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The effects of nonpharmacological therapeutic interventions on pain and physical function in adults with rib fractures: a systematic review

Weinberg, Beverley Joan

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THE EFFECTS OF NON-PHARMACOLOGICAL THERAPEUTIC INTERVENTIONS ON PAIN AND PHYSICAL FUNCTION IN ADULTS WITH RIB FRACTURES:

A SYSTEMATIC REVIEW.

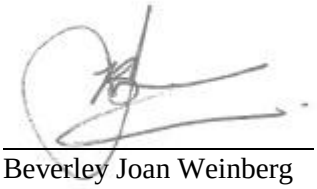
Beverley Joan Weinberg

A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science (Physiotherapy).

Johannesburg, 2020

DECLARATION

I, Beverley Joan Weinberg, declare that the work contained in this dissertation is my own work. This dissertation is being submitted for the degree of Masters of Science (Physiotherapy) at the University of the Witwatersrand, Johannesburg, South Africa. This work has not been submitted for any other degree or examination in this or any other university.



Beverley Joan Weinberg

20th day of **June 2020** in **Johannesburg**.

PUBLICATIONS ARISING FROM THIS DISSERTATION.

Weinberg, B., Roos, R. and Van Aswegen, H. (2018). Effectiveness of non-pharmacological interventions for pain and physical function in adults with rib fractures: a systematic review protocol. JBI Database System Rev Implement. 16(8), p. (1599–1605).

ABSTRACT

Background:

Rib fractures are the most common thoracic injury encountered following blunt chest trauma and are notable source of chest pain. Chest pain may lead to compromised respiratory function and physical function. Consequently, prolonged lengths of stay as well as high morbidity and mortality rates may be observed. Non-pharmacological therapeutic interventions often form part of the care plan of patients diagnosed with rib fractures, however these treatment interventions are frequently published in isolation and no concise summary of management options exists.

Purpose:

This systematic review aims to establish what non-pharmacological therapeutic interventions are utilised to treat pain following acute rib fractures, as well as to determine the effects of these non-pharmacological therapeutic interventions on pain and physical function in adults with rib fractures. Secondary outcomes included length of stay (LOS), respiratory function and respiratory complications.

Methods:

A systematic review was conducted to answer the aims of the study. A three-step search strategy was utilised, and databases searched included MEDLINE using PubMed, EMBASE, PsycINFO, Scopus, CENTRAL, CINAHL Plus and PEDro and Google Scholar, OpenGrey (SIGLE), Cochrane Library and the International prospective register of systematic reviews (PROSPERO). The Joanna Briggs Institute's System for the Unified Management, Assessment and Review of Information (SUMARI) was used to conduct the study. Meta-analysis was conducted for pre-bundle of care versus post-bundle of care implementation for the outcome measures of hospital length of stay (LOS), incidence of pneumonia and mortality rate. The GRADE approach for grading quality of evidence was followed, and a summary of findings table generated for each included outcome.

Results:

Sixteen studies were included for final review. No interventions were identified which objectively improved physical function. Acupuncture, continuous positive airway pressure, physiotherapy modalities and transcutaneous electrical nerve stimulation (TENS) reduced pain. Acupuncture, TENS and non-invasive ventilation (NIV) improved respiratory function. Physiotherapy modalities, acupuncture, NIV and multidisciplinary care pathways reduced pulmonary complications. NIV modalities and multidisciplinary care pathways resulted in reduced LOS and mortality rate. Meta-analysis of pre versus post bundle of care implementation on incidence of pneumonia revealed a 63% reduction in risk of developing pneumonia in comparison to those managed without care bundles ($p < 0.00$).

Conclusion:

Non-pharmacological therapeutic interventions were shown to aid pain relief, improve respiratory function and reduce the incidence of pneumonia following rib fractures in the acute care setting. Bundled care pathways were identified as important management strategies

in the treatment of patients following acute rib fractures, aiding identification of early respiratory compromise and promoting standardisation of care and multidisciplinary team collaboration.

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LIST OF ABBREVIATIONS

ABG	arterial blood gas
ACBT	active cycle of breathing technique
AIDS	acquired immune deficiency syndrome
ALI	acute lung injury
ARDS	acute respiratory distress syndrome
ATLS	advanced trauma life support
BI	Barthel index
BiPAP	bi-level positive airway pressure
BMI	body mass index
BPI	brief pain index
breaths/min	breaths per minute
ChIP	chest injury early activation protocol
CI	confidence interval
CNEP	continuous negative extrathoracic pressure
CNS	central nervous system injury
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
CPAP	continuous positive airway pressure
CPAx	Chelsea critical care physical assessment
CPG	clinical practice guidelines
CT	computerized tomography
DBE	deep breathing exercise
ET	endotracheal tube
FET	forced expiratory technique
FEV_1	forced expiratory volume in the first second
FIM	functional independence measure
FRC	functional residual capacity
FSS-ICU	functional status score for ICU
FVC	forced vital capacity
GRADE	grading of recommendations assessment, development and evaluation
HFNC	high flow nasal cannula
HIV	human immunodeficiency virus
ICU	intensive care units
IPPV	intermittent positive pressure ventilation
IQR	interquartile range
IS	incentive spirometry

ISS	injury severity score
IV	intravenous
JBI	Joanna Briggs Institute
L/min	liter per minute
LOS	length of stay
MDT	multidisciplinary team
MEP	maximal expiratory pressure
MeSH	medical subject headings
MIP	maximal inspiratory pressure
ml	millilitre
MPQ	McGill pain questionnaire
MV	mechanical ventilation
MVAs	motor vehicle accidents
NIPPV	non-invasive positive-pressure ventilation
NIV	non-invasive ventilation
NRS	numerical rating scale
NSAIDs	non-steroidal anti-inflammatory drugs
O_2	oxygen
$PaCO_2$	partial pressure of carbon dioxide in arterial blood
PaO_2	partial pressure of oxygen in arterial blood.
PCA	patient controlled analgesia
PEEP	positive end expiratory pressure
PEFR	peak expiratory flow rate
%	percentage
PIC	pain, inspiratory capacity, and cough
PMVT	pedestrian-motor vehicle trauma
QOL	quality of life
RCT	randomised controlled trial
RR	relative risk
SF-36	short form health survey
SF-MPQ	short-form McGill Pain Questionnaire
SMI	sustained maximal inspiration
SpO_2	peripheral capillary oxygen saturation
SUMARI	System for the Unified Management, Assessment & Review of Information
TENS	transcutaneous electrical nerve stimulation
TLC	total lung capacity
VAP	ventilator-associated pneumonia

VAS	visual analogue scale
VRS	verbal rating scale

WORKING DEFINITION

For the purposes of this systematic review:

- "physical function" will refer to range of movement or strength, localised mobility of joints, or general ability to mobilise in or out of bed, walk/move or carry out activities of daily living, or tasks and activities.

CHAPTER 1: INTRODUCTION TO THE STUDY

This chapter serves as an introduction and provides justification and discusses the significance of the study.

1.1 Introduction:

1.1.1 Background:

Trauma resulting from motor vehicle accidents (MVAs), pedestrian-motor vehicle trauma (PMVT) (Kong et al., 1996), falls and violence often result in blunt thoracic injuries. Blunt thoracic injuries may result from acceleration, deceleration, shearing and compressive forces distributed over a large surface area of the chest wall (Yeo, 1999; Van Aswegen & Morrow, 2015). Rib fractures are considered to be one of the most prevalent injuries in adults following blunt thoracic trauma (Truitt et al., 2010), with MVAs being one of the most common mechanisms of blunt thoracic chest wall injury worldwide (Easter, 2001; Mefire et al., 2010; Skinner et al., 2015). Mefire et al., (2010) reported that rib fractures (50.3%) and haemothorax (38.7%) were the most common injuries observed in patients with blunt chest wall trauma following MVAs.

Intense, acute pain is a common presenting symptom often described in the literature following rib fractures (Sloan et al., 1986; Easter, 2001; Kerr-Valentic et al., 2003; Karmakar & Ho., 2003; May et al., 2016). This intense, debilitating pain causes significant hindrance to recovery in patients following acute injury (Sloan et al., 1986; Easter, 2001; Karmakar & Ho., 2003; May et al., 2016). Pain that is not managed early and effectively in hospital can lead to respiratory compromise and ventilatory failure (Easter, 2001; Karmakar & Ho., 2003; Sareen et al., 2015). Pain following rib fractures promotes thoracic splinting as well as hypoventilation, and together with mechanical disruption to the chest wall interferes with normal respiratory mechanics. As a result of this direct influence of pain on the respiratory system, ventilation is compromised due to an inability to breathe deeply and atelectasis may occur (Easter, 2001). This may lead to ventilatory insufficiency and respiratory compromise, a major factor contributing to the need for intubation in these patients (Easter, 2001). The ability to cough effectively is also compromised if pain management is suboptimal, resulting in secretion retention leading to possible respiratory infection (Easter, 2001; Oncel et al., 2002; Karmakar & Ho., 2003). An increased risk of respiratory complications is associated with each additional rib fractured, and in the elderly population this incidence increases the likelihood of mortality by 19% and that of pneumonia by 27% (Bulger et al., 2000; Unsworth et al., 2015).

Early mobilisation is a vital component of management following blunt thoracic trauma. Early mobilisation assists in reducing the incidence of respiratory complications such as pneumonia, respiratory failure and resultant length of hospital stay (Easter, 2001; Unsworth et

al., 2015). Early effective pain control is necessary to assist and benefit mobilisation. According to Cohn & DuBose, (2010) with adequate pain control, survival rates in adults following pulmonary contusion and rib fractures improved from 60% to 93.5%. Effective pain management allows for early respiratory physiotherapy interventions to take place as well as mobilisation (Van Aswegen & Morrow, 2015). Rib fracture pain was reported by patients to be aggravated by any movement of the chest wall (Kerr-Valentic et al., 2003). It is therefore understandable that in the presence of poor pain control functional activities such as turning in bed, transferring from supine into sitting on the edge of the bed and mobilising away from the bed may be grossly limited by pain and may lead to further exacerbation of ventilatory compromise as well as further complications associated with immobility itself (Easter, 2001).

Inadequately managed initial pain not only leads to acute respiratory compromise and complications but may also lead to long-term chronic pain, reduced quality of life (QOL) and long-term disability (Marasco et al., 2015). Fabricant et al., (2013) found that pain intensity experienced within the initial days following the injury could be a predictor of pain and disability at eight weeks post injury. Shelat et al., (2012) however advocated that there are no known predictors of chronic pain and optimal acute pain management does not reduce chronic pain incidence at one year follow up. Gordy et al., (2014) stated that chronic pain and disability are still evident at six months following traumatic rib fractures, whilst Marasco et al., (2015) in their retrospective review found significantly reduced QOL evident at 24 months post injury.

Ineffective or delayed pain management may not only result in acute and chronic limitations but is also well known to cause and contribute to psychological stress. Evidence advocates that following trauma, patients have impaired QOL as measured by the short form health survey (SF-36) (Tøien et al., 2011). Physical and pain domains related to QOL were the most impaired in comparison to reports from the general population (Tøien et al., 2011). Health related QOL has been shown to be influenced by factors such as depression and post-traumatic stress symptoms, and depression was also shown to influence physical functioning (Tøien et al., 2011). Chronic pain has been identified as a significant contributor to reduced QOL (Gordy et al., 2014). Sixty percent of patients indicated reduced functional capacity and 20% still experienced pain of thoracic origin at 24 months post injury (Marasco et al., 2015). In light of these findings it is evident that functional capacity and QOL are not only affected by pain and physical limitations but by psychological factors which in turn influence physical functioning. All components (physical and psychological) should therefore be addressed in trauma patients to optimise recovery.

Following analysis of the literature, it becomes clearly evident that pain management forms an integral component of treatment following rib fractures. Numerous publications have placed significant emphasis on adequate pain control being the cornerstone of management of these patients (Todd et al., 2006; Fabricant et al., 2013; Sareen et al., 2015). As expressed by Ho et al. (2014) ‘it is the pain that disturbs recovery and ability to return to normal function’ (p.153). It thus becomes clear and is without question that optimal pain management in this population is crucial if management is to be successful.

A number of conservative therapeutic interventions such as incentive spirometry, mobilisation and respiratory physiotherapy are reliant on effective pain management to be in place first, in

order for these interventions to be effective in successfully influencing and achieving optimal patient outcomes (Easter, 2001).

Various non-pharmacological therapeutic interventions have been identified in the literature for managing pain following rib fractures. These interventions include but are not limited to transcutaneous electrical nerve stimulation (TENS), (Sloan et al., 1986; Oncel et al., 2002; Mehta, 2013), rib belts (Lazcano et al., 1969), acupuncture (Ho et al., 2014), taping (Sareen et al., 2015), incentive spirometry (Easter, 2001; Brown & Walters, 2012), multidisciplinary clinical pathways (Sesperez et al., 2001; Todd et al., 2006; Unsworth et al., 2015), mobilisation (Easter, 2001; Unsworth et al., 2015), as well as respiratory physiotherapy interventions such as active cycle of breathing technique (ACBT) (Grammatopoulou et al., 2010). In addition, physiotherapy interventions form part of multidisciplinary clinical pathways, and interventions included in these care pathways may include use of incentive spirometers, mobilisation and range of movement and strengthening exercises (Easter, 2001; Todd et al., 2006).

For the purpose of this review non-pharmacological therapeutic interventions will refer to all rehabilitative and treatment modalities and interventions utilised by health care professionals in the acute care setting in the management of pain and/or rehabilitation of function following acute rib fractures. These non-pharmacological therapeutic interventions may be standalone modalities or treatment interventions utilised in addition to pharmacological management. The population evaluated in this review consists of patients admitted to an acute care setting including hospital wards, high care or intensive care units (ICU). It is therefore anticipated that most non-pharmacological therapeutic interventions under review will be utilised in combination with pharmacological pain interventions as part of standard care management. This is in light of the fact that withholding standard care analgesic management to evaluate the effects of non-pharmacological therapeutic intervention in complete isolation would prove highly unethical in such an acute care population requiring prompt pain relief.

1.2 Problem statement and justification for the research

Pain has been emphasised as a crucial component in influencing care and outcomes in patients following rib fractures. Certain authors have highlighted the need for improved effective therapies and strategies for managing and treating acute rib fracture pain due to the potential risks and devastating side effects that may ensue if pain management is not appropriate (Kerr-Valentic et al., 2003; Fabricant et al., 2013). In addition to the adverse acute complications some studies have indicated that unmanaged acute initial pain may give rise to chronic pain symptoms, increase disability and reduce QOL (Kerr-Valentic et al., 2003; Fabricant et al., 2013).

Various non-pharmacological therapeutic interventions are utilised in the literature to treat pain following acute rib fractures. These modalities are however published in isolation and no concise summary of treatment options exists. Results are not provided in a holistic manner integrating the effects of the interventions in a consolidated easily accessible format. This may leave the clinician unsure as to what modality should be used and what the effects of the interventions on pain and physical function are. No systematic review has been conducted to date where these therapeutic interventions are identified and reviewed together in order that results can be pooled. As such overall conclusions with regards to what these non-

pharmacological therapeutic interventions are, as well as their effects on pain and physical function, are yet to be established.

There is therefore a need to bring together all clinically significant non-pharmacological interventions and determine their effects on pain and function, as well as on clinical outcomes following acute rib fractures. These findings are essential in order to drive evidenced-based practice. Clear clinical evidence with regards to the most effective treatment options needs to be available in concise format, so that clinicians can determine the effects of these interventions without having to search for these results in isolation.

Physiotherapists form an integral part of the multidisciplinary health care team that manage patients with acute rib fractures (Witt & Bulger, 2017). Physiotherapists are frequently involved in the treatment of patients in the acute care setting who have sustained rib fractures following blunt chest trauma (van Aswegen et al., 2019). Respiratory complications often ensue as a result of inadequate pain management in these patients. Various modalities directed at managing respiratory care and mobility are often implemented by physiotherapists in this setting, however pain management interventions and strategies have been shown globally to be seldomly utilised in the physiotherapy management of patients with major chest trauma (van Aswegen et al., 2019). Identification of evidence-based non-pharmacological therapeutic interventions addressing pain may thus assist with directing management interventions and clinical implementation of these modalities in this population. As such a review summarising the evidence related to the effects of different non-pharmacological treatment interventions on clinical patient outcomes would thus prove beneficial.

This systematic review therefore aims to identify and evaluate the effect of non-pharmacological therapeutic interventions on patients' levels of pain and physical function which may be utilised by health care professionals in the acute care setting.

1.3 Systematic review question

What are the effects of non-pharmacological therapeutic interventions on pain and physical function in adults with rib fractures?

1.3.1 Aim of the study

To determine the effects of non-pharmacological therapeutic interventions on pain, physical and respiratory function in adults admitted with rib fractures to acute care settings.

1.3.2 Objectives of the study

The objectives of this study are to:

- determine what non-pharmacological therapeutic interventions in addition to pharmacological management strategies (standard care) are used to treat pain following acute rib fractures.

- determine the effects of non-pharmacological therapeutic interventions on pain levels in adults following acute rib fractures.

- establish the effects of non-pharmacological therapeutic interventions on physical function and respiratory function in adults following acute rib fractures.

1.4 Significance of the study

The significance of this systematic review is consequently highlighted in that it will bring together literature providing information on the effects of non-pharmacological therapeutic interventions in a concise clear manner. In addition, it will summarise what effects these non-pharmacological therapeutic interventions have on the management of acute pain and physical function in adult patients following acute rib fractures. The information generated with this study could thus be used by clinicians as a means of improving patient care and translating research evidence into a clinical setting.

In addition, future areas of research or gaps in current practice in the management of these patients hope to be identified. This will facilitate ongoing evidence based investigation into the effects of non-pharmacological therapeutic interventions on pain and physical function in adults with rib fractures.

1.5 Conclusion of Chapter 1

Chapter 1 has highlighted the aims, the objectives and the rationale for conducting this study, identifying the importance of early, adequate pain control in the management of patients with acute rib fractures.

Chapter 2 consists of a comprehensive discussion of the available literature pertaining to blunt chest trauma, pain management and other strategies used to prevent complications related to physical and respiratory function.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review will provide the reader with an overview of the incidence, prevalence, mechanisms and type of injuries which can be incurred following chest trauma. Sources covered in conducting the literature review included journal articles sourced from databases as well as exploration of medical textbooks (Pryor & Webber, 1998; Van Aswegen & Morrow, 2015; Edgecombe & Angus, 2018). Data bases searched included MEDLINE using PubMed, EMBASE, PsycINFO, Scopus, CENTRAL, CINAHL Plus, PEDro as well as Google Scholar. Studies written in English or translated into English, between January 1990 to October 2019 of the reviewed databases were considered. Key words utilised in the search included: rib fracture/s, flail chest/segment, blunt chest trauma, thoracic trauma/injury and chest trauma. Additionally these keywords were reviewed relative to pain and/or acute pain as well as physical and respiratory/pulmonary function and non-pharmacological therapeutic interventions utilised in the acute care setting following rib fractures.

Blunt chest trauma will be specifically considered as this is the focus of the study. Rib fractures sustained as a result of blunt chest trauma, as well as signs and symptoms presenting following acute rib fractures will be reviewed in detail together with their influence on management and recovery. Patients identified as high risk patients following rib fractures will additionally be reviewed, with differences in stratification and management of these patients being highlighted. Frequently encountered complications identified following rib fractures will be discussed, and implications for management reviewed. Overall goals of medical, surgical and physiotherapy management will be outlined, providing a holistic overview of rib fracture interventions in the acute care setting. In addition, non-pharmacological therapeutic interventions and conservative methods of management utilised following rib fractures will be evaluated and explored in detail. This will assist in determining the scope of treatment options available in this field.

The literature presented in this chapter will be discussed under the following main headings:

2.2 Chest trauma

2.3 Pain associated with acute rib fractures

2.4 Impact of rib fracture injuries on physical function

2.5 Summary of main findings of this chapter

2.2 Chest trauma

2.2.1 Incidence and prevalence of traumatic injury globally

Trauma has been identified as a leading cause of death and disability worldwide, specifically in the population under 45 years of age (Sakran et al., 2012; Ludwig & Koryllos, 2017), with a greater male to female predominance presenting following traumatic injury (El-Menyar et al., 2014; Khursheed et al., 2019). Annually in the western world, trauma accounts for a greater loss in pre-retirement years of life than malignant disease, heart disease, and acquired immune deficiency syndrome (AIDS) combined (Muckart, 1991). Of all trauma patients, approximately two thirds have been found to sustain chest trauma of varying severity (Ludwig & Koryllos, 2017). Isolated thoracic injury may occur following thoracic trauma or in association with extra-thoracic injuries (Ludwig & Koryllos, 2017). Chest trauma has been identified as a significant cause of morbidity and mortality in both adults and children (Milisavljević et al., 2012). In addition chest trauma accounts for 25% of fatalities following traumatic injury and has been identified as the second leading cause of death from physical trauma after head and spinal cord injuries (Shah & Solanki, 2015; Vana et al., 2016). Chest trauma incurred may range from simple rib fractures, to complex flail chest and sternal fractures (Ludwig & Koryllos, 2017). Together with traumatic chest wall injuries, injuries to the heart or lungs (pleural and parenchymal) as well as associated injuries to the tracheobronchial tree, diaphragm, mediastinum and great vessels of the thorax may be incurred (Sabri et al., 2018). Compromise to both the circulatory as well as respiratory system may thus ensue following chest trauma.

