanism of skin graft contraction: an update on current research and potential future therapies. *Burns.* 2008;34(2):153-163.
49. Schouten HJ, Nieuwenhuis MK, van Zuijlen PP. A review on static splinting therapy to prevent burn scar contracture: do clinical and experimental data warrant its clinical application? *Burns.* 2012;38(1):19-25.
50. Godleski M, Holden MS, Luby D, et al. Clinical outcomes from a foam wedge splinting program for axillary contracture prevention in the intensive care unit. *J Burn Care Res.* 2014;35(6):379-386.
51. Huang TT, Blackwell SJ, Lewis SR. Ten years of experience in managing patients with burn contractures of axilla, elbow, wrist, and knee joints. *Plast Reconstr Surg.* 1978;61(1):70-76.
52. Dobbs ER, Curreri PW. Burns: analysis of results of physical therapy in 681 patients. *J Trauma.* 1972;12(3):242-248.
53. Goverman J, Mathews K, Goldstein R, et al. Adult Contractures in Burn Injury: A Burn Model System National Database Study. *J Burn Care Res.* 2017;38(1):e328-e336.
54. Oosterwijk AM, Mouton LJ, Schouten H, et al. Prevalence of scar contractures after burn: A systematic review. *Burns.* 2017;43(1):41-49.
55. Kraemer MD, Jones T, Deitch EA. Burn contractures: incidence, predisposing factors, and results of surgical therapy. *J Burn Care Rehabil.* 1988;9(3):261-265.
56. Hop MJ, Langenberg LC, Hiddingh J, et al. Reconstructive surgery after burns: a 10-year follow-up study. *Burns.* 2014;40(8):1544-1551.
57. Richard RL, Hedman TL, Quick CD, et al. A clarion to recommit and reaffirm burn rehabilitation. *J Burn Care Res.* 2008;29(3):425-432.
58. Richard R, Staley M, Miller S, et al. To splint or not to splint--past philosophy and present practice: Part I. *J Burn Care Rehabil.* 1996;17(5):444-453.

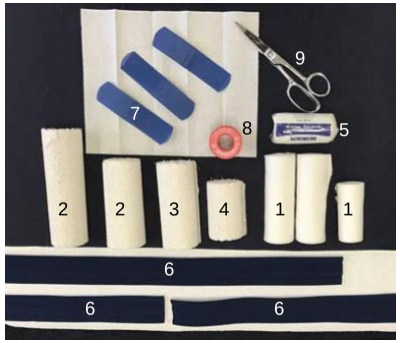
59. Flowers KR, LaStayo PC. Effect of total end range time on improving passive range of motion. 1994. *J Hand Ther.* 2012;25(1):48-54; quiz 55.
60. Arem AJ, Madden JW. Effects of stress on healing wounds: Intermittent noncyclical tension. *J Surg Res.* 1976;20(2):93-102.
61. Richard R, Staley M, Miller S, et al. To splint or not to splint-past philosophy and present practice: part III. *J Burn Care Rehabil.* 1997;18(3):251-255.
62. Junker JP, Kratz C, Tollback A, et al. Mechanical tension stimulates the transdifferentiation of fibroblasts into myofibroblasts in human burn scars. *Burns.* 2008;34(7):942-946.
63. Richard R, Dewey WS, Parry I, et al. Letter to the editor. *Burns.* 2013;39:528-541.
64. Richard R, Miller S, Staley M, et al. Multimodal versus progressive treatment techniques to correct burn scar contractures. *J Burn Care Rehabil.* 2000;21(6):506-512.
65. Rundquist PJ, Obrecht C, Woodruff L. Three-Dimensional Shoulder Kinematics to Complete Activities of Daily Living. *Am J of Phys Med Rehabil.* 2009;88(8):623-629.
66. Doorenbosch CAM, Harlaar J, Veeger D. The globe system: An unambiguous description of shoulder positions in daily life movements. *J Rehabil Res Dev.* 2003;40(2).
67. Manigandan C, Bedford E, Ninan S, et al. Adjustable aesthetic aeroplane splint for axillary burn contractures. *Burns.* 2005;31(4):502-504.
68. Lester ME, Hazelton J, Dewey WS, et al. Influence of Upper Extremity Positioning on Pain, Paresthesia, and Tolerance. *J Burn Care Res.* 2013;34(6):342-350.
69. Korp K, Richard R, Hawkins D. Refining the idiom "functional range of motion" related to burn recovery. *J Burn Care Res.* 2015;36(3):136-145.
70. Palmieri TL, Petuskey K, Bagley A, et al. Alterations in functional movement after axillary burn scar contracture: a motion analysis study. *J Burn Care Rehabil.* 2003;24(2):104-108.
71. Sison-Williamson M, Bagley A, Petuskey K, et al. Analysis of upper extremity motion in children after axillary burn scar contracture release. *J Burn Care Res.* 2009;30(6):1002-1006.
72. Manigandan C, Gupta AK, Venugopal K, et al. A multi-purpose, self-adjustable aeroplane splint for the splinting of axillary burns. *Burns.* 2003;29(3):276-279.
73. Gorka R, Gupta AK, Prakash S, et al. Simple, self-adjustable airplane splint for axillary contractures. *Burns Open.* 2017;1(2):54-58.
74. Salibi A, Van Niekerk WJ. Simple design for an aeroplane plaster of Paris splint in the immobilisation of axillary skin grafts. *Ann R Coll Surg Engl.* 2013;95(4):298.
75. Chown GA. The high-density foam aeroplane splint: a modified approach to the treatment of axilla burns. *Burns.* 2006;32(7):916-919.
76. Kolmus AM, Holland AE, Byrne MJ, et al. The effects of splinting on shoulder function in adult burns. *Burns.* 2012;38(5):638-644.
77. Jang KU, Choi JS, Mun JH, et al. Multi-axis shoulder abduction splint in acute burn rehabilitation: a randomized controlled pilot trial. *Clin Rehabil.* 2015;29(5):439-446.
78. Macdonald LB, Covey MH, Marvin JA. The papoose: device for positioning the burn child's axilla. *J Burn Care Rehabil.* 1985;6(1):62-63.

79. Webb DC, Byrne M, Kolmus A, et al. Outcomes of a shoulder treatment flowchart in patients with axillary burns. *J Burn Care Res.* 2011;32(2):224-230.
80. Byl C, Puttlitz C, Byl N, et al. Strain in the median and ulnar nerves during upper-extremity positioning. *J Hand Surg Am.* 2002;27(6):1032-1040.
81. Coppieters MW, Stappaerts KH, Everaert DG, et al. Addition of Test Components During Neurodynamic Testing: Effect on Range of Motion and Sensory Responses. *JOSPT.* 2001;31(5):226-237.
82. Johnson J, Silverberg R. Serial casting of the lower extremity to correct contractures during the acute phase of burn care. *Phys Ther.* 1995;75(4):262-266.
83. Bennett GB, Helm P, Purdue GF, et al. Serial casting: a method for treating burn contractures. *J Burn Care Rehabil.* 1989;10(6):543-545.
84. Ridgway CL, Daugherty MB, Warden GD. Serial casting as a technique to correct burn scar contractures. A case report. *J Burn Care Rehabil.* 1991;12(1):67-72.
85. Sprague S, Leece P, Bhandari M, et al. Limiting loss to follow-up in a multicenter randomized trial in orthopedic surgery. *Control Clin Trials.* 2003;24(6):719-725.
86. Sporbeck B, Jacobs A, Hartmann V, et al. Methodological standards in medical reporting. *J Dtsch Dermatol Ges.* 2013;11(2):107-120.
87. Parry I, Sen S, Sattler-Petrocchi K, et al. Cutaneous Functional Units Predict Shoulder Range of Motion Recovery in Children Receiving Rehabilitation. *J Burn Care Res.* 2017;38(2):106-111.
88. Richard R, Staley M, Miller S, et al. To splint or not to splint: past philosophy and current practice-Part II. *J Burn Care Rehabil.* 1997;18:64-71.
89. Serghiou MA, Niszczak J, Parry I, et al. Clinical practice recommendations for positioning of the burn patient. *Burns.* 2016;42(2):267-275.
90. Palastanga N, Field D, Soames R. *Anatomy and human movement.* Oxford: Butterworth-Heinemann Ltd; 1995.
91. Coley B, Jolles BM, Farron A, et al. Arm position during daily activity. *Gait Posture.* 2008;28(4):581-587.
92. Suksathien R, Suksathien Y. A new static progressive splint for treatment of knee and elbow flexion contractures. *J Med Assoc Thai.* 2010;93(7):799-804.
93. Richard R, Shanesy CP, Miller SF. Dynamic versus static splints: a prospective case for sustained stress. *J Burn Care Rehabil.* 1995;16:284-287.
94. Ngu F, Patel B, McBride C. Epidemiology of isolated foot burns in children presenting to a Queensland paediatric burns centre- a two-year study in warmer climate. *Burns Trauma.* 2017;5:6.
95. Liodaki E, Kisch T, Mauss KL, et al. Management of pediatric hand burns. *Pediatr Surg Int.* 2015;31(4):397-401.
96. Birch JR, Eakins B, Gosen J, et al. Musculoskeletal management of the severely burned child. *Can Med Assoc J.* 1976;115(6):533-536.
97. Scott JR, Costa BA, Gibran NS, et al. Pediatric palm contact burns: a ten-year review. *J Burn Care Res.* 2008;29(4):614-618.
98. Dunst CM, Scott EC, Kraatz JJ, et al. Contact palm burns in toddlers from glass enclosed fireplaces. *J Burn Care Rehabil.* 2004;25(1):67-70.
99. Chan QE, Barzi F, Harvey JG, et al. Functional and cosmetic outcome of full- versus split-thickness skin grafts in pediatric palmar surface burns: a prospective, independent evaluation. *J Burn Care Res.* 2013;34(2):232-236.