From an etiological perspective thoracic trauma is divided into blunt and penetrating chest injuries. Blunt chest trauma accounts for over 15 % of all trauma admissions to emergency departments worldwide, with mortality rates varying between 4% and 60% (Battle et al., 2014; Manay et al., 2017). Rib fractures are the most common thoracic injury encountered following blunt chest trauma (Brasel et al., 2017; Chrysou et al., 2017; de Moya et al., 2017; Sabri et al., 2018), with two thirds of all blunt chest trauma involving at least one rib fracture (Sahr et al., 2013). Overall incidence of rib fractures may however be higher than initially reported as more than 50% of rib fractures may be missed on plain chest X-ray evaluation (Bhattacharya et al., 2015). As the focus of this review is that of blunt chest trauma, this will be discussed in further detail.

2.2.2 Mechanisms of blunt injury to the thorax and risk of mortality

Blunt chest trauma accounts for a significant proportion of debilitating and life-threatening injuries which predominantly occur as a result of MVA's (Pharaon et al., 2015; Chrysou et al., 2017; Okonta & Ocheli, 2018), falls (Okonta & Ocheli, 2018) and acts of violence (Moodley et al., 2014; Sabri et al., 2018). Other recognised mechanisms of blunt chest trauma include pedestrian vehicle accidents (Nyangena & Bruce, 2000; Sirmali et al., 2003), motorcycle accidents (Alam El-Din et al., 2018), natural disasters and industrial accidents (Okonta & Ocheli, 2018).

The main mechanism of blunt chest injury encountered may however vary significantly depending on geographical location and the political state (relative state of war or peace) and

societal influence in respective countries (Sakran et al., 2012). In certain regions and world populations MVA's and falls have been identified as the most common mechanisms of injury whilst in others, prevalence of intentional injuries and interpersonal violence may be more influential causative factors (Sakran et al., 2012). The mechanism of injury encountered may also depend upon the population reviewed. In the elderly population falls have been identified as one of the most common mechanisms of blunt injury (Bergeron et al., 2003; Kent et al., 2008; Shi et al., 2017) and constitute one of the leading causes of trauma-related deaths in this population (Llompart-Pou et al., 2017). Whilst low-velocity falls are more commonly identified as the main mechanism of blunt thoracic injury presenting in the elderly population, MVA's are more commonly cited as the principal cause in those less than 65 years of age (Bergeron et al., 2003). Blunt chest trauma has been shown to occur more frequently in young males (Mohta et al., 2006; Chrysou et al., 2017; Okonta & Ocheli, 2018 ,Yadollahi et al., 2018), who are more inclined to be involved in higher risk behaviour leading to a predisposition to this type of injury (Nyangena & Bruce, 2000).

Fractures of the bony thorax including rib, sternal, clavicle and scapula fractures are characteristic features of blunt thoracic trauma and give an indication of the large transfer of energy imparted to the chest wall and underlying thoracic viscera (Al-Sadek et al., 2016; Rendeki & Molnár, 2019). Blunt chest trauma may not only result in skeletal injury, but may also result in significant intra-thoracic injuries including thoracic aorta rupture, cardiac contusion, lung lacerations, rupture of the diaphragm, injury to the spleen, central nervous system injury (CNS) as well as extremity fractures and soft tissue injuries (Ziegler & Agarwal, 1994; de Moya et al., 2017; Chrysou et al., 2017; Edgecombe & Angus, 2018). Significant morbidity and mortality has thus been associated with blunt chest injuries (Nyangena & Bruce, 2000).

Determinants of mortality following blunt chest injury have been found to include high injury severity score (ISS), severe head injury and bilateral chest injury, with deaths often being attributed to respiratory failure (Okonta & Ocheli, 2018). Delayed onset of complications following blunt chest trauma frequently occur leading to further difficulties in the management and treatment of these patients (Battle et al., 2014). In addition pulmonary contusions, pneumothorax, haemothorax and pleural effusions are associated pulmonary injuries often noted following blunt chest injury and lead to increased morbidity and mortality (de Moya et al., 2017; Chrysou et al., 2017).

The most common thoracic injury presenting following blunt chest trauma is that of rib fractures (Brasel et al., 2017; Chrysou et al., 2017; de Moya et al., 2017; Sabri et al., 2018). Rib fracture classification, presenting symptoms and overall management will now be reviewed in detail.

2.2.3 Types of rib fractures and patients' presenting signs and symptoms.

Rib fractures may be classified as simple to multiple in nature and range from a single fractured rib that may be sustained from a fall to multiple fractured ribs or flail chest injury (Ziegler & Agarwal, 1994; Pharaon et al., 2015; Chrysou et al., 2017). Rib fractures may occur at the point of impact or at the weakest point of the rib at its angle. Ribs four to ten are reported to be the most commonly fractured ribs. Fractures of the lower ribs (9th -12th), are often associated with injuries to the liver and spleen and are markers for serious intra-thoracic

or abdominal injury (Ekpe & Eyo, 2016). Rib fractures often occur in conjunction with other associated thoracic injuries including underlying lung contusion, haemothorax, pneumothorax or both (Chrysou et al., 2017; Manay et al., 2017; Beks et al., 2019). Rib fractures may be used as predictors for further pulmonary deterioration (Ekpe & Eyo, 2016) and have been identified as a marker of injury severity especially in the elderly (Ziegler & Agarwal, 1994; Stawicki et al., 2004).

Rib fractures are considered clinically significant in that they are a notable source of chest pain (Ekpe & Eyo, 2016). Intense unremitting chest pain specifically on inspiration has been identified as the main presenting symptom following rib fractures, with pain originating from the site of the fractured bone and injured muscle (Kerr-Valentic et al., 2003; Ekpe & Eyo, 2016). In addition to chest pain, dyspnea is a common finding on presentation and may occur due to restriction of effective ventilation resulting from pain or from mechanical limitation of respiratory function (Easter, 2001; Liman et al., 2003; Kent et al., 2008). Splinting of the chest wall due to pain may also present, with an inability to breathe deeply and cough and clear secretions effectively (Bulger et al., 2000; Easter, 2001; Ekpe & Eyo, 2016). Pathophysiological findings of ventilation-perfusion abnormalities, increased work of breathing, hypoxemia, and decreased functional residual capacity (FRC) (Kent et al., 2008), as well as decreased lung compliance and resultant respiratory distress are common findings following rib fractures (Ekpe & Eyo, 2016). On physical examination local chest tenderness and muscle spasm over the chest wall, bone crepitation as well as subcutaneous emphysema may be palpated (Sharma et al., 2016; Sabri et al., 2018).

Rib fracture location and pattern are considered clinically important (Witt & Bulger, 2017). Rib fracture classification will now be reviewed and discussed relative to presenting signs and symptoms as well as management.

2.2.3.1 Simple rib fractures

Rib fractures that are single and non-displaced are classified as simple fractures. A non-displaced rib fracture is defined as a rib fracture with complete cortical disruption but with maintained alignment, with a lucent line visible on radiological assessment (Talbot et al., 2017).

Simple fractures may be considered serious in the elderly as well as those with reduced pulmonary reserve in whom impairment of ventilation and coughing following injury may result in pneumonia (Ekpe & Eyo, 2016). As such management should be tailored with these considerations in mind.

2.2.3.2 Multiple rib fractures

Multiple rib fractures are the hallmark of severe trauma and are injuries indicative of exceptional force and high energy transfer (Ekpe & Eyo, 2016). Chien et al., (2017) in their retrospective cohort study, found that three or more rib fractures or any displaced rib fracture were the most significant predictors for developing pulmonary complications following injury. Displaced rib fractures, are rib fractures presenting with cortical disruption and abnormality in alignment, with varying degrees of displacement. Displaced fractures may lead to injury to the surrounding tissues and organs and have the potential to penetrate the pleura

and lacerate lung parenchyma (Chien et al., 2017; Talbot et al., 2017). Displaced rib fractures thus hold greater potential for the occurrence and likelihood of pulmonary complications following injury (Chien et al., 2017).

In a study reviewing rib fractures and prognosis in multiply injured trauma patients, an increase in the number of fractured ribs was associated with an increase in the injury severity score (higher ISS), complication rate and length of stay (LOS) both in hospital and intensive care unit (ICU) (Hashemzadeh et al., 2018). In the study conducted by Lin et al., (2016) reviewing the management of traumatic rib fractures as well as morbidity, mortality and associated injuries, the number of rib fractures was significantly associated with prolonged hospital and ICU LOS as well as pulmonary complications. For each additional rib fractured, mortality rate has shown to increase, with increasing number of rib fractures being directly correlated with increasing pulmonary morbidity and mortality (Flagel et al., 2005). Hypoventilation induced by pain, altered breathing mechanics as well as impaired gaseous exchange in the damaged lung parenchyma underlying the rib fractures all contribute to the associated morbidity and mortality associated with this injury (May et al., 2016; Ahn et al., 2013). Severe or multiple rib fractures may lead to damage to the underlying lung parenchyma and resultant inability of the damaged tissue to take part in gaseous exchange. Lung contusion sustained leads to poorly compliant lung tissue and compromises ventilation and perfusion matching, further compromising respiratory function (Ahn et al., 2013). Shortness of breath, low blood oxygenation, and reduced FRC are thus often observed (Park et al., 2017). Resultantly, acute respiratory distress syndrome and pneumonia may often ensue following pulmonary contusion (Ganie et al., 2013).

2.2.3.3 Flail chest injuries

Flail injury is the most serious of blunt chest wall trauma and usually follows high energy transfer to or crush-injury of the thoracic cage (Bastos et al., 2008; Wanek & Mayberry, 2004; Ekpe & Eyo, 2016). A flail chest injury is diagnosed when three or more consecutive ribs are fractured in two or more places, and an independent segment, moving paradoxically from the chest wall is observed (Naidoo et al., 2017). Flail chest injuries are associated with severe pain as well as compensatory splinting of the chest wall leading to inadequate lung volumes. An inability to breathe deeply and cough effectively as a result of severe pain results in retention of secretions, as well as increases the risk of pneumonia, further compromising respiratory function (Jena et al., 2016; Noorbakhsh & Kriley., 2018). Hypoxemic respiratory failure ensues as a result of atelectasis incurred due to an inability to breathe deeply, and in the presence of underlying pulmonary contusion this becomes more prevalent (Wilson, 2011; Jena et al., 2016; Noorbakhsh & Kriley., 2018).

In most patients with flail chest injury, respiratory compromise is due to underlying lung contusion and severe pain following injury, as opposed to paradoxical movement of the rib segments only (Brasel et al., 2017). The paradoxical movement of the flail segment inward is seen when the lung expands on inspiration, the flail segment collapses inward as a result of the negative intrathoracic pressure instead of expanding outwards with the rest of the rib cage on inspiration. In contrast during expiration, the flail segment bulges outward in comparison to the surrounding rib cage (Wilson, 2011; May et al., 2016). Instability of the chest wall and underlying lung contusion thus contribute to compromised respiratory and ventilatory function following injury.

Lung contusion associated with flail chest injury may be considered life-threatening and is primarily accountable for the acute morbidity encountered following injury (Bastos et al., 2008). Mortality following flail chest injuries has been found to range from 9% to 16% for these patients. Extended hospital stay and a complicated recovery further increase morbidity following flail chest injury (Bastos et al., 2008; de Campos & White, 2018). In addition the likelihood of death following flail chest injury has been shown to increase to 132% with every ten year-increase in age at the time of injury. As a result flail chest injury in association with old age has been coupled with poorer outcomes in this population (Albaugh et al., 2000).

2.2.4 Management of patients with rib fractures in an acute care setting

Initial evaluation and management of patients with chest trauma is based on the advanced trauma life support (ATLS) guidelines, allowing for rapid identification of immediate life-threatening injuries and management thereof (Ludwig & Koryllos, 2017). The main aims of management in the acute care setting following rib fractures include optimisation of pain control as well as pulmonary hygiene and maintenance of adequate oxygenation and ventilatory strategies (de Campos & White, 2018; Hashemzadeh et al., 2018). Support of respiratory and ventilatory function including the prevention of pulmonary complications such as atelectasis and pneumonia as well as ventilatory failure are important aims of management (Van Aswegen & Morrow, 2015; Wijffels et al., 2019).

One of the key components of management following rib fractures is early recognition of those at risk of deterioration (Battle et al., 2013; Sahr et al., 2013; May et al., 2016). This allows for prompt, early effective management thereby reducing the risk of associated complications from ensuing (May et al., 2016). Presentation of pulmonary complications may be delayed up to 48–72 hours following injury. As such continued assessment and re-evaluation even in patients who have incurred initially minor trauma are essential components of management (Battle et al., 2013; Bellone et al., 2016; May et al., 2016).

Presence of co-morbidities as well as presence of concomitant underlying thoracic injury or associated extra-thoracic injuries (severe spinal or head injuries) may also influence management implemented (Demirhan et al., 2009., Battle et al., 2012; Pressley et al., 2012; Van Vledder et al., 2019). In the study conducted by Battle et al., (2013) significant predictors affecting outcome following blunt chest wall trauma were identified. Age, number of rib fractures, presence of chronic lung disease, pre-injury anticoagulants use and low oxygen saturation levels on admission to the emergency department were identified as significant risk factors for the development of complications following blunt chest wall trauma. Patients identified with these risk factors should thus be closely monitored to allow for early detection of deterioration and directed management thereof.

The elderly have specifically been identified as a particularly vulnerable population following rib fractures and present with twice the mortality and thoracic morbidity of younger patients with similar injuries. These patients often present with diminished physiological reserves and increased prevalence of comorbid conditions (Bergeron et al., 2003; Ferrah et al., 2018; Kuo & Kim., 2019). Both pneumonia and mortality risk have been shown to increase exponentially for each additional rib fractured in the elderly population (Bulger et al., 2000). As a result older individuals typically experience greater lengths of stay with resultant increase in resource utilisation and costs following thoracic trauma (Ferrah et al., 2018).

Recommendation has thus been made that elderly trauma patients with rib fractures, especially multiple rib fractures, even following seemly minor trauma should be closely observed and managed (Bergeron et al., 2003). It is therefore vital that high risk patients such as the elderly and those who have sustained more than three rib fractures be identified and managed promptly.

Once at risk patients have been identified appropriate management strategies can be implemented and directed relative to the main treatment goals.

Early, effective pain control is considered an essential component of care and has been identified by numerous authors as the most important intervention for patients following rib fractures (Easter, 2001; Karmakar & Ho, 2003; Michelet & Boussen, 2013; Curtis et al., 2016; May et al., 2016; Flarity et al., 2017). Pain management provides not only improved patient comfort but also assists in reducing the risk of respiratory complications which may only present in the days following injury. Adequate analgesia enables deep breathing and effective coughing as well as improves patient compliance and tolerance to other treatment interventions including chest physiotherapy, incentive spirometry and mobilisation (Simon et al., 2005; Unsworth et al., 2015, May et al., 2016; Bilalee et al., 2017). This allows for maintenance of pulmonary hygiene which aids in reducing the incidence of secondary pulmonary complications, including atelectasis, pneumonia, respiratory failure and resultant need for respiratory support (May et al., 2016).

Pain control therefore assists in the prevention of associated respiratory complications following rib fractures and so promotes improvements in both respiratory function and physical activity following injury (Pharaon et al., 2015; De Moya et al., 2017). Adequate pain control and maintenance of pulmonary function are vital management principles to attain in the treatment of these patients, together with frequent re-evaluation of respiratory function (Witt & Bulger, 2017).

Attainment of these management goals may be achieved through various interventions and management options including pharmacological as well as non-pharmacological and operative alternatives. The main management interventions will be reviewed in detail to provide an overall picture of the management avenues and practices implemented following rib fractures. Thereafter these management strategies will be applied to specific rib fracture presentations.

2.2.4.1 Pharmacological pain management strategies

Analgesic pathways and scoring systems have been developed to assist in determining appropriate initial analgesic interventions following rib fractures with subsequent steps of action if pain management is deemed suboptimal (May et al., 2016; He et al., 2019). Various options and methods of pain management may be progressed in a step wise manner according to the patients presenting clinical condition. Pain management may include and be progressed from simple analgesia, to opioids, patient controlled analgesia (PCA) and regional anesthetic techniques including thoracic epidurals and ultrasound-guided paravertebral and serratus plane blocks (May et al., 2016). Modalities identified for use in the management of patients with rib fractures each have their own recognised unique advantages and disadvantages and this balance should be weighed respectively prior to implementation (Ekpe & Eyo, 2016).

Multimodal conservative pain management has been advocated for use in the management of rib fracture pain (Witt & Bulger., 2017). Use of intravenous (IV) and oral analgesia, including opioids and non-steroidal anti-inflammatory drugs (NSAIDs) may be utilised if the respiratory system is not compromised (Ahn et al., 2013). Intravenous narcotics administered by intermittent injection or continuous infusion are also potential treatment avenues (Simon et al., 2005). The preferred technique for pain control after severe blunt thoracic trauma, including flail chest injury is that of epidural analgesia (Simon et al., 2005). Epidural analgesia has been shown to provide optimal pain relief and improve pulmonary function following use. Epidural analgesia is thus considered the gold standard of pain management following rib fractures especially when multiple in nature, and when opioid analgesia is inadequate (Simon et al., 2005; Wardhan, 2013; May et al., 2016). Careful selection of patients is recommended as many trauma patients may have other associated injuries which contraindicate the use of epidurals, or positioning required for insertion of the epidural catheter (May et al., 2016).

Thoracic paravertebral block is an additional analgesic technique which involves injection of a local anesthetic into the thoracic paravertebral space with minimal to no risk of spinal cord injury in comparison to possible risk involved with epidural analgesia (Ahn et al., 2013; May et al., 2016). Thoracic paravertebral block has been shown to provide effective pain relief in patients with multiple rib fractures (Wardhan, 2013).

Other analgesic treatment modalities available for pain management include, serratus muscle plane block (May et al., 2016) and interpleural block (not often used due to suboptimal pain relief following rib fractures) (Wardhan, 2013; May et al., 2016). In addition, intercostal blocks have been found to be highly effective in providing pain relief for up to four to 24 hours, with reductions in LOS and mortality being documented. Intercostal blocks however involve multiple injections and benefit (pain relief) to risk (risk of pneumothorax and anesthetic toxicity) should be weighed prior to use (Ahn et al., 2013; May et al., 2016).

2.2.4.2 Respiratory and ventilatory interventions

Respiratory support and maintenance of adequate ventilation has been identified as crucial components in the management of patients following rib fractures (Easter, 2001). Respiratory and ventilatory interventions may include oxygen therapy, ventilatory modalities and aggressive pulmonary toilet including respiratory physiotherapy techniques. These interventions aim to support respiratory function as well as aid in the prevention of respiratory complications and ventilatory failure (Saillant & Sein, 2018).

Ventilatory management for patients following rib fractures may begin with initiation of supplemental humidified oxygen therapy to prevent hypoxemia, as well as nebulisation to assist in loosening secretions and clearance thereof (May et al., 2016). Humidified oxygen is recommended so as to avoid compromise to the mucociliary escalator and improve patient comfort (Van Aswegen & Morrow., 2015; May et al., 2016). If despite supplemental oxygen therapy the patient's partial pressure of oxygen in the arterial blood (PaO_2) is not maintained, ventilatory support in the form of continuous positive airway pressure ventilation (CPAP) may be required (May et al., 2016).

The overall goals of mechanical ventilation (MV) for patients with multiple rib fractures or flail chest injury are to support the respiratory system via provision of positive pressure to the airways. Mechanical ventilation should however be reserved for patients presenting with persistent respiratory insufficiency or failure after adequate pain control (Alzahrani et al., 2018). Respiratory support provided by MV aids in improving chest wall stability and assists in achieving pneumatic stabilisation via provision of positive intrathoracic pressure (Richter & Ragaller, 2011; Easter, 2001;Van Aswegen & Morrow., 2015). Ventilatory support may be in the form of non-invasive or invasive means and these two strategies of management will be discussed further.

2.2.4.2.1 Non-invasive ventilation

Non-invasive ventilation (NIV) may be defined as delivery of MV to the lungs using modalities that do not require an endotracheal airway (Mehta & Hill., 2001). The main ventilatory goals are to improve oxygenation, unload respiratory muscles and relieve dyspnea (Schreiber et al., 2018). The need for patient sedation and paralysis are avoided by use of NIV modalities (Mehta & Hill, 2001; Richter & Ragaller, 2011).

Non-invasive ventilation may be subdivided into negative-pressure ventilation and non-invasive positive-pressure ventilation (NIPPV). Positive pressure ventilation is applied to the airway to inflate the lungs directly, whereas negative pressure ventilatory techniques are applied externally to the abdomen and thorax to draw air into the lungs through the upper airway (Scala & Pisani, 2018). Non-invasive positive pressure ventilation delivers positive pressure to patient's airways via nasal, facial or helmet interfaces (Richter & Ragaller, 2011). Examples of NIPPV may include continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP), whereas continuous negative extrathoracic pressure (CNEP) is a form of negative pressure ventilation.

Non-invasive positive pressure ventilatory techniques have been shown to be successfully utilised in the management of patients with blunt chest trauma (Chiumello et al., 2013; Duggal et al., 2013). Both CPAP and BiPAP have been found to be safe and efficient techniques in managing respiratory failure and decreasing the incidence of intubation in patients following blunt chest trauma (Shebl et al., 2015). The use of CPAP involves constant positive pressure delivery during both inspiration and expiration leading to recruitment of under ventilated alveoli and the avoidance of airway and alveolar collapse. Alveolar recruitment thereby aids in the prevention of atelectasis and maintenance of FRC (Mehta & Hill., 2001, Richter & Ragaller, 2011). Findings from a meta-analysis concluded that early use of NIV in chest trauma patients facilitated stabilisation of the chest and promoted recruitment of collapsed lung regions (Chiumello et al., 2013).

Non-invasive ventilation is considered by some authors as a first choice of treatment in the compliant blunt chest wall trauma patient presenting with poor oxygenation (Chiumello et al., 2013; Richter & Ragaller, 2011). Only in the event of failure of NIV, is intubation and invasive MV recommended (Richter & Ragaller, 2011).

High flow nasal prong / cannula (HFNC) therapy may also be considered in the management of patients following blunt chest trauma (Curtis et al., 2016; Sharma & Chakraborty, 2019). High flow nasal cannula therapy is considered a non-invasive respiratory support and is

thought to provide efficient respiratory assistance and oxygenation via physiological deadspace washout of carbon dioxide (CO_2). In addition the provision of low level positive end expiratory pressure (PEEP) leads to alveolar recruitment as well as reduction in nasopharyngeal resistance to inspiration (Sharma & Chakraborty, 2019). Warming and humidification of oxygen delivered promotes mobilisation of secretions as well as improves patient comfort in comparison to other NIV strategies (Dries, 2018). In addition, preservation of speech and ability to eat increases patient compliance and tolerance to HFNC (Dries, 2018; Sharma & Chakraborty, 2019). High flow nasal cannula oxygen therapy implementation may thus allow for avoidance of endotracheal intubation and MV in these patients (Dries, 2018; Saillant & Sein, 2018).

2.2.4.2.2 Invasive mechanical ventilation

Severe forms of chest trauma including flail chest injuries not responding to non-invasive management may warrant endotracheal intubation and MV in the presence of anticipated or manifest hypoxemic or hypercapnic respiratory failure (Saillant & Sein, 2018). In association with pulmonary contusion, poor lung compliance presents as a result of alveolar-capillary leakage into the lung parenchyma. Use of PEEP may aid recruitment of the alveoli and decrease shunting, whilst CPAP may aid improvement in lung compliance (Saillant & Sein, 2018) as also occurs during NIPPV use (Cross, 2000). Pain has also been identified as a major factor contributing to the need for intubation in patients following acute rib fractures (Easter, 2001). Pain management is thus considered vital and once ventilated, early weaning of the patient from the ventilator is paramount to reduce the risk of ventilatory associated complications (May et al., 2016). Over 80% of ICU-acquired pneumonias occur during MV and half of ventilator-associated pneumonias develop within four days of intubation (Ahn et al., 2013).

In addition to ventilation modalities, respiratory physiotherapy has been advocated as an important component in the management of respiratory and ventilatory function following chest trauma (Richter & Ragaller, 2011; Van Aswegen et al., 2019). Physiotherapy intervention will now be reviewed further.

2.2.4.2.3 Respiratory physiotherapy

Physiotherapists form part of the multidisciplinary team assisting in the management and treatment of patients in the acute care setting following traumatic injury (Pathmanathan et al., 2015; Van Aswegen & Morrow, 2015).

Optimisation of pulmonary hygiene is considered a vital goal of management following rib fractures. Respiratory physiotherapy together with adequate pain management form important components of care in achieving this goal (May et al., 2016; de Campos & White, 2018). Maintenance of pulmonary hygiene via aggressive pulmonary toilet, effective coughing and deep breathing together with early mobilisation have been identified as key components in the management of patients following rib fractures (Brasel et al., 2017). Physiotherapy management intends to improve the patient's pattern of breathing as well as reduce the work of breathing ensuring adequate ventilation of all lung areas (Van Aswegen & Morrow, 2015). Physiotherapists also aim to assist facilitation of early weaning from MV for intubated

patients as well as aid in the removal and clearance of excess bronchial secretions. This will aid in the prevention of secondary chest infections (Van Aswegen & Morrow, 2015). Furthermore physiotherapists are also involved in the evaluation and implementation of mobilisation as part of treatment in the acute care setting (Stiller, 2013). Early mobilisation is deemed essential in the management of these patients especially when the associated side effects of bed rest and immobility are reviewed (Knight et al., 2009). The utilisation of mobilisation and therapeutic respiratory physiotherapy techniques will be reviewed in further detail under the heading of non-pharmacological therapeutic interventions.

2.2.4.3 Surgical management

Operative stabilisation of rib fractures aims to provide restoration of chest wall integrity and stability, reducing pain and thereby improving pulmonary mechanics (May et al., 2016; Park et al., 2017; Saillant & Sein, 2018). Effective reduction and fixation may reduce associated pain and inflammation, with resultant reduction in risk of pain-associated respiratory failure. Risk of non-union and chronic pain may also by lowered by effective stabilisation (Pieracci et al., 2016). Early fixation within 72 hours of injury and ideally within 24 hours of injury is recommended (Brasel et al., 2017; de Campos & White, 2018). Potential indications for surgical intervention include rib fractures not responding to optimal non-operative management (irrespective of the rib fracture pattern), rib fracture non-union, chest wall deformity/defect, three or more acutely displaced rib fractures or a flail chest injury (Nirula et al., 2009; Brasel et al., 2017; de Campos & White, 2018).

Surgical intervention may also be considered in patients with respiratory compromise especially in non-intubated patients with deteriorating pulmonary function, difficulty weaning patients from a ventilator or when thoracotomy is indicated primarily for other injuries (May et al., 2016; Pieracci et al., 2016). Ribs four to ten are the most mobile and produce significant pain when fractured, and are the ribs most frequently repaired (De Moya et al., 2017). Multiple techniques have been described in the literature, including use of metal plates, absorbable plates, intramedullary fixation, Judet struts as well as U-plates (Alzahrani et al., 2018). The optimal approach for rib fracture fixation has not yet however been established. Currently there is no evidence to support one method of fixation over another (Brasel et al., 2017; Alzahrani et al., 2018; Saillant & Sein, 2018).

Surgical intervention for flail chest injury has produced favourable outcomes with regards to incidence of pneumonia in this population (Zhang et al., 2015; Schuurmans et al., 2017). Surgical intervention via rib plating has also demonstrated positive outcomes in the management of patients 65 years of age and older with rib fractures in comparison to a non-operative injury matched control group (Fitzgerald et al., 2017). Positive outcomes included measurable decreases in mortality and respiratory complications, as well as reduction in ICU LOS with accelerated return to function were documented by Fitzgerald et al., (2017) in this population. These authors concluded that rib fracture fixation is a viable alternative to conservative strategies in the management of severe chest wall trauma. Additionally Pieracci et al., (2016) conducted a prospective controlled clinical evaluation of early surgical stabilisation of severe rib fractures including flail chest injury compared with optimal medical management. Both groups received escalating levels of analgesia as well as pulmonary toilet. The operative group presented with a 76% decrease in the likelihood of respiratory failure ($p = 0.03$) following intervention as well as an increase in median daily spirometry values ($p =$

0.04) in comparison to the non-operative group. Decreased likelihood of tracheotomy as well as duration of MV were also observed in the surgical group, although results were unable to specify for which fracture pattern surgical intervention provided the most benefit (Pieracci et al., 2016).

In terms of long term outcomes following surgical intervention, the study conducted by Fagevik Olsén et al., (2016) reviewed operatively managed patients with multiple rib fractures for a year following surgical intervention. Results indicated that patients having undergone surgery had a similar long-term recovery to those who were treated conservatively. The operative group did however achieve better range of motion in the thorax and presented with fewer limitations in physical function and presented with a tendency towards decreased pain.

Surgical intervention may thus provide positive short and long-term outcomes in select patients.

2.2.4.4 Management of specific rib fracture patterns

2.2.4.4.1 Simple rib fractures

Simple, isolated rib fractures in most instances may be managed effectively by conservative means. Conservative therapy may include appropriate analgesia, rest and ice (Kuo & Kim, 2019). Simple rib fractures may be managed without hospital admission, but this will also be dependent on the severity of the trauma sustained, age of the patient and as well as degree of pain, and whether pain control can be achieved (Kuo & Kim, 2019). In the absence of underlying cardiopulmonary pathology simple rib fractures even when multiple in nature are reported to be well tolerated (Lodhia et al., 2019).

In the event that hospitalisation is required, humidified oxygen, incentive spirometry and physiotherapy may also be considered important management components which may be implemented following injury (Lodhia et al., 2019). Use of incentive spirometry is encouraged to prevent pulmonary atelectasis and splinting and to maintain respiratory function (Kuo & Kim, 2019).

2.2.4.4.2 Multiple rib fractures

Multiple rib fractures or flail chest injuries may cause significant compromise to respiratory function (Ahn et al., 2013). The main goals of management are thus to prevent pulmonary complications as well as prevent respiratory failure from ensuing. Conservative management requires early effective pain control and aggressive pulmonary support and care to avoid intubation where possible (Kuo & Kim, 2019).

Multiple rib fractures, displaced rib fractures, or those with underlying concomitant injuries require in-hospital pain management, as well as frequent re-evaluation and monitoring especially of respiratory function (Kuo & Kim, 2019). This is essential as respiratory function may only show signs of deterioration 24-48 hours following injury (Sirmali et al., 2003; Ahn et al., 2013; May et al., 2016; Chien et al., 2017). Hospitalisation has been recommended in

the presence of three or more rib fractures to allow for effective pain management which may include epidural analgesia and continued evaluation.

Respiratory support in the form of NIPPV in the presence of adequate analgesia may be utilised to assist chest wall stabilisation following multiple rib fractures, thus aiding ventilatory function (Van Aswegen & Morrow, 2015; Manay et al., 2017). Sirmali et al., (2003) advocated that elderly patients with six or more fractured ribs should be treated in ICU due to high morbidity and mortality risk.

A trend towards early fixation of multiple rib fractures is on the horizon, with reported reductions in hospital and ICU LOS, incidence of pneumonia, pain and shorter periods of invasive ventilation and reduced overall costs being reported (de Campos & White, 2018; Lodhia et al., 2019). Respiratory support and pain control however remains the preferred treatment in the majority of patients with multiple rib fractures, in the absence of indications advocating surgical intervention is required (de Campos & White, 2018).

2.2.4.4.3 Flail chest injuries

Traumatic flail chest injuries may be considered life-threatening injuries (de Campos & White, 2018). As such patients with flail chest injuries are frequently managed in the ICU due to their high risk of respiratory insufficiency following injury, and subsequent need for NIV or early MV and appropriate analgesia which often requires epidural analgesia (Liman et al., 2003; Sirmali et al., 2003; Gunduz et al., 2005; Battle et al., 2013). Adequate pain relief together with aggressive chest physiotherapy and secretion clearance may assist in effective management of patients without the need for ventilatory support (Jena et al., 2016). Patient-controlled analgesia, oral pain medications, as well as indwelling epidural catheters are frequently utilised to manage patients' pain following flail chest injury (Gunduz et al., 2005).

Operative management has been advocated by various authors for the management of flail chest injuries with positive outcomes being observed (Pharaon et al., 2015; de Campos & White, 2018). In the meta-analysis conducted by Schuurmans et al., (2017), results showed that operative management of flail chest improved the outcomes of patients with regards to days of MV, ICU and hospital LOS, tracheostomy rate, FVC, and treatment costs. The operative management group showed a significantly lower incidence of pneumonia, however mortality rate did not differ between treatment and operative management groups. It was concluded that operative management may therefore be a promising option for treatment of flail chest injuries with improved patient's outcomes as well as lowered treatment costs being documented (Schuurmans et al., 2017).

2.2.5 Complications that patients may develop due to rib fractures

Rib fractures are notoriously painful with the vast majority of complications following rib fractures being attributed to chest wall pain which limits pulmonary function and effective ventilation (Bulger et al., 2000; Easter, 2001; Kent et al., 2008). Pain promotes splinting and an inability to breathe deeply or cough effectively due to severe pain inhibition (Bulger et al., 2000; Easter, 2001). This leads to reductions in FRC and sputum retention (Easter, 2001; Ekpe & Eyo, 2016).

2.2.5.1 Simple rib fractures

By in large isolated fractures of one or two ribs in the absence of associated injuries are typically not considered life-threatening. At any level of rib fracture however, the risk of pneumothorax and pulmonary contusion exists (Richter & Ragaller, 2011). Delayed presentations of haemothorax as well as pneumothorax have been reported following one to two rib fractures. As a result, continued re-evaluation and monitoring for these complications is thus recommended (Sırmalı et al., 2003).

2.2.5.2 Multiple rib fractures and flail chest injuries

Difficulty coughing and clearing secretions is often observed in patients following multiple rib fractures as well as flail chest injury, and as such associated increases in mortality and duration of hospital and ICU LOS are frequently observed (Park et al., 2017). Pulmonary morbidity (including atelectasis and pneumonia) as well as mortality increase as the number of ribs fractured increase (Sirmali et al., 2003; Flagel et al., 2005; Park et al., 2017). Multiple rib fractures may often lead to acute respiratory failure as a result of these factors (Manay et al., 2017). Pulmonary contusion frequently occurs in conjunction with multiple rib fractures and flail chest injuries and in ventilated patients the risk of ventilator associated pneumonia is increased in these patients (Park et al., 2017). In addition multiple rib fractures and flail chest injuries are often associated with an increased likelihood of intrathoracic and abdominal injuries due to the magnitude of trauma required to elicit these fractures. As such complications encountered may be compounded as a result of these associated injuries (Kent et al., 2008). The elderly are specifically at risk following multiple rib fractures and significantly higher mortality rates have been reported in the presence of three or more rib fractures in this population (Bergeron et al., 2003).

Pulmonary complications noted due to flail chest injury may include pneumothorax, haemothorax, pulmonary contusion, atelectasis and pneumonia (Jena et al., 2016). Pneumonia has been described as the most common non-acute complication following flail chest injury (Gunduz et al., 2005; Pharaon et al., 2015; Alzahrani et al., 2018). Pulmonary contusion has been found to frequently accompany flail chest injuries, with up to 55.9% of patients being found to present with both pulmonary contusion and flail chest following injury (Bastos et al., 2008). Pulmonary contusion promotes the development of acute lung injury (ALI), which may progress to acute respiratory distress syndrome (ARDS). In addition, the severity of pulmonary contusion correlates with the development of pulmonary infections, respiratory failure, and mortality (Karcz & Papadakos, 2015). Pulmonary contusion in and of itself has therefore been identified as an independent risk factor for the development of pneumonia, acute lung injury and ARDS (Rendeki & Molnár, 2019).

In addition to acute complications presenting following flail chest injury, survivors have reported more long term complications including chronic chest wall pain as well as deformity. These presenting symptoms may give rise to high disability levels and reduced QOL (Fagevik Olsèn et al., 2016; de Campos & White, 2018).

2.3 Pain associated with acute rib fractures

Pain following rib fractures has been described as severe and debilitating (Karmakar et al., 2003; Pharaon et al., 2015) and may adversely affect respiratory function and ventilation (Van Aswegen & Morrow, 2015; Ekpe & Eyo, 2016). Intense pain following rib fractures can lead to prolonged hospitalisation and contribute to the development of pneumonia and respiratory failure (Pharaon et al., 2015). Pain related chest wall splinting leads to limitation of inspiratory capacity, deep breathing and coughing with atelectasis ensuing (Saillant et al., 2018). In addition uncontrolled pain may lead to prolongation of weaning from MV support, thus increasing the risk of ventilator associated complications (Park et al., 2017). Unrelieved acute pain may also give rise to feelings of anxiety, helplessness and loss of control and may lead to sleep disturbances, sleep deprivation and increase the risk for development of persistent and chronic pain pathologies (Sinatra, 2010; Painsa.org.za, 2019). Limited physical activity frequently presents following rib fractures as any movement of the chest wall has been found to exacerbate pain thus limiting physical function (Kerr-Valentic et al., 2003). In addition pain following rib fractures has been identified as the symptom causing the most significant hindrance to recovery following discharge (Pharaon et al., 2015).

Pain can thus be seen to impact both respiratory and physical function as well as psychological well-being following injury. Pain and its associated side effects and complications may thus be devastating if left unmanaged as all aspects of function may be compromised (Ziegler & Agarwal, 1994; Ho et al., 2014; Bilalee et al., 2017).

2.3.1 Tools used to assess level of pain experienced

A patient's personal report of pain is essential in guiding management following rib fractures. Patients self-report of pain are considered the gold standard for determining pain intensity (Gélinas et al., 2016). Regular monitoring of pain is deemed important and has been considered as the fifth vital sign in patient evaluation (SASA-Acute-Pain-Guidelines, 2015). Pain perception may however be affected by a number of factors including culture, personality type, expectations and psychological status and may thus provide a very subjective means of analysis by itself (Younger et al., 2009). As a result evaluation of pain in a broader context considering interference with appetite, activities of daily living as well as sleep are integral components to be considered in combination with pain intensity (Cole, 2002).

Validated scales for assessment of pain provide objective tools by which pain can be assessed. Pain rating scales and scores provide a more objective measure which can be utilised to guide appropriate pain management. Each has their own strengths and weaknesses. Assessment tools selected need to be appropriate to the patient's developmental age, cognitive status and emotional status (SASA-Acute-Pain-Guidelines, 2015). Pain intensity scales assist patients in communicating the extent of their pain (Sullivan et al., 2009) and structured pain assessment is considered vital in evaluating pain and in assisting and directing appropriate management (Bendinger & Plunkett, 2016).

Pain scales listed in the literature which can be used to evaluate pain in this population may include the numerical rating scale (Tulay et al., 2018; Peek et al., 2019), the visual analogue

scale (Bijur et al., 2001; Bendinger & Plunkett, 2016), the verbal rating scale (Bendinger & Plunkett, 2016), the Wong-Baker faces pain rating scale (Garra et al., 2009) and multidimensional scales, namely the McGill Pain Questionnaire (SF-MPQ) (Katz & Melzack, 1999).

2.3.1.1 The numerical rating scale (NRS)

The numerical rating scale is a commonly used unidimensional tool used to assess pain, and is administered verbally. The NRS typically consists of scores from 0 to 10 (or 0–100), with the far left being described as "no pain" and the far right described as "worst pain imaginable (Younger et al., 2009). The NRS has been utilised to assess pain and pain post implementation of interventions in the rib fracture population in various studies (Tulay et al., 2018; Peek et al., 2019) as well as in the acute care setting (Ahlers et al., 2008).

2.3.1.2 The Visual analogue scale (VAS)

As an alternative to the NRS, the visual analogue scale (VAS) may be utilised in the evaluation of pain. The patient marks anywhere along a 10-cm line to indicate their current pain intensity, which can be measured in millimetres. Younger et al., (2009) noted that the VAS provided a high degree of resolution and was probably the most sensitive single-item measure for clinical pain in research. The VAS has been deemed easy to administer and has been validated in both adults and older children (Garra et al., 2010). The VAS has also been considered the gold standard for assessment of acute pain and is frequently utilised in pain-related research (Bijur et al., 2001; Bendinger & Plunkett, 2016).

2.3.1.3 The verbal rating scale (VRS)

The verbal rating scale (VRS) is a categorical pain scale utilised for individuals who have difficulty translating their pain experience into a number value. The numerical values are instead replaced by descriptors, such as no pain, mild pain, moderate pain, and severe pain (Younger et al., 2009; Bendinger & Plunkett, 2016). The VRS has been shown to have high validity as an indicator of pain intensity (Bendinger & Plunkett, 2016).

2.3.1.4 Wong-Baker faces pain rating scale

The Wong-Baker faces pain rating scale is a popular scale used to evaluate pain. The scale is composed of a series of facial expression drawings (faces scales) to illustrate a spectrum of pain intensity and is a favoured method of pain severity assessment in paediatric as well as adult populations with cognitive impairment or when a language barrier exists (Garra et al., 2009; SASA-Acute-Pain-Guidelines, 2015).

2.3.1.5 Multidimensional scales

The short-form McGill Pain Questionnaire (SF-MPQ) allows for pain evaluation as well as assessment of the effect of pain on various dimensions of the patient's life. Pain assessment via the SF-MPQ is more complex and involves assessment of the multidimensional nature of

pain (Katz & Melzack, 1999). Several dimensions of pain are evaluated with differing combinations including pain intensity, quality, affect, interference with functioning, and effects on general QOL (Younger et al., 2009). The SF-MPQ has been used extensively in clinical research and is considered a well validated, reliable and consistent measurement tool for pain evaluation (Melzack, 1987; Katz & Melzack, 1999). The SF-MPQ is also composed of a single VAS item for pain intensity and a VRS for rating the overall pain experience (Younger et al., 2009).

2.3.2 Non-pharmacological interventions used to manage pain

Various non-pharmacological therapeutic interventions have been identified and utilised in the management of pain following acute rib fractures to alleviate pain and improve function (Witt & Bulger, 2017). Non-pharmacological management interventions have the benefit of negating the potentially adverse side effects of pharmacological management. Non-pharmacological interventions may be utilised independently/or in conjunction with pharmacological management to assist in pain relief and promote recovery of function following acute rib fractures. These interventions and modalities will now be reviewed in detail.

2.3.2.1 Acupuncture

Acupuncture is based on the theory of energy travelling along lines/ meridians within the body. These energy pathways are deemed to be responsible for maintenance of good health. Blockages or disturbances in the flow are considered to result in disease. Acupuncture needles (very thin metal needles) are utilised at specified body points to stimulate and regulate this energy flow along the meridian pathways (Goertz et al., 2006). Acupuncture may also lead to and stimulate the release of endogenous opioids in the body. Another potential explanation for the treatment effects of acupuncture is the gate theory, proposed by Melzack and Wall in 1965 whereby small diameter nociceptive fibres are blocked by tactile stimulation that activates larger diameter fibres. In accordance with the gate control theory, acupuncture may act in a similar way by inhibiting nociceptor function through gentle stimulation of the mechanoreceptors at the needle insertion point, thus producing an analgesic effect (Goertz et al., 2006).