100. Barret JP, Desai MH, Herndon DN. The isolated burned palm in children: epidemiology and long-term sequelae. *Plast Reconstr Surg.* 2000;105(3):949-952.
101. Choi JS, Mun JH, Lee JY, et al. Effects of modified dynamic metacarpophalangeal joint flexion orthoses after hand burn. *Ann Rehabil Med.* 2011;35(6):880-886.
102. Kamal RM, Elshazely A, Nagib S. Dynamic splint versus static splint and active range of motion treatment of post hand burn contracture. *International Journal of PharmTech Research.* 2016;9(6):75-83.
103. Schwanholt C, Daugherty MB, Gaboury T, et al. Splinting the pediatric Palmar burn. *J Burn Care Rehabil.* 1992;13(4):460-464.
104. *PDMS-2: Peabody developmental motor scales*. Austin, Texas: Pro-Ed; 2000.
105. Kellor M, Frost J, Silberberg N, et al. Hand strength and dexterity. *Am J Occup Ther.* 1971;25(2):77-83.
106. Aaron DH, Jansen CW. Development of the Functional Dexterity Test (FDT): construction, validity, reliability, and normative data. *J Hand Ther.* 2003;16(1):12-21.
107. Calvert M, Blazeby J, Altman DG, et al. Reporting of patient-reported outcomes in randomized trials: the CONSORT PRO extension. *JAMA.* 2013;309(8):814-822.
108. Rahman T, Sample W, Yorgova P, et al. Electronic monitoring of orthopedic brace compliance. *J Child Orthop.* 2015;9(5):365-369.
109. Havey R, Gavin T, Patwardhan A, et al. A reliable and accurate method for measuring orthosis wearing time. *Spine.* 2002;27(2):211-214.

Axilla splint materials, design and fabrication

• Assessment for splinting requirement made by burns therapist on first presentation to the unit.
• If the burn is across or in close proximity to the axilla, splinting is commenced in the form of a plaster cast.
• The plaster cast is reapplied at subsequent dressing changes until wound closure. If wound healing in the axilla region is greater than 14 days or if skin grafting is required, the child is transitioned to a removable thermoplastic axilla splint.
• A thermoplastic axilla splint is usually worn for periods of the day and overnight as determined by the burns therapist.



Plaster axilla splint Materials

1| Cotton cast padding
2| 15cm or 20cm roll of plaster for body
3| 10cm or 15cm roll of plaster for arm
4| 10cm roll of plaster for additional strengthening
5| Crepe bandage to secure arm
6| Foam straps to secure splint to body
7| Velcro to secure foam straps
8| Brown tape
9| Scissors
10| Bowl of water

Method

1 Line body with cotton cast padding to;
• Protect skin and bony prominences
• Allow plaster shell to lift away from bandages with ease as plaster will be difficult to remove if placed directly onto crepe bandages.

2 Lay 8-10 layers of plaster horizontally across abdomen and flank to form base of splint (as shown).

3 Lay 8-10 layers of plaster vertically along upper limb from wrist to flank (as shown).

4 Use additional rolls of plaster to join both slabs by laying plaster back and forth. This will strengthen the plaster.

5 Secure cast to body with two straps around trunk after cast has set (these are laid under the body prior to applying the cast for ease of application).