Acupuncture has been used in the management of a wide array of pain related conditions and diseases, these include cancer related pain, migraines, dysmenorrhea, anxiety, depression and schizophrenia as well as chronic urticaria to name a few (Patil et al., 2016). Acupuncture is considered a safe procedure overall, for use in the management of pain and in conditions where pain may be a side effect. Benefits of acupuncture are considered to outweigh any possible drawbacks (Patil et al., 2016).

Numerous studies have demonstrated positive outcomes following acupuncture intervention use. In the systematic review on acupuncture use in osteoarthritis, it was concluded that acupuncture lead to significant reductions in pain intensity as well as improvements in both functional mobility as well as QOL (Manyanga et al., 2014). The systematic review and meta-analysis conducted by Yeh et al., (2014) on the efficacy of auricular acupuncture therapy for pain management revealed significant pain relief following auricular acupuncture when

compared to sham or control groups in the various studies reviewed. Findings thus suggest that auricular therapy can be used as an adjunct therapy for pain management, reducing analgesic use as well as reducing the potential adverse effects associated with pharmacological intervention. Further studies particularly large scale RCT were however recommended to further confirm the efficacy of auricular therapy for pain (Yeh et al., 2014).

Acupuncture may also demonstrate improvements in respiratory function following application. In the study conducted by Maimer et al., (2013), patients who had conventional bypass surgery via median sternotomy were reviewed. Acupuncture intervention in comparison to standard analgesia control without additional intervention showed significant increases in post treatment FVC following acupuncture therapy. In patients with chronic obstructive pulmonary disease acupuncture intervention in combination with standard medication lead to improvements in exercise capacity as well as oxygenation following 10 weeks of acupuncture intervention (Suzuki et al., 2012).

In summary, acupuncture therapy may thus produce positive outcomes on pain as well as respiratory and physical capacity following intervention. Acupuncture thus appears to hold potential as a non-pharmacological therapeutic intervention for producing positive outcomes on pain intensity, respiratory function and physical capacity when viewed in light of these findings.

2.3.2.2 Rib belts

Use of rib belts are thought to aid pain relief following rib fractures via stabilisation of the chest wall. Use of rib belts have however fallen out of favour as a result of the beliefs held that rib belts compromise chest wall expansion as well as lung function. This in turn may increase the incidence of pulmonary complications including atelectasis and secondary pneumonitis (Quick, 1990).

Two studies were retrieved that reviewed the use of rib belts for the management of pain following rib fractures. Lazcano et al., (1989) conducted a pilot study reviewing use of circumferential rib belts in comparison to oral analgesics in managing patients with uncomplicated acute rib fractures. Although the authors documented subjective reports of pain relief by patients using rib belts on telephonic follow-up on day three, overall analysis revealed no statistically significant differences in pain levels between the two groups. Of the overall complications identified in this study, all occurred in patients utilising rib belts. Reported complications included: two cases of asymptomatic atelectasis; one case of mild contact dermatitis and one of traumatic pleural effusion. The authors concluded that limited and cautious use of rib belts in the management of acute rib fractures should thus be implemented, until such time that additional studies with larger sample sizes could verify the clinical observations of high complication rates observed.

Quick (1990) conducted a pilot study in which 20 patients with simple rib fractures were prospectively randomised into two treatment groups. One group received ibuprofen and the other group ibuprofen plus a rib belt for analgesia. Although the study title specifies simple rib fractures for review, the authors included patients in this study with displaced and undisplaced rib fractures, as well as patients with multiple rib fractures (4-6 rib fractures) in their result analysis. Results showed no significant difference in pulmonary function testing or

in incidence of atelectasis or pneumonitis between groups. Increased occurrence of haemothorax in the group managed with rib belts was however documented. Difficulty ascertaining whether this finding was as a result of rib belt use or represented a coincidental finding due to the small sample size was reported by the authors. As such, as an increased incidence of haemothorax was however noted in association with multiple rib fractures, the authors recommended cautious use of rib belts in patients with multiple displaced rib fractures until this finding was clarified by further studies (Quick (1990).

Rib belts thus appear to offer subjective pain relief however possible risk of respiratory complications associated with use may limit utilisation of this modality in pain management. Further studies are recommended to establish overall conclusions regarding the use of rib belts as an adjunct to conventional analgesia in this population (Battle et al., 2013). Current findings appear to caution practitioners with regards to use of rib belts in clinical practice due to increased incidence of respiratory complications observed.

2.3.2.3 Cold/cold compression therapy

Cold therapy in the form of ice packs, gel packs or ice application may be utilised in the management of pain, the review below highlights conditions in which it has been successfully utilised for pain management.

Cold therapy utilised for post cardiac incisional and sternal pain was found to assist with pain relief associated with deep breathing and coughing following cardiac surgery. It was concluded that cold therapy was a low risk, low cost modality that could easily be applied as a safe and effective pain management intervention (Chailler et al., 2010; Khalkhali et al., 2014). Cold compression has also been utilised in the management of pain following chest trauma. In the study conducted by Bilalee et al., (2017), of which 81% of the patients had sustained blunt chest trauma, cold compression applied around the chest was reported by more than half of the participants to provide pain relief. Detail regarding how and when cold compression therapy was utilised was however not documented in the study.

2.3.2.4 Transcutaneous electrical nerve stimulation (TENS)

Transcutaneous electrical nerve stimulation (TENS) is a non-invasive electrotherapeutic modality used as an adjunct for pain control in various pain states (Sluka & Walsh, 2003; DeSantana et al., 2008; Sluka et al., 2013). Use of TENS therapy is via the application of electrical current through self-adhering conducting pads called electrodes placed on the skin. The parameters of amplitude, frequency and intensity of TENS may be adjusted dependent on the goal of therapy and patients' tolerance (Sluka & Walsh, 2003; Jones & Johnson, 2009). High-frequency TENS is frequently utilised in the management of pain at an intensity and frequency producing a non-painful paresthesia and is patient dependent (Sluka et al., 2013).

The mechanism of action by which TENS exerts its electro-analgesic therapeutic effects has been explained by the gate control theory of pain as established by Melzack &Wall in 1965 (Sluka & Walsh, 2003; Jones & Johnson, 2009). Transcutaneous electrical nerve stimulation is seen to generate nerve impulses that collide and extinguish noxiously induced impulses initiated from peripheral structures. Transcutaneous electrical nerve stimulation also induces activity in small diameter afferents leading to activation of descending inhibitory pathways

and inhibition of descending pain facilitatory pathways (Jones & Johnson, 2009). The effects of TENS is also mediated through many neurotransmitters, including opioids, serotonin, acetylcholine, norepinephrine, and gamma-aminobutyric acid (Jones & Johnson, 2009). The effect of TENS on primary afferent fibres as well as changes induced on autonomic activity may explain the mechanism of action by which TENS exerts its analgesic effects (Sluka & Walsh, 2003). Transcutaneous electrical nerve stimulation has been found to be effective in pain management in numerous pain settings.

Following thoracotomy, TENS used postoperatively together with postoperative medication, was found to be effective in reducing pain and improving capacity to cough during chest physiotherapy (Freynet & Falcoz, 2010). Positive effects were also noted on pulmonary ventilatory function specifically forced expiratory volume in the first second (FEV_1) and FVC. It was therefore concluded that TENS was effective in improving patient recovery after thoracic surgery.

Transcutaneous electrical nerve stimulation has also been seen to demonstrate positive outcomes following abdominal surgery when used as a supplement to pharmacological analgesia (Rakel & Frantz, 2003). Significantly reduced pain intensity during walking and deep breathing was reported following TENS intervention in comparison to placebo TENS and pharmacologic analgesia alone. Significant increases in the distance walked and walking speed was also noted following active TENS intervention. These improvements were attributed to TENS capacity for eliciting a reduction in hyperalgesia and movement-evoked pain (Rakel & Frantz, 2003). Positive effects on the outcomes of respiratory function as well as pain intensity were also documented in the study conducted by Jahangirifard et al., (2018). Transcutaneous electrical nerve stimulation used postoperatively following coronary artery bypass surgery in comparison to routine management, lead to statistically significant reductions in pain at rest and during coughing. In addition statistically significant improvements in pulmonary function (FEV_1 and FVC), and reduced narcotic use were also noted (Jahangirifard et al., 2018). As a result of pain relief induced following TENS application, increases in respiratory and physical capacity may therefore also be demonstrated following TENS use. Increased patient tolerance to other therapies and activities, with resultant improvements in QOL may also be observed after TENS therapy implementation (Sluka & Walsh, 2003).

With regards to TENS application in the management of rib fracture pain, TENS has been shown to be an effective, reliable and practical method in controlling pain following mild rib fractures in comparison to NSAID or placebo use (Oncel et al., 2002). Transcutaneous electrical nerve stimulation was found to be more beneficial than NSAIDs in the early and late post-traumatic period. Transcutaneous electrical nerve stimulation use was therefore advocated in the management of these patients due to its prominent and admirable efficacy in reducing pain.

In summary, TENS holds potential benefit in reducing pain and improving both respiratory and physical function.

2.3.2.5 Taping and strapping

Taping and strapping with various types of tape (rigid to more elastic tapes) and a variety of

taping techniques may be utilised for injury prevention, treatment, as well as rehabilitation. Taping can provide support and protection to soft tissue or joints following acute injury, as well as reduce swelling and pain (Kaur et al., 2016).

The mechanism by which tape may induce pain relief is via stimulation of cutaneous mechanoreceptors when applied, providing load and creating pressure or stretch to the skin which activates nerve impulses travelling to the CNS (Montalvo et al., 2014; Sarkar et al., 2018). Stimulation of these large-fibre cutaneous mechanoreceptors may lead to inhibition of nociceptive impulses in the spinal column and decrease pain via an ascending pathway (Montalvo et al., 2014). Elevation of the dermis created by the stretch applied when kinesiotaping is administered to the skin, reduces stimulation of the nociceptors and thus reduction in pain may occur (Kaur et al., 2016). In addition the convolutions formed during application of kinesiotape, which are raised ridges of tape and skin, are thought to decompress underlying structures, thereby forming an enlarged subcutaneous space allowing for enhanced circulation (Montalvo et al., 2014) as well as improved lymphatic drainage (Sareen et al., 2015). The lifting effect of the kinesiotape and creation of space may also assist in pain relief, reduce swelling as well as muscle spasm (Sareen et al., 2015).

Kinesiotape is a type of elastic tape widely used to facilitate pain management especially during physical activity in the sports and orthopaedic settings (Montalvo et al., 2014). Kinesiotaping can however be utilised in various clinical settings and can be used for biomechanical correction as well as pain relief (Kaur et al., 2016). Via provision of support to injured or overused muscles musculoskeletal pain may be reduced (Banerjee et al., 2016). Few studies have however been conducted reviewing taping application and use in pain relief following rib fractures.

In the study conducted by Wu et al., (2015), surgical intervention was compared to conservative management with strapping following multiple rib fractures. Surgical intervention lead to a greater reduction in pain over the eight weeks of assessment in comparison to the non-operative group. Strapping intervention utilised was however poorly described with regards to method and application of strapping, type of strapping applied and duration of use (Wu et al., 2015). Granetzny et al., (2005), through a prospective randomised comparative study, reviewed treatment of flail chest injury via operative and non-operative means. A non-surgical method of packing and strapping in the form of dressing and fixing with elastoplast, applied adhesively to the flail segment was compared to surgical intervention via wiring following flail chest injury. This non-surgical strapping method was found to be disadvantageous as ventilation and expansion of the thorax was reduced by limitation of thoracic movement by the strapping. In addition the authors noted that this application would be limited by the location of the rib fractures. The taping application (tape placement and how applied) as well as tension applied to the tape (percentage of support or complete immobilisation) was also poorly described in these studies. In comparison Sareen et al., (2015) reviewed the immediate effect of kinesiology taping in the treatment of undisplaced middle rib fracture pain. Application was carried out at a specified kinesiology taping institute and ten patients were reviewed retrospectively. Kinesiology taping, a more elastic taping was utilised in the management of these patients in comparison to the studies reviewed above. Kinesiology taping was selected as the preferred application material as rigid taping or tight wrap although assisting in provision of support and stabilisation to the chest wall, was thought to restrict movement and limit the patients ability to breathe deeply. Kinesiology taping application as well as method of evaluation was well documented in this study. Results

showed that following tape application immediate statistically significant reductions in pain during deep breathing and coughing were noted ($p < 0.00$). Although the study conducted by Sareen et al., (2015) was not conducted in an acute care setting, patients with undisplaced rib fracture greatly benefited from kinesiotape application. Limitation to the study and interpretation of results included a small population size, only immediate effects of taping were noted and only inclusion of undisplaced middle rib fractures was included with no control group. Additional studies in other populations reviewed have also shown increased thoracic and respiratory benefits following tape application. Imperatori et al., (2016), noted a reduction in chest pain after lobectomy for lung cancer resection following kinesiology taping application. Imperatori et al. (2017) also concluded that immediately after tape application following thoracotomy and lobectomy for pulmonary malignancy, significant improvements in inspiratory volumes were achieved in comparison to the control group.

Elastic tapes such as kinesiotape, according to studies conducted by Sareen et al., (2015) and Imperatori et al., (2016) show promising results with regards to its use for pain relief following rib fractures and following post-operative thoracic surgery. More rigid tapes and strapping however appear to limit thoracic movement and expansion and may thus lead to respiratory complications (Wu et al., 2015).

Elastic taping therefore appears to offer possible benefit as a non-pharmacological therapeutic intervention with regards to its use for both pain relief and improvement induced in respiratory function.

2.4 Impact of rib fracture injuries on physical function

Pain following rib fractures gives rise to sleep disturbances and altered daily activities in more than 90% of patients, as documented in the study conducted by Bilalee et al., (2017). Pain emanating from rib fractures may thus influence physical function and capacity to move and perform functional activities. Physical limitation was also noted in the study conducted by Kerr-Valentic et al., (2003) in which rib fracture pain was reported to be aggravated by any movement of the chest wall. From this one can deduce that any movement involving use of the trunk for example rolling to side-lying, sitting up over the edge of the bed or mobilising to a chair could prove to be exceptionally painful, and may be limited or impossible for a patient presenting with severe pain following rib fractures.

Pain therefore inhibits a patient's ability to mobilise and may result in longer periods of bedrest. Prolonged bedrest increases the risk of immobility associated complications which can give rise to severe and adverse side effects (Sinatra, 2010). These side effects and complications include development of pressure ulcers, muscle wasting, reduced respiratory capacity, rapid reductions in bone mineral density as well as muscle mass (Parry & Puthucheary, 2015). Dehydration, cardiac deconditioning, increased risk of thromboembolic events, insulin resistance as well as the development of delirium or cognitive processing impairments have also been associated with prolonged periods of immobility (Knight et al., 2009 part 1; Parry & Puthucheary, 2015). These impairments in the various body systems may become evident within the first week of bed rest, and are exacerbated in individuals with critical illness resulting in profound physical deconditioning (Gosselink et al., 2011; Parry & Puthucheary, 2015).

The evidence thus advocates that therapeutic strategies to enable early rehabilitation and physical activity need to be instituted in the critical care setting, with emphasis on physical activity being an important component of regular care (Parry & Puthucheary, 2015). The ability to mobilise thus becomes an important intervention so as to avoid neuromuscular dysfunction associated with bedrest (Hashem et al., 2016). Tools utilised to assess physical function as well as interventions utilised to improve physical function such as mobilisation will now be reviewed.

2.4.1 Tools used to assess physical function in patients with acute rib fractures

Outcome measurement tools commonly utilised in the acute care setting to evaluate patients' level of function include: the Barthel Index, Chelsea Critical Care Physical Assessment (CPAx), the Functional Independence Measure (FIM) and the Functional Status Score for ICU (FSS-ICU) (Christakou et al., 2013; Van Aswegen & Morrow, 2015; Huang et al., 2016; Parry et al., 2017). These scales may be appropriate for evaluation and use in assessment of function in patients following rib fractures or flail chest injuries. Each scale will briefly be reviewed.

2.4.1.1 FSS-ICU

The FSS-ICU is utilised for in-patient rehabilitation in ICU and includes five functional tasks for evaluation (rolling, transfer from supine to sit, sitting at the edge of bed, transfer from sit to stand, and walking). Each category is rated on an ordinal scale using a 1 (total dependent assistance) to 7 (complete independence) scale to obtain a total score ranging from 0-35, with higher scores indicating better physical functioning (Christakou et al., 2013; Huang et al., 2016). The FSS-ICU has been shown to be internally consistent, valid and a responsive measure of physical function in the ICU and acute hospital ward setting (Huang et al., 2016).

2.4.1.2 CPAx

The CPAx is a measurement tool used to assess physical function of patients in the ICU setting. It consists of assessment of 10 domains of physical activity including respiratory function, cough, bed mobility, supine to sitting on the edge of the bed, dynamic sitting, sit to stand, standing balance, transfer from bed to chair and stepping and grip strength, graded on a six point scale from 0 (dependent) to 5 (independent) and scored out of a total of 50 (Corner et al., 2013). The CPAx tool is considered a reliable and valid measure of physical function in ICU patients and has the potential to act as a predictor of functional outcome in the ICU population (Corner et al., 2010).

2.4.1.3 Functional Independence Measure (FIM)

The FIM is the most widely accepted functional assessment tool used for assessing basic functional activities of ICU patients and their progress during in-patient rehabilitation (Christakou et al., 2013). Two separate domains of items comprise the motor domain consisting of 13 items and the cognitive domain consisting of 5 items. The FIM is a multi-dimensional measure which assesses self-care, sphincter control, transfers, locomotion,

communication, and social cognition in addition to cognitive and motor sub-scales. Functional independence measure scores range from 1 to 7; a FIM item score of 7 is categorized as "complete independence," while a score of 1 is "total assistance" (Christakou et al., 2013).

2.4.1.4 Barthel Index

The Barthel Index is utilised to measure physical functioning and measures the capacity to perform 10 basic activities of daily living (feeding, grooming, bathing, dressing, bowel and bladder care and toilet use) and mobility (ambulation, transfers and stairs climbing). It provides a quantitative estimation of the patient's level of dependency with scoring from 0 (totally dependent) to 100 (totally independent). The range of the Barthel index is described by classifying the patients as having minimal or no disability (BI score, >90), moderate disability (BI score, 55–90) or severe disability (BI score <55). This tool has been reported to have high reliability (Christakou et al., 2013).

2.4.2 Interventions used to manage physical function of patients with acute rib fractures

2.4.2.1 Multidisciplinary care bundles

Care bundles are defined as a small set of evidence-based interventions for a defined patient population and care setting, that when implemented together result in significantly improved outcomes than when implemented separately (Resar et al., 2012). Effective and consistent multidisciplinary communication and collaboration are deemed essential in care bundle implementation (Salmond et al., 2017). Clinical pathways are utilised for specific well-defined groups of patients during a specified time period and are patient-care driven management procedures (De Bleser et al., 2006). Pathway goals and key elements of clinical pathways are based on evidence-based medicine and best practice guidelines. Care pathways aim to improve quality of care, reduce risks, increase the efficiency of resource usage as well as increase patient compliance and satisfaction (Sesperez et al., 2001; De Bleser et al., 2006).

Clinical pathways and care bundles have been successfully utilised and recommended for use in the management of various health conditions, including the prevention of ventilator associated pneumonia and pressure ulcers in patients in the ICU setting (Hellyer et al., 2016; Lavallée et al., 2017). In addition care bundles and clinical pathways have been utilised in the management of patients with blunt chest trauma and rib fractures to direct management and standardise care implemented in an attempt to improve and provide more consistent outcomes (Sesperez et al., 2001; Kourouche et al., 2018). Various modalities and interventions may be included in care bundles and clinical pathways dependent on the population or condition under review. In their integrative appraisal of the literature Kourouche et al., (2018) aimed to identify and establish critical components for blunt chest injury care bundles. Respiratory support (using positive-airway-pressure devices) and multimodal analgesia were considered critical components of care following blunt chest trauma. In addition complication prevention strategies including chest physiotherapy and surgical fixation were also identified as key elements of the blunt chest injury care bundle (Kourouche et al., 2018). Components of complication prevention strategies included in the blunt chest injury care bundle advocated use of chest physiotherapy as well as active deep breathing and coughing techniques to be

utilised in the management of all blunt chest trauma patients. These components of bundled care were deemed effective in optimising outcomes in patients following blunt chest injury (Kourouche et al., 2018).

Implementation of care bundles in the management of patients following chest trauma have demonstrated positive outcomes in various studies with regards to incidences of pneumonia and LOS (Todd et al., 2006; Curtis et al., 2016). In the study conducted by Todd et al., (2006), the effect of clinical pathway implementation in patients greater than 45 years of age with more than four rib fractures found an associated reduction in ICU and hospital LOS as well as reduced incidence of pneumonia and mortality rate following pathway implementation. Multidisciplinary pathway implementation involved directed intervention from respiratory therapy, pain control, physical therapy, and nutrition services (Todd et al., 2006). Pain control was deemed essential to maximise tolerance to other specified components of care including physiotherapy intervention (Todd et al., 2006). A multi-disciplinary team approach is thus considered a vital component in care bundles and clinical pathways utilised in the management of patients following acute rib fractures (Sesperez et al., 1999; Todd et al., 2006; Witt & Bulger, 2017; Salmond et al., 2017). Physiotherapy often forms part of clinical pathways instituted in the management of patients with blunt chest trauma and rib fractures (Todd et al., 2006; Sahr et al., 2013; Kourouche et al., 2018). Modalities implemented and utilised by physiotherapists in the treatment of these patients will now be reviewed and discussed in detail.

2.4.2.2 Physiotherapy techniques

Physiotherapists aim to assist and alleviate pain associated with joint stiffness as well as muscle spasm, and rehabilitate patients to their highest level of functional independence as they recover from traumatic injury. Physiotherapy in the trauma context aims to aid restoration of mobility, normalise gait patterns and assist postural re-education within the context of the injury sustained. Maintenance and improvement of muscle strength and restoration of full joint and muscle length to pre-injury status are vital components of management (Van Aswegen & Morrow, 2015).

Respiratory management aims to assist with facilitation of early weaning (that is weaning the patient as soon as medically stable and weaning criteria have been met) from MV for intubated patients, as well as aids in the removal and clearance of excess bronchial secretions in order to prevent secondary chest infections from developing. Physiotherapists in this setting also assist with the prevention and resolution of pulmonary complications utilising appropriate therapeutic techniques and interventions. Management additionally intends to improve the patient's pattern of breathing as well as reduce the work of breathing and ensure adequate ventilation of all lung areas (Van Aswegen & Morrow, 2015).

Physiotherapy in both the acute and subacute stages following traumatic injury should prioritise early mobilisation as part of management as soon as the patient is medically stable. Early mobilisation has been identified as a critical component of care in the management of all patients with blunt chest wall trauma including those who are mechanically ventilated (Battle et al., 2013). In addition, physiotherapy intervention including mobilisation have been identified as an important component of bundled care pathway intervention following blunt chest trauma (Kourouche et al., 2018). The benefits of mobilisation contribute to

improvement and prevention of complications in many aspects of the patients' recovery. Physiotherapists in the acute care setting may also lead to improvement in patient's overall well-being by providing emotional support and improving communication (Gosselink et al., 2011).

Physiotherapy techniques utilised in the management of patients following rib fractures in the acute care setting will now be reviewed.

2.4.2.2.1 Respiratory Physiotherapy techniques

As has already been highlighted, respiratory compromise is a major factor contributing to morbidity and mortality following acute rib fractures especially when multiple in nature (May et al., 2016). Pain and inadequate respiratory efforts following multiple rib fractures and flail chest injuries increase the patients vulnerability to atelectasis and together with a decrease in the ability to clear secretions, respiratory function is further compromised (Ahn et al., 2013). In addition the risks of respiratory complications are increased in patients subject to prolonged periods of bedrest and immobility as a result of traumatic injuries. Impairment of coughing and stagnant mucus as a result of immobility and traumatic injury increases the risk of respiratory infection in these patients (Knight et al., 2009).

Physiotherapists may make use of various techniques in the prevention, management and treatment of respiratory complications in this patient population. These techniques may collectively be referred to as "chest physiotherapy" or "respiratory physiotherapy" and intervention selection is based on thorough examination of the patient and their presenting condition (Van Aswegen & Morrow, 2015). Accurate, reasoned assessment and evaluation of the patients presenting respiratory condition as well as review of overall deconditioning and related complications is of paramount importance for physiotherapists to consider in the ICU setting. Evaluation of these factors guides and directs appropriate intervention selection. Techniques or interventions that may be utilised by respiratory physiotherapists in the management of trauma patients may include one or a combination of the following interventions; breathing exercises, respiratory muscle retraining, incentive spirometry, positioning as well as manual chest physiotherapy techniques (chest wall percussion, vibration and shaking). Body positioning for postural drainage and ventilation perfusion matching may also be utilised, aiding in the maintenance and improvement of pulmonary hygiene. Airway humidification to improve mucociliary function, together with enhancement of the patients cough effort, can also be utilised to facilitate secretion clearance and assist in reducing the risk of secondary chest infections. Suctioning to clear excessive bronchial secretions may also be used as part of physiotherapy management (Van Aswegen & Morrow, 2015). Exercise therapy together with early mobilisation has also been identified as important therapeutic components of physiotherapy rehabilitation (Van Aswegen & Morrow, 2015).

2.4.2.2.2 Mobilisation

Critically ill patients often have limited activity as a result of their injuries or as a result of attachments to various monitors and the mechanical ventilator or due to pharmacological side effects. Bed rest and immobility are thus common consequences following traumatic injury. This inactivity may lead to deconditioning, increased risk of infections as well as rapid

skeletal muscle atrophy with resultant weakness which may occur throughout the body (Knight et al., 2009 part 1; Zomorodi et al., 2012). Physical deconditioning has been reported to occur within a few days of stay in the ICU (Zomorodi et al., 2012).

From these adverse effects associated with bedrest and immobility, the importance of early mobilisation and its benefits becomes clearly apparent. Mobilisation and rehabilitation are thus valuable interventions utilised to avoid the sequela associated with prolonged bed rest and immobility in the critically ill (Hashem et al., 2016).

Physiotherapists are involved in the evaluation and implementation of mobilisation as part of treatment in the acute care setting (Stiller et al., 2013; Pathmanathan et al., 2015). Mobilisation as described by Gosselink et al. (2011) refers to "physical activity sufficient to elicit acute physiological effects that enhance ventilation, central and peripheral perfusion, circulation, muscle metabolism, and alertness" (p.69). Mobilisation may involve a number of progressive interventions including: passive and active turning and moving in bed, active-assisted and active exercises as well as mobilisation out of bed (Pathmanathan et al., 2015). Progressive mobilisation strategies may include transferring in bed, sitting over the edge of the bed, moving from bed to chair, standing, stepping in place, walking with or without support and sitting out of bed in a chair (Zafiropoulos et al., 2004; Gosselink et al., 2011). Duration or number of steps next to the bed or away from the bed may also be progressed depending on the patient's tolerance.

With regards to the effects of mobilisation on respiratory function, in the study conducted by Zafiropoulos et al., (2004) mobilisation of intubated patients into standing following abdominal surgery produced significant increases in tidal volumes. In addition, mobilisation resulted in significant increases in rib cage displacement when compared with supine baseline values (Zafiropoulos et al., 2004). Positioning and mobilisation may thus assist in optimising oxygenation by enhancing alveolar ventilation and reducing ventilation/perfusion mismatch by using gravity dependency to assist alveolar recruitment and lung perfusion (Pathmanathan et al., 2015).

Early mobilisation of mechanically ventilated patients in the ICU setting has additionally been shown to lead to reductions in ICU LOS and duration of MV. This was shown in the systematic review conducted by Zhang et al., (2018) on the effects of early mobilisation in this population. Early mobilisation is thus deemed a critical intervention that leads to enhancement of functional status, promotes recovery and decreases hospital LOS, as well as morbidity and mortality (Zomorodi et al., 2012). Early progressive mobilisation in the ICU setting has been found to be both feasible and safe, resulting in significant functional benefits. These functional gains may lead to positive outcomes on ICU and hospital LOS (Stiller, 2013). In the systematic review conducted by Tipping et al., (2017) reviewing the effects of active mobilisation and rehabilitation in ICU on mortality and function, active mobilisation and rehabilitation was shown to have no effect on patient mortality, but lead to improved body function (muscle strength) at ICU discharge, reduced activity limitations at hospital discharge and reduced participation restriction at six months.

In summary, mobilisation may hold potential as a non-pharmacological therapeutic intervention which may influence both physical and respiratory function based on the literature reviewed. In addition early mobilisation together with optimal pain relief and

effective respiratory support has been identified as key components of care in blunt chest trauma management (Battle et al., 2013).

2.4.2.2.3 Deep breathing exercises (DBE's)

Deep breathing exercises have positive effects on respiratory function in various patient populations, including those who are post-surgical as well as those with lung disease (Westerdahl et al., 2003; Cecily & Alotaibi, 2013; Tripathi & Sharma, 2017). The aims of DBE's implemented by physiotherapists are to achieve maximal inspiration and so re-expand collapsed alveoli or prevent atelectasis from occurring. Deep breathing exercises may thus result in increased alveolar recruitment, tidal volumes, functional residual capacity and oxygenation, as well as aid the removal of airway secretions (Pathmanathan et al., 2015).

Reductions in atelectatic lung regions as well as improvement in aeration and oxygenation have been documented post deep breathing exercise (DBE) implementation in cardiac surgery patients (Westerdahl et al., 2003). To facilitate these effects of DBE's following rib fractures, adequate pain control is however necessary to allow for tolerance to these interventions (Unsworth et al., 2015).

Breathing techniques utilised by physiotherapists in the acute care setting may include ACBT which incorporates the forced expiratory technique (FET). Breathing techniques such as ACBT may be implemented following rib fractures to facilitate recruitment of alveoli and prevent the onset of respiratory complications. These breathing exercises are airway clearance techniques utilised to promote clearance of excess secretions from the airways, and improve lung volumes (Lewis et al., 2012: Van Aswegen & Morrow, 2015). The FET consists of one to two forced expirations or low to high volume huffs, followed by breathing control (relaxed breathing). The FET is a vital component in a cycle of ACBT together with thoracic expansion exercises, interspersed with periods of breathing control (Pryor & Webber, 1998; Lewis et al., 2012). Forced expiratory technique (huffing between low and high volumes) is thought to promote secretion clearance by changes in thoracic pressures and altered airway dynamics (Pryor & Webber, 1998). The number and frequency of each component of the ACBT may be tailored and adapted for use in any patient where excess bronchial secretions are present, but all components of the cycle should be utilised and interspersed with breathing control (Pryor & Webber, 1998; Lewis et al., 2012). Breathing control assists in preventing desaturation and bronchospasm whereas thoracic expansion exercises assists in the recruitment of collateral ventilation, as well as loosening and clearance of secretions (Pryor & Webber, 1998; Lewis et al., 2012). Forced expiratory technique and ACBT may be utilised to enhance secretion clearance and can be used with or without assistance or as a self-treatment on discharge (Pryor & Webber, 1998; Lewis et al., 2012).

In addition to DBE's, incentive spirometers which are mechanical breathing devices may be utilised to facilitate increases in lung volumes in spontaneously breathing patients (Van Aswegen & Morrow, 2015). Incentive spirometry devices work by encouraging patients to achieve either a preset volume or flow. Patients are encouraged to take long, slow deep breaths to achieve a sustained maximal inspiration. The incentive spirometer gives visual feedback with regards to the volume or flow attained, thus providing motivation and encouragement to patients to practice deep breathing (Pryor & Webber, 1998; Restrepo et al., 2011; Van Aswegen & Morrow, 2015). During incentive spirometry expansion of the lower

chest is encouraged to ensure an adequate breathing pattern is executed (Pryor & Webber, 1998; Singh et al., 2017). Incentive spirometry has been utilised in a number of patient populations in an attempt to improve pulmonary volumes and prevent associated respiratory complications (Restrepo et al., 2011). Incentive spirometry has been documented to be successfully used in the management of patients with multiple rib fractures, provided adequate analgesia is given (Easter, 2001; Unsworth et al., 2015).

In the systematic review conducted by Carvalho et al. (2011), these authors however documented that no evidence was found supporting the use of incentive spirometry in the management of surgical patients in the prevention of postoperative pulmonary complications and recovery of pulmonary function. In contrast, Singh et al. (2017) found that incentive spirometry was an effective conservative treatment protocol after bilateral total knee replacement surgery in improving total lung capacity and breath-holding time (a semi-objective measure which may indicate a direct relationship between the resting $PaCO_2$, with breath holding time increasing as the breathing pattern becomes more regular and stable). In a clinical practice guideline reviewing incentive spirometry use, recommendation was made that incentive spirometry not be routinely used or used in isolation in the pre or post-operative setting (Restrepo et al., 2011). Furthermore it was recommended that incentive spirometry be used in combination with deep breathing techniques, directed coughing, early mobilisation, and optimal analgesia in the prevention of postoperative pulmonary complications (Restrepo et al., 2011).

Non-pharmacological therapeutic interventions have thus been reviewed relative to management interventions directed at acute pain and compromise to physical function. Chronic impairments may also be evident following rib fractures and these will be reviewed next.

2.4.3 Quality of life of patients with rib fractures and hospital re-admission rates

Chronic pain, increasing disability levels and reduced QOL are some of the reported long term complications which may ensue following rib fractures. These manifestations may often present following poor initial acute pain management giving rise to chronic long term impairments and disability (Kerr-Valentic et al., 2003; Fabricant et al., 2013). Pain has been identified as one of the most important determinants of QOL (Katz, 2002). Ongoing or poorly managed pain can adversely affect all aspects of function including mood, ability to perform activities of daily living, as well as diminish productivity. These consequences result in high costs associated with pain management in the healthcare setting (Katz, 2002). In the population of patients having sustained rib fractures, QOL is negatively impacted following injury.

In the study conducted Kerr-Valentic et al., (2003) patients with rib fractures were reviewed and pain and disability levels were evaluated up to 120 days post injury. Results indicated substantial loss in days missed from work and resultant productivity. The critical effect of rib fractures on disability levels was demonstrated by those patients with isolated rib fractures who were unable to return to work or usual activity for an average of 50 days. In addition patients with rib fractures were found to be significantly more disabled at 30 days than the reference population with chronic illness (Kerr-Valentic et al., 2003). Fabricant el al., (2013) reviewed patients for two months after having sustained rib fractures with results revealing

that 59% of patients still experienced prolonged chest wall pain and 76% had prolonged disability. One of the most predictive indicators of prolonged pain and disability was found to be the pain intensity experienced within the first few days following injury (Fabricant et al., 2013).

Gordy et al., (2014) reviewed patients at six months following rib fractures and found a significant portion of patients still experienced considerable chest wall pain. Of these patients 22% of patient's experienced chronic pain, and 53% chronic disability, measured via diminished work or functional capacity (Gordy et al., 2014). Güngör et al., (2017) reviewed blunt minor thoracic trauma of which rib fractures constituted the most frequent thoracic injury. Pain intensity as well as ongoing pain appeared to be more influential on re-admission rates than patients' diagnoses. Severe and long-lasting pain was identified as the main determinants of hospital re-admissions in this population.

Prolonged pain and disability therefore appear to be commonly encountered complications following rib fractures (Fabricant et al., 2013; Pharaon et al., 2015). Various authors have reviewed the possible association between acute pain control in the initial days following injury and prediction and subsequent progression to chronic pain states (Fabricant et al., 2013; Gordy et al., 2014).

Consideration has been given to the theory that if pain were better controlled in the initial acute stages following injury, reduced risk of sensitisation of neurons may occur, with reduced risk of chronic pain ensuing (Fabricant et al., 2013). Gordy et al., (2014) established that the severity of acute pain experienced within the first two weeks following injury was predictive of chronic pain development. This author also concluded that bilateral rib fractures were also predictive of chronic disability development (Gordy et al., 2014). Thus following review of the literature, if acute pain is managed and controlled effectively from initiation, this may potentially lead to a reduction in the progression to chronic pain states (Sinatra, 2010; Fabricant et al., 2013).

2.5 Summary of main findings of this chapter

The aim of this chapter was to provide a thorough background and foundation regarding the main presenting symptoms following rib fractures and associated complications and underlying injuries which may present and impact management.

The importance of early optimal pain management was highlighted, and the dire effects of pain and its debilitating consequences on function, recovery and QOL were evaluated. Pain was identified as the most limiting symptom that presents following acute rib fractures. Pain is the component of care that, if not managed appropriately, impacts respiratory function the most significantly and may result in life threatening pulmonary complications if not adequately controlled. In addition, uncontrolled pain negatively impacts function (physical, respiratory and psychological) as well as implementation of interventions and rehabilitation deemed essential in management.

Overall medical management of patients following rib fractures in the acute care setting was also reviewed providing a holistic outline of the management of these patients in this setting.

Non-pharmacological therapeutic interventions were identified and discussed in detail, providing an overview of possible interventions available for use following rib fractures. The mechanism by which these interventions work were also reviewed and the populations in which positive effects were achieved with use of these interventions was highlighted.

The available research reviewed points towards current voids in acute care management of pain in patients following rib fractures especially from a non-pharmacological therapeutic interventions perspective. Many authors have made clear reference to the fact that gaps exist in pain management in this population and capacity for improvement in pain management strategies following rib fracture injury is greatly needed (Easter, 2001; Ker-Valentic et al., 2003; Fabricant et al., 2013; Curtis et al., 2016).

Chapter three will review the methodology followed to conduct this systematic review and meta-analysis.

CHAPTER 3: METHODOLOGY

This systematic review follows the Joanna Briggs Institute (JBI) Systematic Review Methodology outlined in the JBI Reviewers' Manual (The Joanna Briggs Institute, 2014; Aromataris & Munn, 2017).

This systematic review was registered with the international Prospective Register of Systematic Reviews (PROSPERO) (reference number CRD42018089060). In addition it was also registered with JBI (reference number JBISRIR-2017-003600).

3.1 Type of study:

This is a systematic review of quantitative evidence. The systematic review conducted is a systematic review of effectiveness, and meta-analysis was performed.

3.1.1 Methodological discussion

This type of study methodology is considered worthwhile to conduct as systematic reviews and meta-analysis are considered to provide the highest level of evidence (Impellizzeri & Bizzini, 2012). Systematic reviews synthesize results from all available studies for a specific focus or field of interest, providing a comprehensive analysis of these results thereby making the latest available evidence more accessible (Gopalakrishnan & Ganeshkumar, 2013). Systematic reviews and meta-analyses are considered important in healthcare settings as clinicians frequently make use of systematic reviews to keep up-to-date with evidence based practice. Additionally systematic reviews and meta-analyses are often used as an initiation point for developing clinical practice guidelines and can also demonstrate where knowledge is lacking, guiding future research (Gopalakrishnan & Ganeshkumar, 2013).

3.2 Inclusion Criteria

3.2.1 Type of participants

The current review considered all studies with patients aged 18 years or older (male and female) who were admitted to an acute care setting (intensive care unit, high care unit or ward) with rib fractures (simple, multiple or flail chest injury) that were confirmed radiologically. The rib fractures must have been sustained via blunt thoracic trauma and patients must have been able to describe and evaluate their pain.

Studies were excluded if patients were admitted with penetrating chest wall trauma, possessed co-morbidities preventing physical activity or mobilisation such as acute spinal cord injury, polytrauma (including complex lower limb & orthopaedic injuries) or traumatic brain injuries.

Studies were also excluded if patients were pregnant, suffered from any psychiatric illness (dementia or delirium) or had abdominal or cranial surgeries. Studies were also excluded if the primary outcomes or secondary outcomes specified for analysis in the review were not measured or evaluated.

3.2.2 Types of Interventions

This review considered non-pharmacological interventions used to treat patients following acute rib fractures. The non-pharmacological interventions evaluated were those modalities utilised by health care professionals in the management of pain and restoration of physical function in patients with rib fractures. Interventions considered for the management of pain included, but were not limited to, transcutaneous electrical nerve stimulation (TENS), acupuncture, and taping. Interventions considered and included for physical function included, but were not limited to, incentive spirometry, multidisciplinary clinical pathways, mobilisation and respiratory physiotherapy techniques including ACBT.

3.2.2.1 Comparators

The review considered studies with no comparison group, a passive comparison e.g. standard care management with analgesia or an active comparison e.g. an alternative intervention group where a different modality was included.

3.2.3 Outcomes

The review considered studies with primary outcomes of pain and physical function.

Studies were included in the review when methods in the sourced literature indicated how pain and/or physical function were assessed or measured.

The following primary outcomes were considered:

- Pain as could be measured by (but not limited to): the visual analogue scale, numeric pain rating scale, Wong-Baker Faces Pain rating scale, McGill Pain Questionnaire, etc.
- Physical function as could be measured by (but not limited to): the Functional Status Score of Intensive Care Unit (FSS-ICU), Chelsea Critical Care Physical Assessment (CPAx) tool, Functional Independence Measure, Barthel Index, etc.

In addition, secondary outcomes considered included:

- Intensive care unit (ICU) or hospital LOS.
- Incidence of respiratory or pulmonary complications, e.g. pneumonia, atelectasis and ARDS.
- Respiratory function such as peak expiratory flow rate (PEFR), forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), functional residual capacity (FRC), maximal inspiratory pressure (MIP), Maximal expiratory pressure (MEP), total lung capacity (TLC).
- Hospital re-admission rates due to pain or limitation in physical function as a result of blunt thoracic chest trauma pain.
- Outcomes related to QOL following traumatic blunt thoracic chest trauma.

3.2.4 Types of studies

This review considered all quantitative study designs and included randomised controlled trials as well as observational study designs including prospective and retrospective cohort studies, and analytical cross sectional studies.

Additionally, the review included descriptive epidemiological study designs including case reports. Systematic review and research syntheses, together with text and opinion studies were considered for narrative synthesis to report on current best evidence.

The JBI reviewers' manual (Aromataris & Munn, 2017) advises that inclusion of all quantitative study designs including RCT's, experimental studies and cohort studies, both prospective and retrospective allows for examination of the totality of empirical evidence. This is considered the most inclusive approach according to the manual, providing invaluable insights regarding the agreement or disagreement of the results from differing study designs.

3.3 Search Strategy

The search strategy aimed to find published studies written in English or translated into English from the year 2000 of the named search engines until December 2017. The databases included and searched were MEDLINE using PubMed, EMBASE, PsycINFO, Scopus, CENTRAL, CINAHL Plus and PEDro. The following unpublished databases and trial registries were also searched: Google Scholar, OpenGrey (SIGLE), Cochrane Library and the International prospective register of systematic reviews (PROSPERO). The specific search time frame was utilised as early trauma management has changed significantly over the last 20 years and advances in the management and treatment of trauma patients have consequently been made (Cohen et al., 2004; Hussmann & Lendemans, 2014; Unsworth et al., 2015).

The PubMed Medical Subject Headings (MeSH) database was utilised to determine and establish all specific terms and vocabulary used for each component of interest searched. This was to establish all possible synonyms and alternate forms of the relevant search words and strings prior to the formal search commencing. This was to ensure a comprehensive search relevant to the key terms was implemented. The MeSH terms established and searched can be viewed in the search strings provided in the final PubMed database search in Table 3.1.