6 Secure cast to upper limb with crepe bandage circulars from wrist to axilla.

7 In sedated patients, it is particularly important to position the wrist in neutral with a volar plaster slab.

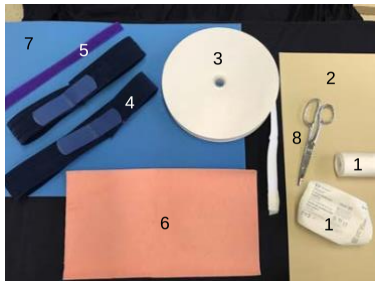
8 Without this plaster slab the wrist may fall into hyperextension, which may increase the risk of prolonged neural tension.

Parent consent provided for use of these images

Appendix 1

Axilla splint materials, design and fabrication

Thermoplastic axilla splint | Materials



1| Cotton padding (used only for moulding)
2| Thermoplastic sheet with appropriate strength
3| Adhesive Velcro
4| Foam straps to secure splint around body
5| Velcro strap to secure splint to upper limb
6| Adhesive fleecy padding to line splint
7| Adhesive thick foam to pad proximal edge of splint
8| Scissors

Method

1 Measure
- Wrist to axilla
- Axilla to hip
- Width required at wrist
- Width required across flank and abdomen

2 Cut thermoplastic to size, angling the upper limb forward from the axilla to facilitate horizontal adduction.

3 Lay warm thermoplastic over cotton padding in as much shoulder abduction as possible, ensuring horizontal adduction approximately 15-20 degrees.

4 When thermoplastic has set, apply Velcro anchoring points in a 3 point arrangement (as shown)

Parent consent provided for use of these images

Axilla splint materials, design and fabrication

Thermoplastic axilla splint | Method cont.

5 Line all surfaces in contact with the body with adhesive flecy paddi ng.

6 Apply thicker adhesive foam around lower edge of splint to provide extra padding to pelvic rim and wrist as required.

Burns across or in close proximity to the flexor surface of the elbow can be managed in a long arm splint to maintain elbow extension (as shown).

Burns not across or in close proximity to the flexor surface of the elbow can be managed with a shorter version (as shown).

7 Secure the splint to the body with

- 2 foam straps around trunk,
- 1 foam strap around axilla
- 1 velcro strap around wrist if long arm splint or
- 1 velcro strap above elbow if short arm splint

Parent consent provided for use of these images

Appendix 2

Journal of Burn Care and Research manuscript preparation

Journal of Burn Care and Research manuscript preparation available at https://academic.oup.com/jbcr/pages/general_instructions. Accessed 10 October 2018.

Manuscripts must be written in English. Original articles, editorials, historical and current reviews, case reports, and descriptions of clinical care, rehabilitation, and surgical techniques are sought. All submitted papers must not have been previously published.

Manuscripts must be written in English. Original articles, editorials, historical and current reviews, case reports, and descriptions of clinical care, rehabilitation, and surgical techniques are sought. Previously published work cannot be submitted.

Readers are urged to respond to articles and to share ideas about burn care in Letters to the Editor. Editors reserve the right to edit letters without changing meaning. All letters must be signed; no anonymous correspondence will be published.

There are no length limits for Original Articles, Summary Articles, or Editorials; however, authors are encouraged to be as concise as possible and to use tables and figures only where essential. Case Reports cannot exceed 2,000 words (word count excludes abstract, references, figures, and tables), 25 references, and a total of 3 figures and tables. Letters to the Editor cannot exceed 300 words and 6 references, and they cannot have figures or tables.

Please use standard 12-point font, double spacing, page numbers, and continuous line numbering throughout the manuscript.

All manuscripts must meet applicable length limits, have required formatting, and be organized as detailed below. Those that do not adhere to these guidelines will be returned to the corresponding author for technical revision.

Title Page:

The title page should be saved and submitted as a separate file. Include the following on the title page:

(a) Complete manuscript title

(b) All authors' full names, highest academic degrees, and affiliations

(c) Name and address for correspondence, including fax number, telephone number, and Email address

(d) Address for reprints if different from that of the corresponding author

(e) All possible conflicts of interest, as described above, and disclosure of funding received for the work from any source including the following: National Institutes of Health, Welcome Trust, and Howard Hughes Medical Institute

(f) Total word count if a Case Report or Letter to the Editor

Blinded Title Page: The blinded title page should be the first page of the manuscript. Include on this page only the complete manuscript title. No author or institutional information identifying the authors or supporting institution should appear on this page. This title page will be the one sent with the manuscript to the reviewers.