A three-step search strategy was utilised in this review. An initial limited search of Medline (PubMed), CINAHL and PEDro databases using initial keywords was undertaken with the aim of identifying all possible keywords from the text contained in the title and abstract and retrieved from the literature, and of index terms used to describe the article. A second extensive search using all keywords identified and index terms were carried out across all included databases. Thirdly, the reference list of all identified literature was searched for additional studies not previously identified during the first or second search strategies. A preliminary search strategy for the PubMed database is provided in Table 3.1.

The extensive search strategy thus included keywords and MeSH terms relating to traumatic rib fractures, physical function, acute pain/ pain and respiratory function. These keywords and MeSH terms were searched utilising "all fields" search function. The search filters utilised for all search strategies included: publication date from 2000/01/01 to 2017/12/31; humans;

English language and adult: 19+ years (where 18 years and older filter was not available for selection). The main search strategies implemented were as per search strings #1 to #6 as represented in Table 3.1. Additional keywords and search combinations examined can be reviewed in appendix B Table 1.

Table 3.1: Preliminary search strategies for PubMed

Search	PubMed syntax	(N) Number retrieved
#1	(Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’) Filters: Adult: 19 + years	2354
#2	(((((Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’)) AND adult[MeSH])) AND Pain) OR ‘‘Acute Pain’’ Filters: Adult: 19+ years	325
#3	((((Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’)) AND adult[MeSH])) AND (‘‘Physical Function’’ OR ‘‘Physical Activity’’ OR Mobility OR Exercise OR ‘‘Functional Activity’’ Of Function OR ‘‘Activities of daily living’’) Filters: Adult: 19+ years	171
#4	((((Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’)) AND adult[MeSH])) AND (‘‘Respiratory Function’’ OR ‘‘Pulmonary Function’’ OR Ventilation OR ‘‘Respiratory Status’’ OR ‘‘Pulmonary Status’’) Filters: Adult: 19+ years	200
#5	(((((Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’)) AND adult[MeSH])) AND (Pain OR ‘‘Acute Pain’’)) AND (‘‘Physical Function’’ OR ‘‘Physical Activity’’ OR Mobility OR Exercise OR ‘‘Functional Activity’’ Or Function OR ‘‘Activities of daily living’’) Filters: Adult: 19+ years	24
#6	(((((((Rib Fracture* OR ‘‘Flail Segment’’ OR ‘‘Flail Chest’’ Or ‘‘Thoracic Injur*’’ OR ‘‘Chest Injur*’’ OR ‘‘Chest Trauma’’ OR ‘‘Thoracic Trauma’’ OR ‘‘Blunt Chest Trauma’’ Or ‘‘Blunt Thoracic Trauma’’)) AND adult[MeSH])) AND (Pain OR ‘‘Acute Pain’’)) AND (‘‘Physical Function’’ OR ‘‘Physical Activity’’ OR Mobility OR Exercise OR ‘‘Functional Activity’’ Or Function OR ‘‘Activities of daily living’’)) AND adult[MeSH])) AND (‘‘Respiratory function’’ OR ‘‘Pulmonary Function’’ OR Ventilation OR ‘‘Respiratory Status’’ OR ‘‘Pulmonary Status’’) Filters: Adult: 19 +years	7

In addition to the initial publication period reviewed, an updated search using PubMed was conducted on the 4 June 2020, for the period between 1 January 2018 to 31 May 2020, to source any additional recent studies for inclusion in this study.

3.4 Assessment of methodological quality

Titles and abstracts of all records retrieved were screened for inclusion by the two reviewers (BW) and (RR). Selected titles and abstracts were screened against eligibility criteria by both reviewers (BW) and (RR). A list was compiled of articles for full text review and retrieval. Full text articles selected for retrieval were assessed and reviewed by two reviewers (BW) and (RR). Relevant articles were evaluated by these two reviewers independently for methodological validity prior to inclusion in the review. Standardised appraisal instruments from the JBI System for the Unified Management, Assessment and Review of Information (JBI SUMARI) were utilised. Any disagreements that arose between the reviewers were resolved through discussion with a third reviewer (HvA).

The JBI is an international collaborative supporting evidence-based practice in the medical field and has been in existence since the institute's inception in 1996. The JBI critical appraisal tool developed by JBI and its collaborators has been approved by the JBI Scientific committee following extensive peer review (JBI, 2018). These standardised critical appraisal tools developed by JBI were selected and utilised for appraising the selected articles dependent on the design of the included study (JBI, 2017).

Each appraisal instrument has specific questions that direct the appraisal process and are specific to the study design selected as summarised in Table 3.2. Study specific questions were answered by each reviewer based on the answer options provided by the appraisal tool: yes, no, unclear or not applicable (N/A). Each study was appraised individually by each reviewer and a final result of include or exclude was provided by each reviewer. The reviewers then met after individual appraisal to discuss results and decide on the final studies to be included in the extraction process. For inclusion following critical appraisal, studies must have included evaluation of the primary and/or secondary outcomes relative to implementation of non-pharmacological therapeutic interventions following acute rib fractures. Additionally, documentation of these outcomes (primary/secondary) relative to the intervention under review must have been evaluated and recorded. Any discrepancies between the two reviewers' decisions was reviewed and discussed with the third reviewer (HvA). This specific approach was followed for appraisal of the randomised controlled trials, case reports, analytical cross sectional studies, cohorts, text and opinion as well as systematic review and research syntheses included for review.

Table 3.2: Description of appraisal tools relative to the study design.

Study Design	Assessment tool	Description of appraisal tool.
RCT	Joanna Briggs Institute critical appraisal checklist for randomised controlled trials (version 10 October 2007).	The appraisal is composed of 13 questions relating to randomisation, concealment, treatment, blinding, follow-up, outcome measurements and statistical analysis. Tufanaru et al. (2017).
Case reports	Joanna Briggs Institute (JBI) critical appraisal checklist for case reports (Version 29 August 2017)	This appraisal consists of eight questions specific to a case report evaluation. Questions evaluated relate to demographic characteristics, patients history, presenting clinical condition, diagnostic tests and assessments, clarity of interventions and post intervention clinical presentation. Identification and description of adverse events (harms) as well as final conclusion and take away message are evaluated. Moola et al. (2017).
Analytical cross sectional studies	Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical cross sectional studies (Version 29 August 2017).	The appraisal tool consists of eight questions for evaluation. Evaluation of inclusion criteria, clear description of study subjects and setting, valid measures of the exposure, objective standard measures utilised, confounding factors identified and management thereof, as well as evaluation of outcomes measured and statistical analysis utilised are reviewed. Moola et al. (2017).
Cohort studies	The Joanna Briggs Institute (JBI) critical appraisal checklist for cohort studies (Version 10 October 2017).	Appraisal included evaluation of 11 questions. Evaluation related to whether groups were similar and

		recruited from the same population as well as whether exposures were measured similarly to assign patients to both exposed and unexposed groups. Identification of confounding factors was assessed together with strategies to deal with these confounding factors. Outcomes were assessed with regards to validity and reliability of the measure utilised. Follow-up was also evaluated, as well as loss to follow-up and strategies to address incomplete follow. Appropriateness of statistical analysis instituted was also reviewed. Moola et al. (2017)
Text and opinion studies	Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Text and opinion studies (Version 29 August 2017).	Six questions related to the appraisal were completed. Components evaluated related to the source as well as expertise of the opinion documented, as well as whether the stated position resulted from an analytical process. Evaluation of the population included as well as extent of the literature reviewed and extent of any incongruences with the literature/sources documented, were assessed. McArthur et al. (2015).
Systematic review and research syntheses	JBI appraisal of systematic review and research syntheses appraisal (version 29 August 2017)	Eleven questions were completed related to appraisal of systematic review and research syntheses. Appraisal questions related to the review question and appropriateness of inclusion criteria, search strategy and sources utilised. Criteria and method for appraising studies, as well as data extraction were evaluated. Publication bias was assessed. Review of recommendations for policy and/or practice was evaluated relative to identification of reported supporting data. Directives for new research were assessed relative to their appropriateness. Aromataris et al. (2015).

3.5 Data extraction

Two reviewers (BW and RR) independently extracted data from the included articles using the standard JBI SUMARI extraction tool (JBI, 2014).

To ensure quality assurance each reviewer extracted data from the first five papers individually and thereafter met to determine if their method of data extraction was consistent with the review question and purpose. Once confirmed, data extraction continued independently. Data extracted included specific details with regards to the interventions, populations, study methods and outcomes of significance to the review question. Incomplete data was followed up by the primary reviewer who contacted the author of the article for clarification or additional data. Any disagreements on data extraction were resolved through discussion and consensus or were referred to a third reviewer (HvA), as required. A PRISMA flow diagram (Moher et al., 2009) indicating the number of articles retrieved and how many were included and excluded for the review is presented in chapter four.

Final articles selected for extraction are presented in chapter 4 in table format taking into consideration, country of origin, setting, population characteristics, groups, outcome measures and description of the main results.

3.6 Data Synthesis

Meta-analyses were conducted on quantitative data where studies were similar in the population studied, methodologies utilised, intervention of interest and outcomes measured. Results were pooled into a statistical meta-analysis utilising the JBI-SUMARI software program.

Meta-analysis was conducted for pre-bundle of care implementation versus post-bundle of care implementation, with outcome measures of hospital LOS (continuous data), incidence of pneumonia (dichotomous data) and mortality rate (dichotomous data).

3.6.1 Model selection

The random and fixed effects models are the most commonly utilised statistical models for meta-analysis (Tufanaru et al., 2015).

The random-effects model allows that the true effect size may vary from study to study, with variation from both within-study and between study variations being taken into account. The fixed effect model is based on the assumption that all studies in the meta-analysis share a common (true) effect size and the only source of variation in observed outcomes is due to within study variation (Borenstein et al., 2017).

Guided criteria for model selection was published by Tufanaru et al. (2015) in their methodological paper following review of international literature on fixed and random model selection. Recommendation was made that selection of the random effects model is advisable if there is an intention to generalise results (generalisation inference) beyond the included studies. However when the number of studies is small (< 5) a fixed effects model should be utilised (Tufanaru et al., 2015). In the presence of statistical heterogeneity, or when true homogeneity cannot be assumed, the random effects model should be utilised (Tufanaru et al., 2015). In the presence of clinical and methodological heterogeneity, a common effect cannot be considered, and a fixed effects model is not appropriate (Tufanaru et al., 2015). In the presence of no heterogeneity the fixed and random models will yield identical results.

For pre- versus post bundle of care data analysis, the fixed effects model was utilised for continuous outcome data of hospital LOS. This model was selected due to the small number of studies included, according to the guidelines by Tufanaru et al. (2015). In addition the I^2 statistic generated in the random effects model for evaluation of heterogeneity of this data yielded zero, indicating no heterogeneity was present, in which case the fixed effect model is appropriate for selection.

The random effects model was utilised for dichotomous data (incidence of pneumonia and mortality) generated in the pre- versus post bundle of care evaluation. Although study number was less than five, the I^2 statistic generated in the random effects model showed heterogeneity was present, and the random effects model was selected as per the guidance criteria relating to heterogeneity (Tufanaru et al., 2015).

3.6.2 Statistical methods

The statistical method utilised for continuous and dichotomous data in pre- versus post bundle of care evaluation was that of the inverse variance method, which can be used for both dichotomous and continuous data. The inverse variance statistical method was utilised for each analysis based on the Joanna Briggs reviewer's manual recommendation, that where the number of studies to be combined is small, but within-study sample sizes per study are large, the inverse-weighted method should be utilised.

3.6.3 Effect measures and confidence intervals

The effect measure utilised for pre- versus post bundle of care for dichotomous data was that of relative risk. Relative risk was selected as the effect measure as it allows for easier interpretation than the odds ratio (Tufanaru et al., 2015). Both however are suitable for use in interpretation of summary estimates of dichotomous data according to the Joanna Briggs Reviewers manual. The effect measure of relative risk was utilised and a 95% confidence interval was set.

For continuous data of hospital LOS in the meta-analysis of pre-bundle of care implementation versus post-bundle of care, the effect measure of mean difference was utilised as the summary statistic as the outcome measurements in all studies was made utilising the same units (Israel & Richter, 2011).

3.6.4 Heterogeneity

The term 'heterogeneity' refers to the amount of variation in the results of included studies (Israel & Richter, 2011). Heterogeneity or differences across studies may be classified as clinical heterogeneity (differences in patient populations or treatment protocols/ interventions and outcomes), methodological heterogeneity (differences in study design, risk of bias) and statistical heterogeneity (large differences in the outcome of the individual studies that could not be expected to result from chance alone) which may result from clinical or methodological heterogeneity (Israel & Richter, 2011; Melsen et al., 2013).

The different statistical approaches for investigating heterogeneity reviewed in the Joanna Briggs reviewer's manual and for selection in the meta-analysis SUMARI program include the standard chi-squared test, the I^2 statistic, and tau squared (Aromataris & Munn, 2017).

In evaluation of heterogeneity in this systematic review the I^2 test for heterogeneity was utilised. The I^2 test was chosen above the standard chi-squared test as the I^2 index and its confidence interval allow for simultaneous analysis of statistical significance and extent of heterogeneity providing a more complete picture than the chi-square test (Huedo-Medina et al., 2006). The I^2 test is easily interpretable as it is expressed as a percentage, and can assess the magnitude of the heterogeneity in a meta-analysis (Huedo-Medina et al., 2006). The standard chi-squared test for statistical heterogeneity however only informs meta-analysts about the presence versus the absence of heterogeneity, but it does not report on the extent of such heterogeneity. Both the I^2 and chi square test should however be interpreted with caution when the number of studies is small (<20) (Huedo-Medina et al., 2006). Although the I^2 test

may be influenced by study number the I^2 statistic was shown to remain useful in heterogeneity testing (von Hippel, 2015). In addition, although the bias of I^2 depends to some extent on the number of studies, I^2 was found to be much less dependent on study number than the chi-square test was.

According to the Joanna Briggs Reviewers manual, Higgins et al., (2003) proposed interpretation of I^2 relative to low, moderate, and high heterogeneity for I^2 values of 25%, 50%, and 75%. Another guide to interpretation proposed by Deeks et al., (2008) as cited in the Joanna Briggs Reviewers manual (Wiki.joannabriggs.org, 2019), considered heterogeneity of 0% to 30% as heterogeneity which might not be important, whilst heterogeneity of 30% to 60% may represent moderate heterogeneity; 50% to 90% may represent substantial heterogeneity and 75% to 100% considerable heterogeneity. Authors of the guide mention that careful interpretation of the I^2 value depends on magnitude and direction of effects and strength of evidence for heterogeneity.

For the purpose of ease of review of results in this systematic review, the following I^2 interpretations will be utilised for this study based on the proposed interpretations by Higgins et al., (2003) and Deeks et al., (2008) as cited in the Joanna Briggs Reviewers manual (Wiki.joannabriggs.org, 2019).

0 to 30% may be considered low heterogeneity / heterogeneity of low importance

31% to 50 %; may represent moderate heterogeneity

51% to 74 %: may represent substantial heterogeneity

75% to 100%: may represent considerable heterogeneity

In random-effects meta-analysis, the extent of variation among the effects observed in different studies (between-study variance) is referred to as tau-squared, τ^2, or Tau^2 (Higgins et al., 2003). T^2 and Tau^2 reflect the amount of true heterogeneity. T^2 represents the absolute value of the true variance (heterogeneity). Tau^2 will be reviewed in conjunction with the I^2 value in the random effects model analysis in determining whether there is true heterogeneity among studies. Positive correlation with the tau^2 value has been recommended as a good procedure in determining true heterogeneity (Huedo-Medina et al., 2006).

Following analysis of the data generated, where pooling of results was not possible, the findings are presented in a narrative format.

3.7 Assessing certainty in the findings

The quality of evidence was appraised utilising the GRADEpro GDT: GRADEpro Guideline Development software tool (GRADEpro GDT, 2015) where a summary of findings table was created. The grading of recommendations, assessment, development and evaluation (GRADE) approach for grading the quality of evidence was followed. The summary of findings table generated included the question of interest and provides a summary of findings for each of the included outcomes as well as the quality of evidence rating for each outcome across the included studies. Information pertaining to the question of interest, intervention and comparator, the outcomes being assessed, sample sizes, number of studies that contributed to

a specific sample, associated risk with usual care and intervention as well as relative effect are documented.

The GRADE quality of evidence rating for each entry is provided together with additional comments on the GRADE ranking. The GRADE approach to rating the quality of evidence, as per the GRADE handbook will review the quality of the evidence based on five criteria (limitations in study design or execution including risk of bias, inconsistency of results, indirectness of evidence, and imprecision as well as publication bias) to determine if the quality of evidence should be down rated (Schünemann et al., 2013). Hereafter the evidence may be uprated based on evaluation of a further three criteria namely; large magnitude of effect, dose-response gradient and control for all possible confounding factors. Certainty of evidence ratings is then generated. According to the GRADE working group grades of evidence interpretation and classification, appraised evidence is rated as high, moderate, low or very low certainty following criteria evaluation.

3.8 Ethical considerations

The researchers obtained an ethical clearance waiver (Reference:W-CJ-170419-1) (Appendix A) through the University of the Witwatersrand's Human Research Ethics (Medical) Committee as there were no human participants involved in this study.

Chapter four will present the results of the systematic review and meta-analysis.

CHAPTER 4: RESULTS

4.1 Study Selection

The initial systematic search yielded 4518 articles. Review and screening of additional records and reference lists, yielded no additional studies. Following title review and duplicate removal, 247 studies remained. Following screening and review of the 247 abstracts, 186 studies were excluded. Sixty one full text articles were retrieved for review by both BW & RR. Following review of the full text manuscripts against the set inclusion and exclusion criteria, interventions and objectives, 23 articles were selected for review and appraisal with the JBI SUMARI tools. The 38 articles excluded following review of the full text studies retrieved is presented in appendix C Table 1 with reasons for their exclusion. The 23 articles selected for inclusion, were appraised individually by BW and RR, thereafter combined appraisal was conducted. Following combined review and appraisal, seven articles were excluded. Excluded articles with reasons for exclusion and critical appraisal scores are presented in Table 4.1 below.

Table 4.1 Studies excluded following critical appraisal, with reasons for exclusion.

Article	Critical appraisal score	Reason for exclusion
Farquhar et al. (2016) No benefit to surgical fixation of flail chest injuries compared with modern comprehensive management: results of a retrospective cohort study.	7/11	Patients selected for flail chest fixation were not improving despite receiving excellent medical care, and were thus in an already deleterious state prior to surgery. This selection bias could thus have led to more favourable outcomes being observed in non-operatively managed (control) patients. In addition time to surgery was delayed (a week later) which may have allowed for further advancement of deterioration and compromise to these patients, further biasing outcomes observed.
Johnson et al. (2015) Transcutaneous electrical nerve stimulation for acute pain.	11/11	Only one study included in the review was relevant to the population of interest. The study conducted by Oncel et al., (2002) focused on patients admitted to an emergency department due to minor rib fractures. This study had already been appraised and excluded based on the age of the participants falling between 11 to 81 years of age.

Gosnell. (2015) Early intervention of non-invasive positive pressure ventilation in elderly patients with rib fractures.	9/11	The respiratory intervention of NIV was evaluated and reviewed in relation to LOS. The study does not specifically report on or evaluate pain and/or function which are the primary outcomes of the review being conducted, and was thus excluded based on final evaluation by the third reviewer (HvA) who concurred with exclusion based on primary outcomes not being evaluated.
Poirier & Vacca. (2013) Flail chest.	4/8	Specific detail with regards to interventions introduced and implementation procedure were not documented. Mobilisation strategy and progression thereof, as well as deep breathing exercises utilised were not recorded. Detail with regards to the interventions effects on pain levels and mobility were not reported.
Callaghan & Phelan. (2011) Flail chest from blunt thoracic trauma.	1/8	Documentation, evaluation and/ or utilisation of assessment tools (relative to pain and function) in the assessment and management of the patient was not provided. Details with regards to specific interventions (chest physiotherapy and mobilisation) as well as reasoning for changes in the patient's management were not recorded.
Michelet & Boussen. (2013) Case scenario – thoracic trauma.	3/8	Detailed recording relating to intervention use and implementation thereof was not included. Settings of NIV mode utilised, weaning procedure implemented and specific outcome parameters indicating final results were not presented. The primary outcome of pain was only documented prior to admission and not re-evaluated. Evaluation of the primary outcome of pain and effect of the intervention on outcomes could thus not be established.
Wu et al. (2015) Which is better to multiple rib fractures, surgical treatment or conservative treatment?	6/13	Detail regarding conservative intervention utilised was lacking with regards to application and placement (type of tape or chest strap) as well as duration of use. The author was contacted on three separate occasions to clarify this information with no response. Based on lack of documentation of detail regarding conservative intervention use, this study was excluded.

Additionally, following the initial search conducted an updated PubMed search was carried out for the period between 1 January 2018 to 31 May 2020, to source any recent relevant publications. Four full text manuscripts were retrieved for promising studies and evaluated based on the set inclusion and exclusion criteria for this review. Following evaluation, no additional studies were however included following the search update due to: incorrect population inclusion criteria (Carrie et al., 2018); non-pharmacological interventions having not been reviewed/ or relative to specified outcomes (Peek et al., 2019; Kourouche et al., 2019) and incorrect setting being included (Lee et al., 2018). No additional studies were thus included following the updated search or required formal critical appraisal.

Sixteen articles were therefore selected for inclusion in this systematic review based on the initial search and were carried through for data extraction and synthesis using the *JBI extraction tools*. A flow diagram illustrating the processes of study identification, screening, assessing eligibility, inclusion and selection of studies can be viewed in Figure 4.1.