Abstract and Key Words: Provide an unstructured abstract that does not exceed 250 words. It must be factual and concise. Do not use abbreviations and acronyms. After the abstract, list 3 to 5 key words or phrases. Abbreviations and acronyms are not permitted. Letters and editorials do not require abstracts.

Text: Organize manuscripts into journal-specific main headings: blinded title page, abstract and key words page, introduction, methods, results, discussion, acknowledgments, references, tables, and figure legends. All direct references to the parent institutions or specific individuals involved in the project (except for solicited papers) must be removed from the text of the manuscript.

Define abbreviations at first mention in text as well as in each table and figure. Use generic names, whenever possible. If a brand name is cited, supply the manufacturer's name and city, state/country. Report all forms of support, including pharmaceutical and industry support in an Acknowledgements paragraph. Also acknowledge all other forms of assistance, excluding clerical and secretarial help.

Abbreviations: For a list of standard abbreviations, consult the Council of Biology Editors Style Guide (available from the Council of Science Editors, 9650 Rockville Pike, Bethesda, MD 20814) or other standard sources. Write out the full term for each abbreviation at its first use, unless it is a standard unit of measure.

References: The authors are responsible for the accuracy of the references. List the references (double-spaced) at the end of the manuscript. Cite references in text in the order of appearance. Incorporate unpublished data, such as papers submitted but not yet accepted for publication or personal communications, in parentheses in the text. If there are more than 3 authors, name only the first 3 authors and then use et al. Refer to the List of Journals Indexed in Index Medicus for abbreviations of journal names, or access the list here.

Figures:

A) Creating Digital Artwork

1. Create, scan, and save your artwork and compare your final figure to the Digital Artwork Guideline Checklist (below).
2. Upload each figure to Editorial Manager in conjunction with your manuscript text and tables.

B) Digital Artwork Guideline Checklist

Here are the basics to have in place before submitting your digital artwork:

- Artwork should be saved as TIFF, EPS, or MS Office (DOC, PPT, XLS) files. High resolution PDF files are also acceptable.
- Crop out any white or black space surrounding the image.
- Diagrams, drawings, graphs, and other line art must be vector or saved at a resolution of at least 1200 dpi. If created in an MS Office program, send the native (DOC, PPT, XLS) file.
- Photographs, radiographs, and other halftone images must be saved at a resolution of at least 300 dpi.
- Photographs and radiographs with text must be saved as postscript or at a resolution of at least 600 dpi.
- Each figure must be saved and submitted as a separate file. Figures should not be

embedded in the manuscript text file.

Remember:

- Cite figures consecutively in your manuscript.
- Number figures in the figure legend in the order in which they are discussed.
- Upload figures consecutively to the Editorial Manager Web site and enter figure numbers consecutively in the Description field when uploading the files.

Figure Legends: Legends must be submitted for all figures. They should be brief and specific, and they should appear on a separate manuscript page after the references. Use scale markers in the image for electron micrographs, and indicate the type of stain used.

Color Figures: The Journal will consider publishing a limited number of color figures that enhance an article. The Journal's editors will let the author know whether the Journal will cover the cost of color reproduction if an author chooses to submit color art with a manuscript.See article charges for more information.

Tables: Create tables using the table creating and editing feature of the word processing software (ie, Microsoft Word). Do not use Excel or comparable spreadsheet programs. Group all tables at the end of the manuscript or supply them together in a separate file. Cite tables consecutively in the text, and number them in that order. Key each on a separate sheet, and include the table title, appropriate column heads, and explanatory legends (including definitions of any abbreviations used). Do not embed tables within the body of the manuscript. They should be self-explanatory and should supplement, rather than duplicate, the material in the text.

Style: Pattern manuscript style after the American Medical Association Manual of Style (10th edition). Stedman's Medical Dictionary (28th edition) and Merriam Webster's Collegiate Dictionary (11th edition) should be used as standard references. Refer to drugs and therapeutic agents by their accepted generic or chemical names, and do not abbreviate them. Use code numbers only when a generic name is not yet available. In that case, supply the chemical name and a figure giving the chemical structure of the drug. Capitalize the trade names of drugs and place them in parentheses after the generic names, only when necessary.