The 16 articles carried forward for data extraction consisted of three randomised controlled trials (RCT) (18.8%), three case reports (18.8%) one analytical cross sectional study (6.3%), four cohort studies (25%) and five text and opinion studies (31.3%). All studies selected were written in English.

Study selection flow diagram indicating the processes of identification, screening, assessing eligibility and inclusion of studies.

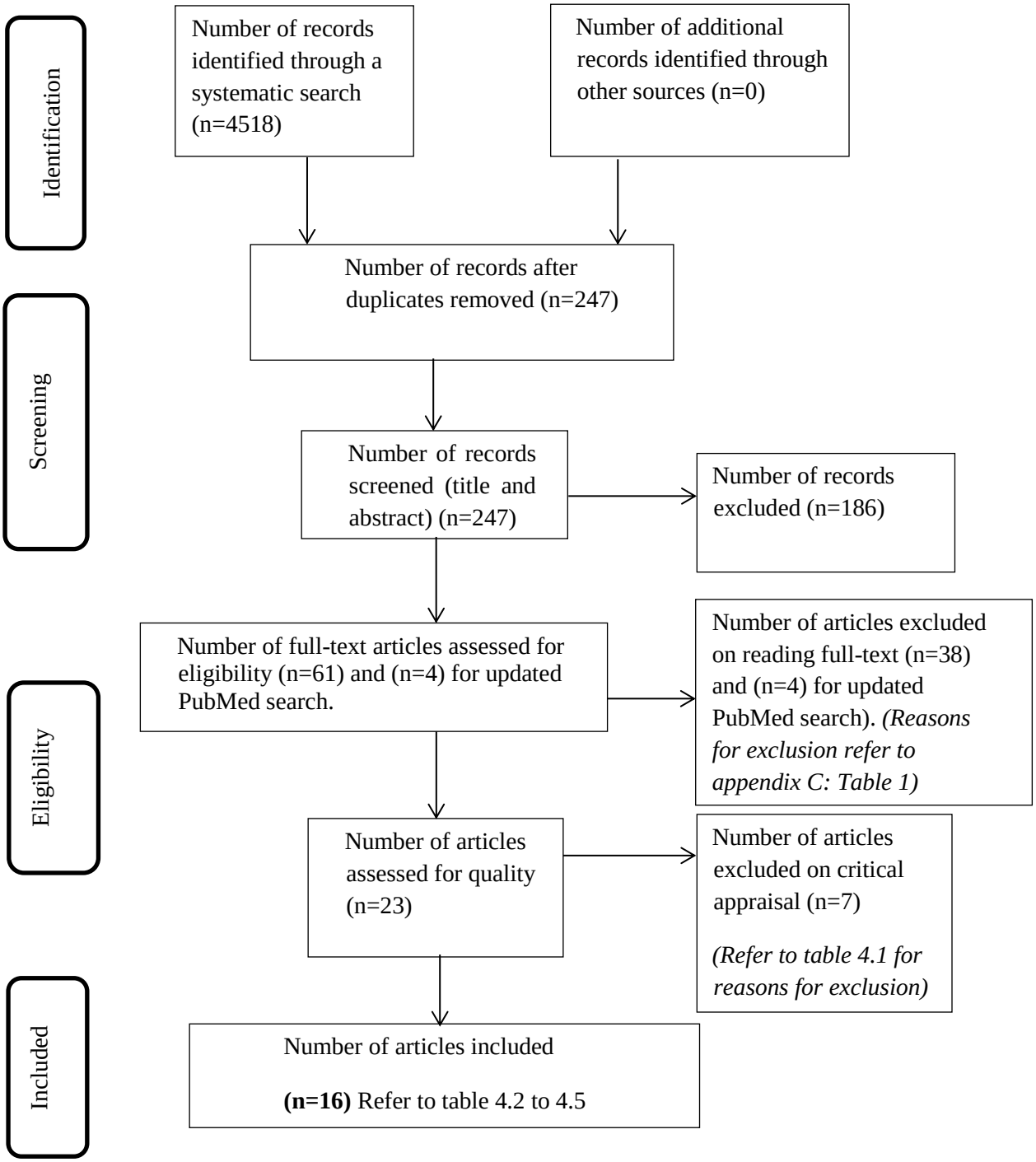


Figure 4.1: PRISMA flow diagram of search and study selection process.

4.2 Study Characteristics

For each RCT, cohort study and analytical cross sectional study included in the meta-analysis and narrative review, the country of publication, setting /context, participant characteristics, group allocation, outcome measures reported as well as a description of the main results were recorded.

For text and opinion studies, type of text, population represented, topic of interest, setting/context as well as stated allegiance/position and description of the main arguments was recorded.

For case reports evaluated, country of publication, setting/context, patient characteristics, patients as well as description of main results were included. Studies with the same study design were grouped together, under similar headings in table format, for ease of review in Tables 4.2 to 4.5 which follow.

Table 4.2: Characteristics of Included Studies - Randomised Controlled Trials

Study	Country	Setting/ context	Participant characteristics	Groups	Outcomes measured	Description of main results
Gunduz et al. (2005).	Turkey	Hospital ICU.	Age range: 23-49 yrs. Flail chest Thoracic Trauma Severity Score: 5 -15	Endotracheal (ET) group (n=21): Male (n=14): Female (n=7). Mean age: 38 (10) yrs. Rx: MV via endotracheal intubation(IPPV) CPAP group (n = 22): Male (n=13): Female (n=9). Mean age: 40 (9) yrs. Rx: CPAP (face mask) & Patient Controlled Analgesia (PCA). Chest physiotherapy (percussion and vibration) was initiated following pain control in all patients.	Verbal Rating score (in CPAP group) & morphine use. ICU LOS. Infections/ complications. ICU survival rate. Complications with IPPV or CPAP use.	Verbal rating scores & morphine consumptions decreased with time in the CPAP group. Mean LOS: (p>0.05):16 days (3) v 15 (4) days (There were no significant differences in length of ICU stay between groups) Pneumonia: p<0.00 ET group (n=10); CPAP group (n=2) (48% vs 9%): CPAP permits better bronchial hygiene. Mortality ET group n=7/21 : CPAP group: n=2/22 CPAP group survival: p <0.01 No complications associated with IPPV or CPAP use. Conclusion: Non-invasive CPAP with PCA led to lower mortality and incidence of pneumonia. Oxygenation & ICU LOS stay were similar. Findings suggest that CPAP may be utilised as a first step in the treatment of flail chest following blunt thoracic trauma.
Grammatopoulou et al. (2010).	Greece	General Hospital	≥ 3 rib fractures.	All patients received analgesic therapy & routine physiotherapy.	VAS: during cough daily post physio session & 2 hrs. post	Pain: between groups on day 3 (p =0 .04), day 4 (p = 0.00), day 5 (p = 0.00), day 6 (p = 0.00) & day 7 (p =0.00): favoured ACBT

			≥ 45 years of age Admitted in hospital. Male (n=71): Female (n=19). Age range: 45-75 yrs. Mean age :58.02 (±9.55)	<u>ACBT group (n=45):</u> Male (n=37): Female (n=8). Mean age: 59.13 (10.17) yrs. Treatment = ACBT BD (first three days) & once a day (remaining four days) + analgesia received. <u>Control group (n=45).</u> Male (n=33): Female (n=12). Mean age =56.91 (8.86) yrs. Treatment= routine physiotherapy: positioning, early mobilisation, supportive coughing (hands/ pillow but not rib belt), IS (QID) + analgesia received.	analgesia. <u>Respiratory volumes</u> (Flow-oriented incentive spirometer Triflo II) <u>Pulmonary complications</u> *Secretions *WCC: *Temperature	intervention. Significant reduction across day to day treatment for both groups. ACBT lower mean pain scores & faster, smoother trend in pain reduction. Incentive Spirometry volumes: not recorded. Pulmonary function tests: not conducted due to pain. Pulmonary complications: not detected in either group. Secretions: no pathological findings. WBC: p=0.02 btw groups on day 7. Temperature: (p>0.05). <u>Conclusion</u>: ACBT lead to pain reduction but did not prevent pulmonary complications compared to routine physiotherapy.
Ho et al. (2014).	Taiwan	Hospital.	Inpatients. ≥ 1 uni/bilateral rib fractures. N=52. ≥18 yrs. <u>Mechanism of injury:</u> Traffic accident (1^{st}) Falls	Daily treatment, 3 consecutive days since enrolment. Identical analgesia provided. <u>Filiform needles (FN) group:</u> n=27. Male (n=19) Female (n=10) Age: 52.7 (±15.2) yrs. <u>FN treatment:</u> Once daily: 5 needles retained 6 hrs. /day. <u>Thumbtack intradermal (TI) needles group</u>	Pain (NRS: 0 to10) assessed with : *deep breathing, *coughing *turning in bed. <u>Duration</u> of pain relief. <u>Sustained maximal inspiration</u> (SMI) lung	<u>Pain</u> intensity <u>FN group</u>: control group. All assessed conditions= $p < 0.05$ for FN (except during deep breathing after the 1^{st} & 2^{nd} treatments ($p > 0.05$). 81.5% FN group and 40% control ≥ 6hrs maintained pain relief. <u>SMI</u> immediate lung volumes after 2^{nd} acupuncturing: ($p < 0.05$): FN group SMI 142.60 ± 204.10 ml : control

			Numerical Rating Scale > 5 after ibuprofen on deep breathing, coughing or turning over.	(Control group): n=25. Male (n=21) Female (n=8) Age: 46.7 (±41.6) yrs. TI treatment: Once daily; 5 needles retained 6 hrs. /day.	volumes. Sleep disturbance NRS (0 to10).	group 6.00 ± 143.10 ml ($p < 0.01$). $p>0.05$ after third treatment. Sleep quality $p<0.05$ sleep (1^{st} intervention) thereafter $p>0.05$. Conclusion: Pain intensity of inpatients with rib fractures during activities of deep breathing, coughing, and turning over was reduced after FN acupuncture intervention.

Key: ACBT- active cycle of breathing technique, BD- twice a day, CPAP- continuous positive airway pressure, ET- endotracheal intubation, hrs.- hours, ICU- intensive care unit, IPPV- intermittent positive pressure ventilation, IS- incentive spirometry, LOS- length of stay, MV- mechanical ventilation, NRS- numeric rating scale, QID- four times a day, WCC- white cell count, Yrs.- years.

Table 4.3: Characteristics of Included Studies - Cohort Studies

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Description of main results
Sahr et al. (2013).	United States of America	Hospital Trauma ICU.	65yrs or older. (Specific ages and ranges not documented by author). At least 1 rib fracture. Mechanism of injury: Falls n = 44 (54.32%) MVA's n= 30 (37.04%) Other n= 7 (8.64%). Stratified according to date & number of ribs fractures (<3, 3 or more).	Pre-Protocol Implementation n=81: Male (n=46): Female (n=35). <3 rib fracture : n=30 > 3 rib fracture: n=51. Post-Protocol Implementation: (Triage protocol multidisciplinary care). n=67: Male (n=30): Female (n=37). <3 rib fracture n=28 > 3 rib fracture n=39 Treatment of elderly at institution: aggressive pain control (PCA), early mobilisation, multidisciplinary care (physical therapy & rehabilitation included).	Hospital LOS. ICU LOS.	Patients with > 3 rib fractures: longer LOS with: Hospital LOS p=0.04 & ICU LOS p=0.03 LOS (pre vs post protocol intervention): p = 0.01 decrease in hospital LOS post protocol intervention. Mortality recorded but not reviewed as a formal outcome: pre intervention (11%): post intervention (7.46%). Conclusion: Standardisation of care via protocol implementation decreased hospital LOS in patients having sustained three or more rib fractures.
Flarity et al. (2017).	USA	Hospital. ICU	N=571. 18 yrs. /older. Median age 58 (28-75) yrs. 1 or > rib fractures. Hospitalised FVC <1000 mL: admitted to the trauma ICU: Rx:	**Total Pre-clinical practice guideline (CPG):** n=252 (44.1%) Age: 56 (40–73) yrs. Male (n=146): Female (n=106). **Total Post-clinical practice guideline (CPG):** n=319 (55.9%). Age: 60 (46–75) yrs.	Hospital LOS. ICU LOS. Mortality rate	Total Pre-CPG: Post-CPG Hospital LOS : p=0.93 ICU LOS: p=0.22 ICU Cohort Pre-CPG: Post-CPG * CPG cohort: ↑ ICU admission *↓ ICU LOS >2 days for patients

			aggressive pulmonary toilet & loco-regional anaesthesia pain service consultation.	Male n= (198): Female (n=121). Management = Early FVC, aggressive analgesia, identify respiratory deterioration. FVC screening guided Rx. ICU COHORTS : N=274 **Pre-CPG ICU**: n=111 (40.5%). Age: 52 (31–67). Male (n=73) Female (n=38). **Post-CPG ICU:** n=163 (59.5%). Age: 57 (45–73). Male (n=104) Female (n=59).		admitted to ICU post CPG Mortality Total cohort : p=0.76 ICU cohort : p=0.95 Conclusion : CPG (bedside FVC, early identification of respiratory compromise, & early loco-regional analgesia) resulted in ↓ LOS. Rib fracture CPG =early ID at risk patients & provided consistency in provider practice. *ISS, rib fractures & CPG = predictive for LOS.
Curtis et al. (2016).	Australia.	Hospital: level 1 trauma centre	18 yrs. and older. Admitted. Blunt chest trauma: rib fractures.	Cohort 1 : Pre- CHiP activation group: n=273 Male (n=119) Female (n=154) Injury severity score = 3 Median age : 82 yrs. (71-88) Cohort 2 : Post CHiP activation group: n= 273 Male (n=129) Female (n=144) Injury severity score = 5	**Primary Outcome:** Pneumonia **Clinical outcomes** Mortality rate Health service outcomes **Hospital LOS** Time to specific MDT personal review (physiotherapy, trauma	**Pneumonia** :p=0.03 *(Pre CHiP pneumonia: 25 vs 12 in post CHiP*). Mortality rate reduction after CHiP p=0.29. (Pre-Chip :6 deaths vs 2 in Post-CHiP) **Hospital LOS** p=0.74 (ISS & nISS p<0.00). LOS not significantly different: * ISS higher post CHiP

				Median age : 81 yrs. (70-87) Initial management = Incentive Spirometry + HFNP oxygen + multimodal analgesia, PCA. *MDT care: physiotherapy, pain & trauma team review	team).	* Elderly LOS affected by many factors. Post CHiP cohort : *pain & trauma team review p<0.00 & PCA p=0.04 *physiotherapy (p=0.01) & earlier review by 4hrs *HFNP 0_2 : p<0.00 Conclusion: CHiP resulted in: *consistent management approach *facilitated multidisciplinary review *reduced pneumonia incidence and mortality rate
Todd et al. (2006).	America	Hospital ICU	> 45 yrs. > 4 rib fractures.	Pre-pathway: (Historic controls prior to the pathway's inception) n=150: Male (n=97): Female (n=53) Age: 60.5 (52–72) yrs. No. rib fractures: 6 (5–7). Flail: n=7 (4.7%) Post-pathway: n=150:	ICU LOS. Hospital LOS. Pneumonia incidence. Mortality rate.	Adjusted analysis for (age, ISS & No.rib fractures) favoured post pathway cohort: ICU LOS (p=0.01) favour clinical pathways (decreased stay by 2.4 days) Hospital LOS (p=0.02), by 3.7 days Post pathway favoured: Pneumonia (p <0.00) Mortality (p= 0.06). Conclusion: *implementation of the rib fracture MDT clinical pathway resulted in decreased ICU & hospital LOS,*

				Male (n= 94) Female (n=56). Age: 56 (51–65) yrs. No. rib fractures: 7 (6–9). Flail: 41(27.3%) Management: PCA & incentive spirometry (on admission). <u>Screening for entry into multidisciplinary pathway (MDP):</u> *VAS(during incentive spirometry/coughing) *Inspiratory volumes (IS) *Cough effort Failure of set criteria => MDT <u>MDT:</u> respiratory therapy, physical therapy, pain and nutrition services. Respiratory therapy (volume expansion protocol: aerosolized pharmacologic therapies, EzPAP positive airway pressure system). Physical therapy (mobility: strengthening, ROM, & balance exercises).		*incidence of pneumonia, and mortality rate.*

Key: CHiP- chest injury protocol, EzPAP- positive expiratory pressure system, FVC- forced vital capacity, HFNP- high flow nasal prong oxygen, ICU-intensive care unit, ISS- injury severity score, IS- incentive spirometry, LOS- length of stay, PCA- patient controlled analgesia, MDP- multidisciplinary pathway, MDT- multidisciplinary team, ROM- range of movement, Yrs.- years, VAS- visual analogue scale.

Table 4.4: Characteristics of Included Studies - Text and Opinion Studies

Study	Type of text	Population represented	Topic of interest	Setting/context/ Culture	Stated allegiance/position	Description of main argument(s)
Easter. (2001).	Review article Protocol recommendation.	Multiple rib fractures. Trauma.	Management of patients with multiple rib fractures. Protocol development.	Hospital: ICU.	Hypothesis: Rapid mobilisation, respiratory support & pain management will decrease ICU LOS.	<u>Vital components of multiple rib fracture management:</u> * rapid mobilisation, * respiratory support (incentive spirometry & ventilation). * appropriate pain management = crucial. Delivery of immediate appropriate care should facilitate patient's speed of recovery.
Unsworth et al. (2015).	Literature review : integrative review	Blunt chest trauma. Adults.	Comprehensive overview of treatment modalities & clinical interventions and their impact on patient and hospital outcomes.	In hospital Blunt chest trauma.	No published reviews evaluating all potential treatment options for blunt chest trauma.	<u>Clinical pathways:</u> * Rapid mobilisation through physiotherapy is vital in respiratory complication prevention. *Multi-disciplinary interventions and care bundles are vital components of multiple rib fracture management. Clinical pathways improve care & patient outcomes. Ventilation modalities assist management. <u>Three modalities with significant evidence for their benefits</u> & improve hospital outcomes (ICU and hospital LOS), morbidity

						and mortality : 1) Surgical rib fixation for flail chest → improves patient outcomes. 2) Epidural analgesia (*3/more rib fractures) lead to improved pain relief & pulmonary function. 3) Transdisciplinary clinical pathways.
Ekpe & Eyo. (2016).	Review article: Literature review	Blunt chest injury. Multiple rib fractures. Trauma. Demographics: not specified.	Approaches to pain management in blunt chest injury (multiple rib fractures) & observed complications.	Literature review. In-hospital management.	Good analgesia reduces respiratory morbidity & mortality in patients with multiple rib fractures. Analgesic modalities reviewed: best treatment modalities advised.	<u>Pain management modalities:</u> *systemic *regional (more measurable evidence) * transcutaneous. <u>Preferred mode of management for blunt chest trauma:</u> *Pain control, chest physiotherapy, & mobilisation TENS (paucity of data in use in management of multiple rib fractures).
Simon et al. (2012).	Practice management guideline. Updated EAST practice management	Pulmonary contusion & flail chest (PC-FC).	Management of pulmonary contusion & flail chest.	In hospital	PC & flail chest (PC-FC) prevalent complex injury. Mortality & short term morbidity form PC-FC have not improved during the last three decades. Updated EAST practice mx guideline (evidence-based recommendations for Rx of	All studies were graded by an established committee according to the standards recommended by the EAST Ad Hoc Committee for Guideline Development with evidence presented as follows: **<u>Level 1 recommendation</u>**: no support for level 1 recommendations regarding PC-FC. **<u>Level 2 recommendations:</u>** *PEEP or CPAP (ventilatory regimen).

					PC-FC).	*Avoid obligatory MV ***Aggressive chest physiotherapy** *Optimal analgesia (epidural catheter for severe flail chest). **<u>Level 3 recommendations:</u>** *Trial mask CPAP (meeting criteria for use). *Surgical fixation in severe flail chest failing to wean or thoracotomy required. <u>*Multidisciplinary protocols*</u>: may improve outcome/ considered where feasible. <u>High-frequency oscillatory ventilation (HFOV):</u> Not shown to improve survival in blunt chest trauma patients.
Witt & Bulger. (2017).	Review. Harborview rib fracture management protocol.	Rib fractures. Blunt chest trauma. Hospitalised (age 65 with ≥ 3 rib fractures admitted to ICU). Acute rib &/or sternal fractures.	Multiple rib fractures. Comprehensive management & bundled rib fracture management protocol.	In-hospital management.	Not stated. Article reviewing risk factors for morbidity, complications & intervention strategies for multiple rib fractures. Multidisciplinary rib fracture management protocol reviewed.	Comprehensive standardised management program for multiple rib fractures reviewed : *Bundled care pathway & management protocol:* *PIC (Pain, Inspiratory capacity, and Cough) scoring tool to serially evaluate and monitor patients: PIC score & frequent assessment → guided care.* <u>Rib fracture management protocol:</u> *multimodal analgesia *hourly pulmonary hygiene *early, frequent mobilisation *elevation of head of bed, *patient and family education

						*Incentive spirometry *Respiratory therapy *Protocol includes interventions & monitoring by nursing staff, respiratory therapists, and physicians. Includes specific guidelines for ICU and acute care status patients.*

Key: CPAP- continuous positive airway pressure, ICU-intensive care unit, LOS-length of stay, MV- mechanical ventilation, PC- pulmonary contusion, PEEP- positive end expiratory pressure.