To comply with trademark law, include the name and location (city and state in the U.S.; city and country outside the U.S.) of the manufacturer of any drug, supply, or equipment mentioned in the manuscript. Use the metric system to express units of measure and degrees Celsius to express temperatures, and use SI units rather than conventional units.

Appendix 3

Sydney Children's Hospital Network ethics approval

The Sydney children's Hospitals Network
care, advocacy, research, education

Contact for this correspondence:
Research Ethics Office
Research Ethics Administration Assistant
Phone: (02) 9845 1253
Facsimile: (02) 9845 1317
Email: SCHN-ethics@health.nsw.gov.au

Corner Hawkesbury Road
and Hainsworth Street
Locked Bag 4001
Westmead NSW 2145
Sydney Australia
DX 8213 Parramatta
Tel +61 2 9845 0000
Fax +61 2 9845 3489
http://www.schn.health.nsw.gov.au/
ABN 53 188 579 090

12 February 2018

Dr Verity Pacey
Burns Treatment Centre
The Children's Hospital at Westmead

Dear Dr Pacey,

HREC Reference: **LNR/18/SCHN/19**

Project title: **End of range splinting to prevent contracture in paediatric axilla burns**

Sites: **The Children's Hospital at Westmead**

Thank you for submitting the above project for single ethical and scientific review. This project was considered by the Sydney Children's Hospitals Network Human Research Ethics Committee's Executive Committee ("the Committee") at its meeting **29 January 2018**, and on the **12 February 2018**.

This HREC has been accredited by the NSW Department of Health as a lead HREC under the model for single ethical and scientific review, and by the National Health and Medical Research Council as a certified committee in the review of multi-centre clinical research projects.

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Human Research* and *CPMP/ICH Note for Guidance on Good Clinical Practice.*

I am pleased to advise that the Committee has granted ethical approval of this research project. Your approval is valid for one (1) year, effective the date of this letter.

This application has been assessed in accordance with, and meets the requirements of the National Statement on Ethical Conduct in Human Research (2007).

The documents reviewed and approved by the Committee are:

Document Reviewed	*Version*	*Date*
HREA Submission Code, AU/1/11A3318		23 January 2018
Axilla project for HREA		Received 24 January 2018
Waiver of consent application form		22 January 2018
Email response to committee		02 February 2018

J:\PROJECT FILES - Ethics & Governance\Ethics\LNR\2018\LNR.18.SCHN.19 - TRIM E18.0023\5. Correspondence Out\Ethics approval letter - 12 Feb 2018 - Exec Officer 12 Feb 2018.docx

The Sydney children's Hospitals Network
care, advocacy, research, education

Please note the following conditions of approval:

1. This approval is restricted to research being conducted in accordance with the approved documents, and the review of the medical records you have nominated. There is to be no contact with patients, parents/guardians or other family members.

2. The Coordinating Investigator will immediately report anything which may warrant review of ethical approval of the project in accordance with the SCHN adverse event reporting policy.

3. All proposed changes to the research protocol, including the conduct of the research, changes to site or personnel, or an extension to HREC approval, are to be provided to the HREC or its delegate for review before those changes can take effect.

4. The HREC will be notified, giving reasons, if the project is discontinued at a site before the expected date of completion.

5. The co-ordinating investigator will provide a final report to the HREC on completion of the study.

6. Your approval is valid for one (1) year from the date of the final approval letter. If your project extends beyond that one year period please submit an application for amendment to extend the approval period. Ethics approval can be extended for a period of twelve (12) months at a time.

7. In the event of a project **not having commenced** within 12 months of its approval, the approval will lapse and reapplication to the HREC will be required.

Should you have any queries about the HREC's consideration of your project please contact the Research Ethics Administration Assistant on (02) 9845 1253.

You are reminded that this letter constitutes ethical approval only. You must not commence this research project at a site until separate authorisation from the Chief Executive or delegate of that site has been obtained. A copy of this letter must be forwarded to all site investigators for submission to the relevant Research Governance Officer.

The HREC wishes you every success in your research.

Yours faithfully

SGarnett

Associate Professor Sarah Garnett
Chair, Sydney Children's Hospitals Network Human Research Ethics Committee
Sydney Children's Hospitals Network Human Research Ethics Committee
cc Ms Rhianydd Thomas

J:\PROJECT FILES - Ethics & Governance\Ethics\LNR\2018\LNR.18.SCHN.19 - TRIM E18.0023\5. Correspondence Out\Ethics approval letter - 12 Feb 2018 - Exec Officer 12 Feb 2018.docx