Table 4.5: Characteristics of Included Studies - Analytical Cross-Sectional Study

Study	Country	Setting/context	Participant characteristics	Groups	Outcomes measured	Main description of results
Mehta. (2013).	India	Hospital.	N=7: Male (n= 5) Female (n=2) Age: 18-70 yrs. (Obtained from author directly) Hospitalised. Rib fractures (simple & multiple) Referred for physiotherapy.	One group with n=7 participants. Rx= TENS Dual channel high TENS (120 Hz), 30 mins at site of pain.	Assess before & immediately after TENS use: *VAS: 0-10 *PEFR (l/min). *Arterial blood (SpO_2): via pulse oximeter.	*Mean difference VAS reduction:6.43 to 3 *PEFR: 90 to 121.43(L/min): Breathing capacity improved due to pain relief. *SpO_2: 97.28% to 99%. No complications due to TENS therapy noted. *Conclusion: TENS was effective in controlling pain with resultant improvement in pulmonary function.*

Key: PEFR- peak expiratory flow rate, SpO_2- oxygen saturation, TENS- Transcutaneous electrical nerve stimulation, VAS- visual analogue scale.

Table 4.6: Characteristics of Included Studies - Case Reports

Study	Country	Setting/context	Participant characteristics	Patients	Description of main results
Linton & Sviri. (2006).	Jerusalem, Israel.	Hospital. ICU	N=1 : Female : 82yrs Cardiac arrest. Anterior flail chest	N=1 <u>Management:</u> continuous negative extrathoracic pressure (CNEP) ventilation strategy (cuirass ventilator): continuous negative pressure = −15cmH2O.	CNEP use: successful ventilation, weaning & extubation of flail chest post blunt chest trauma. CNEP: splinting effect =>increase FRC & improves lung mechanics. Cough and analgesia more effective. Preserves ability to talk, eat & breathe freely.
Garfield & Howard-Griffin. (2000).	England	Accident & emergency department ICU	N=1 35 yr. old. Male. Road traffic accident. Multiple rib fractures left (costovertebral disruption). Left flail chest. Left pulmonary contusion & right lower lobe. Bilateral small pneumothoraces	<u>Management:</u> ICU admission. Day 1: Volume controlled ventilation - tracheal intubation & left & right ICD. Day 3: Thoracic epidural and PCA. Day 5: CPAP (facemask) & IPPV. Day 12: (continuous NIPPV via nasal mask). Day 20: Intermittent NIPPV & O_2 nasal	NIPPV is safe & effective in thoracic trauma management. CPAP & NIPPV effective in ventilatory management. No VAP/septic complications (pulmonary or systemic). Non-invasive ventilation reduced incidence of VAP.

				cannulae. Day 25: nocturnal CPAP via facemask. Day 26: discharged to the ward.	
Papadopoulos et al. (2017).	Greece	Emergency department. Advanced care unit.	60 yr. old. Male. MVA. <u>Previous</u>: spontaneous pneumothorax, COPD, smoker.	N=1 VAS 10/10 Pneumothorax Pulmonary contusion. Fracture lower ribs Fracture sternum Liver injury.	<u>Auricular acupuncture lead to:</u> *<u>rapid pain (VAS) relief</u> and anxiety reduction (decline HR & BP). 1st acupuncture VAS: 10/10 to "complete regression of chest pain". 2nd acupuncture: VAS 10/10 (before): 3/10 (after). *<u>restoration of deep breathing,</u> effective cough, normal ventilation (respiratory rate & saturation), oxygenation (ABG) & haemodynamic profile. 1st acupuncture saturation: 82% (before): 92% (after). 2nd acupuncture saturation: 79% (before): 97-100% (after).

Key: ABG- arterial blood gas, BP- blood pressure, COPD- chronic obstructive pulmonary disease, CNEP- continuous negative extrathoracic pressure, CPAP- continuous positive airway pressure, FRC- functional residual capacity HR- heart rate, ICD- intercostal drain, ICU-intensive care unit, IPPB- intermittent positive pressure breathing, MVA- motor vehicle accident, NIPPV- non-invasive positive pressure ventilation, Yr.- year, VAS- visual analogue scale, VAP- ventilator associated pneumonia.

4.2.1 Country of origination

The countries in which the studies were conducted are represented in the chart below, with global representation having been achieved.

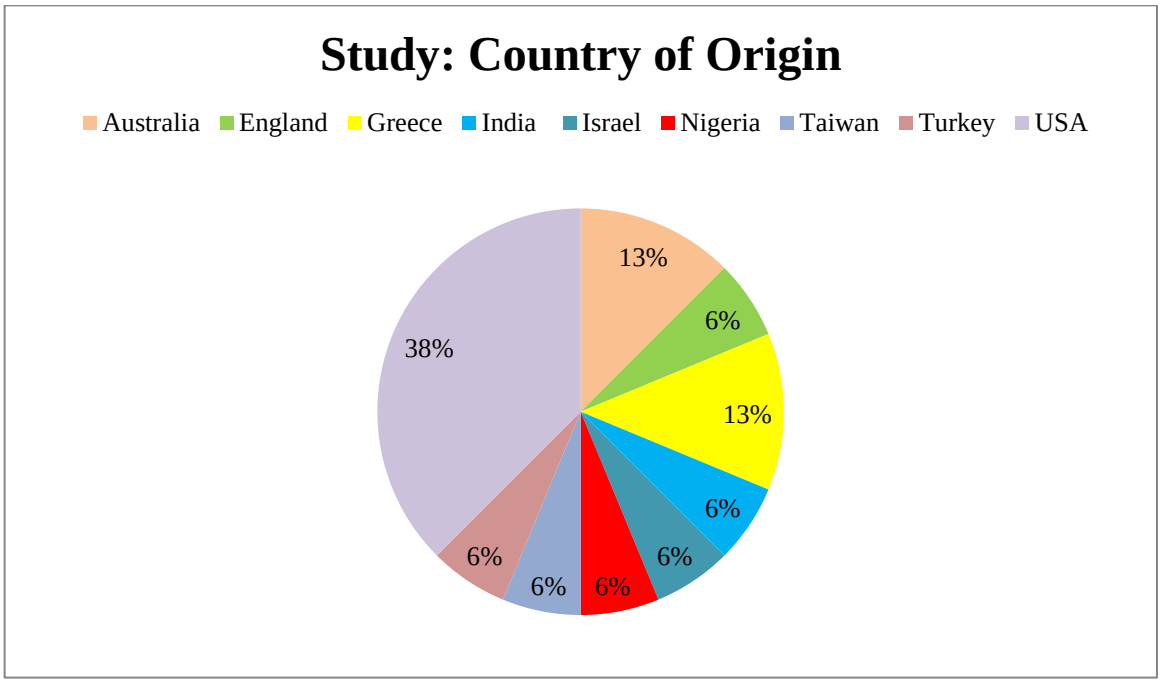


Figure 4.2: Graph representing the countries in which the studies were conducted.

Overall use of non-pharmacological therapeutic intervention in managing patients following acute rib fractures appear to be seldomly explored and reviewed for use when global representation is viewed in Figure 4.2. The USA conducts the greater proportion of research related to non-pharmacological intervention use in the management of patients following acute rib fractures followed by Australia and Greece according to the results of this systematic review.

4.2.2 Setting/context of included studies

All RCTs, cohort studies and case studies involved patients admitted to hospital with or without admission to the ICU.

Admission to the ICU was documented in addition to hospitalisation in the following studies: Garfield & Howard-Griffin, (2000); Linton & Sviri, (2006); Gunduz et al., (2005); Todd et al., (2006); Sahr et al., (2013); Ho et al., (2014); Flarity et al., (2017). Flarity et al., (2017) conducted a separate analysis on patients admitted to the ICU to evaluate the most severely injured cohort.

Papadopoulos et al., (2017) documented admission to an advanced care unit.

4.2.2.1 Text and opinion study format

All text and opinion studies included, reviewed hospitalised patients. The review article and protocol discussed by Easter, (2001) was in the setting of a hospital and ICU context. Unsworth et al., (2015) reviewed and discussed potential interventions relative to outcomes one of which was ICU LOS. The protocol introduced by Witt & Bulger. (2017), was for ICU and acute care status patients. Ekpe and Eyo, (2016) as well as Simon et al., (2012) reviewed in hospital management.

4.3 Patient characteristics

The systematic review sample of included studies consisted of n= 2034 study participants of which n= 864 (42.5%) were female and n= 1180 (58.0 %) were male participants.

4.3.1 Recruitment of Participants

Hospitalised patients with rib fractures were recruited from specified hospitals, during set time periods and meeting set inclusion and exclusion criteria in the following studies: Gunduz et al., (2005) and Ho et al., (2014).

Todd et al., (2006), included hospitalised patients, meeting set criteria that were stratified into groups according to time and implementation of the pathway of care. A historic control served as the control group and data were obtained from the trauma registry, pharmacy database, infection control and continuous quality improvement database, as well as electronic medical records.

Purposive sampling was utilised in the study by Grammatopoulou et al., (2010). Mehta, (2013), utilised a convenient sampling method, whereby consecutive patients with rib fractures, admitted to their specified hospital and referred for physiotherapy were included.

Retrospectively, trauma patients 65 years of age and older and admitted during a set time period, with at least one rib fracture (stratified by the number of rib fractures) were included in the study conducted by Sahr et al., (2013). Curtis et al., (2016) conducted a retrospective before and after cohort study. Patients admitted to the study site meeting set criteria, were identified from the trauma registry. Pre-intervention patient information was derived from the hospital clinical information database using international classification of diseases codes (ICD10) and was also cross referenced with data from the hospital trauma registry.

Flarity et al., (2017) included patients admitted during a specified time period, meeting set inclusion and exclusion criteria. Data was also sourced from the hospital's trauma registry and electronic health records.

4.3.2 Sample sizes

In all, but two studies (Grammatopoulou et al., 2010; Curtis et al., 2016) the method of calculating the sample size was not discussed. Sample sizes ranged from n=7 (Mehta, 2013)

to n=319 participants (Flarity et al., 2017). Specific sample sizes per study included those with:

- less than 50 participants (Gunduz et al., 2005, Grammatopoulou et al., 2010; Ho et al., 2014; Mehta, 2013).
- between 60 and 100 participants (Sahr et al., 2013),
- between 110 and 170 participants (Flarity et al., 2017 (ICU cohort); Todd et al., 2006)
- between 250 and 320 participants (Curtis et al., 2016; Flarity et al., 2017).

4.3.3 Ages of participants

In the vast majority of included studies, patient's average ages fell within the 50-60 year old category followed by the over 65 year age group and those under 50 years of age. The age range of included participants in this review consisted of the youngest patient of 23 years of age to the oldest patient of 82 years of age.

Average ages included in this review generally concur with previous age analysis in the literature (Dongel et al., 2013, Chrysou et al., 2017). Average ages of injury may however fluctuate depending on the mechanism of injury included for review as well as the age range criteria set as inclusion criteria in a study (inclusion of only the elderly or additionally a paediatric age group).

4.3.4 Gender of participants

In all studies both male and female participants were included.

Between study and within study group comparison revealed a greater male dominance to female ratio in the vast majority of reviewed studies. This was evident in the following studies, but with non-significant differences between group analysis for each study; Gunduz et al., 2005 (62.3 % male), Todd et al., 2006 (62% male), Grammatopoulou et al., 2010 (78.9% male).

In the study by Sahr et al., (2013) the control group had a slightly higher male dominance of 56.8% versus the intervention group with a slighter greater female dominance of 55.2%, however, overall male to female ratio in the study was still in favour of a male predominance of 51.4%. Greater male to female ratio was also observed in the study by Ho et al., (2014), with > 65% being male participants. In the study conducted by Flarity et al., (2017), patients in the pre and post protocol intervention group in hospital had a 60% male dominance and in those patients admitted and analysed in ICU, 65% were male. Mehta, (2013) included both male and female participants, with five males to two females as confirmed by the author on request of this information.

Variation in this finding was only found in the study conducted by Curtis et al., (2016), with a slightly greater female to male ratio in both control and intervention groups. Analysis revealed similar female dominance, 56.4% and 52.7% between groups with an overall female

predominance of 54.6% in this study. This study included a more elderly population, (> 65years) in which a more female predominance emerged.

Of the three case reports reviewed, two patients were male (Garfield & Howard-Griffin, 2000, Papadopoulos et al., 2017) and one was female (Linton & Sviri, 2006).

Overall results indicate a greater number of male patients included across studies reviewed, except in the elderly population where numbers were similar or in slight favour of female predominance.

4.3.5 Number of rib fractures

All included studies involved patients with at least one rib fracture.

Multiple rib fractures were reviewed in the majority of studies, including: Todd et al., (2006), Flarity et al., (2017), Gunduz et al., (2005), Mehta, (2013) and Grammatopoulou et al., (2010). Sahr et al., (2013) made analysis in relation to patients with greater than and less than three ribs fractured, with the median number of rib fractures being three. Ho et al., (2014) allowed for inclusion of patients with one or more, unilateral or bilateral rib fractures. The average number of rib fractures within group analysis was three. In the case report presented by Papadopoulos et al., (2017), the patient reviewed presented with bilateral lower rib fractures. Curtis et al., (2016), included patients with simple and multiple rib fractures.

Flail chest was reviewed in isolation or in addition to rib fractures in the following studies; Linton & Sviri et al., (2006) (anterior flail chest); Todd et al., (2006); Garfield & Howard-Griffin, (2000) (flail chest and rib fractures); Gunduz et al., (2005) and Flarity et al., (2017).

In the text and opinion and review articles included, three related to multiple rib fractures: Easter, (2001); Ekpe & Eyo., (2016) and Witt & Bulger, (2017). Flail chest was reviewed in the practice management guidelines of Simon et al., (2012) and in addition to three or more rib fractures in the study by Unsworth et al., (2015).

4.3.6 Mechanism of injury identified

The commonest mechanism of injury identified across included studies was that of road traffic or MVA's, (Garfield & Howard-Griffin, 2000; Ho et al., 2014; Papadopoulos et al., 2017), followed by falls often listed in close second place.

Falls were identified as the primary cause of rib fractures in the studies conducted by Curtis et al., (2016) as well as Sahr et al., (2013). In both studies the population was a more elderly population. More than 80% of the population included in the study conducted by Curtis et al., (2016) had sustained rib fractures from falls from less than one metre, and more than 50% of patients in the study by Sahr et al., (2013) had sustained injury via a fall.

In the case report conducted by Linton & Sviri, (2006) anterior flail chest injury was elicited by vigorous cardiopulmonary resuscitation by paramedics following cardiac arrest.

Specific etiologies of blunt chest trauma were not documented in the following studies (Gunduz et al., 2005, Todd et al., 2006, Grammatopoulou et al., 2010, Flarity et al., 2017 and Mehta, 2013).

4.3.7 Associated pulmonary and thoracic injuries

Associated injuries occurring in conjunction with rib fractures may influence treatment decisions and management, influencing overall outcome as discussed in chapter two (Pharaon et al., 2015, de Moya et al., 2017; Chrysou et al., 2017; Park et al., 2017). Associated injuries occurring in conjunction with rib fractures were noted in the following studies (text and opinion reviews were excluded from analysis based on specific patient evaluation not being included relative to the study design):

Pneumothorax was documented in 63.6% of included studies; Papadopoulos et al., (2017), Garfield & Howard-Griffin, (2000), Todd et al., (2006), Curtis et al., (2016), Gunduz et al., (2005), Grammatopoulou et al., (2010), Ho et al., (2014). Pulmonary contusion was noted in 45.5% of studies: Papadopoulos et al., (2017), Garfield & Howard-Griffin., (2000), Todd et al., (2006), Curtis et al., (2016), Grammatopoulou et al., (2010). Associated haemothorax was present in 45.5% of studies: Todd et al., (2006), Curtis et al., (2016), Gunduz et al., (2005), Grammatopoulou et al., (2010), Ho et al., (2014). Haemopnemothorax was noted in 36.4 % of studies: Todd et al., (2006), Sahr et al., (2013), Gunduz et al., (2005), Ho et al., (2014).Sternal fractures had a prevalence of 36.4% in the reviewed studies: Todd et al., (2006), Sahr et al., (2013), Papadopoulos et al., (2017), Flarity et al., (2017). Of the studies included 9.1% noted the presence of a tension pneumothorax: Gunduz et al., (2005). Associated injuries were not documented in the study conducted by Mehta, (2013).

4.3.8 Confounding factors and co-morbidities

Underlying co-morbidities may affect management and outcome. This is especially evident in the elderly population (Van Vledder et al., 2019). Underlying co-morbidities and confounding factors were examined in the following studies included in the review:

Curtis et al., (2016) identified potential confounders as: age, gender, injury severity score (ISS), mechanism of injury, smoking history, tube thoracotomy, and number of rib fractures, pulmonary contusion, pneumothorax and haemothorax. In addition Curtis et al., (2016) made use of the Charlson co-morbidity index to assess co-morbidities. Smoking history was also considered in the study conducted by Papadopoulos et al., (2017).

Weight or body mass index were considered in two studies (Gunduz et al., 2005; Ho et al., 2014).

Sahr et al., (2013) noted use of age, fall from a higher ground level as well as recent use of anticoagulant or antiplatelet medications to direct management implemented.

Todd et al., (2006) considered age, injury severity score, and number of rib fractures as confounding variables.

Injury severity scores were reviewed in eight studies: Garfield & Howard-Griffin, (2000), Gunduz et al., (2005), Todd et al., (2006), Farquhar et al., (2016), Curtis et al., (2016), Ho et al., (2014), Sahr et al., (2013) and Flarity et al., (2017).

4.4 Assessment of Methodological Quality

Twenty three articles were appraised for methodological quality. Methodological assessment and evaluation of the articles will be reviewed and appraised under the relevant study designs in table format, with discrepancies or results to take notice of discussed in narrative format.

4.4.1 Critical appraisal of randomised controlled trials

Four RCT were critically appraised and are presented with overall score ratings in Table 4.7.

Overall scores following appraisal of the RCT studies ranged from the lowest of 6 (Wu et al., 2015) to 11 (Grammatopoulou et al., 2010; Ho et al., 2014) out of a possible total of 13. The study conducted by Wu et al., (2015) was excluded following critical appraisal. The average appraisal score of the final three included studies was thus 10.3 out of 13 (79.2 %).

Table 4.7: Critical appraisal RCT

Study: RCT	**Q1 Randomisation to groups**	**Q2 Concealed allocation**	**Q3 Baseline similarity**	**Q4 Subject blinding**	**Q5 Were those delivering treatment blind to treatment assignment**	**Q6 Assessor blinding**	**Q7 Identical group management other than intervention of interest**	**Q8 Follow-up complete *analysis**	**Q9 Intention to treat. (Analysis in groups to randomized**	**Q10 Standardised measurement of outcomes between groups**	**Q11 Reliable measurement of outcomes**	**Q12 Appropriate Statistic analysis**	**Q13. Appropriate trial design**	**Final Critical appraisal score**
Appraisal score per question	75%	0%	100%	25%	25%	50%	100%	75%	100%	100%	100%	100%	75%	
Grammatopoulou et al., (2010)	Yes	Unclear	yes	Unclear	Yes	Yes	yes	yes	Yes	yes	yes	yes	Yes	11/13
Ho et al., (2014).	Yes	Unclear	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	11/13
Gunduz et al., (2005).	Yes	Unclear	Yes	No	No	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/13
Wu et al., (2015).	No	No	Yes	No	No	No	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear	6/13

4.4.1.1 Risk of bias assessment

4.4.1.1.1 Selection bias

Selection bias may be introduced into studies when selection of individuals for analysis does not occur by a proper randomised method (Attia, 2005; Kahan et al., 2015). Selection bias may thus ensue when those in charge of recruitment or enrolment of patients selectively enrol patients dependent on treatment allocation (Kahan et al., 2015). Randomisation (when performed correctly) thus reduces the risk of selection bias.

Randomisation and allocation to groups was documented in all RCT included for final review. Randomisation via the following methods were utilised for allocation to groups: table of random numbers, 1:1 ratio (Ho et al., 2014); consecutive randomisation of those with a specific thoracic trauma severity score (Gunduz et al., 2005) and stratified random sampling procedure dependent on number of rib fractures with random assignment via matched pairing (Grammatopoulou et al., 2010). In the study conducted by Wu et al., (2015) random grouping was initially utilised; however, no documentation was made detailing how this was performed. The patients were thereafter given the choice to remain in the allocated groups or to change to their preferred intervention group. This study was not included for final review.

Allocation concealment is a method utilised to prevent selection bias by concealing the allocation sequence from those assigning participants to intervention groups (Kahan et al., 2015). Appraisal of concealment to allocation groups across studies was deemed unclear in three of the included RCT namely; Ho et al., (2014); Grammatopoulou et al., (2010) (by whom and how the concealment to group allocation was performed was not documented) and in the study conducted by Gunduz et al., 2005 (procedure not documented). The study conducted by Wu et al., (2015), documented that patients were randomly grouped (method not stated) and thereafter were given the option to choose their preferred intervention. Overall scoring for concealment to allocation groups was thus 0%.

4.4.1.1.2 Performance bias

Blinding of participants to group allocation as well as those assigned to delivery of treatment aids in preventing or reducing the risk of performance bias from influencing outcomes (Probst et al., 2016).

Blinding of participants to group allocation was clearly documented in only one study (Ho et al., 2014), whilst evidence of participant blinding was appraised as unclear in the study conducted by Grammatopoulou et al., (2010). Due to distinct and obvious visible differences in interventions implemented in the studies conducted by Gunduz et al., (2005) and Wu et al., (2015), blinding was not deemed possible. Additionally, following random grouping in the study conducted by Wu et al., (2015) patients were informed of assigned grouping and could thereafter choose to change interventions. These factors accounted for the overall scoring of 25% for blinding of participants to group allocation.

Blinding of those assigned to delivery of treatment was performed in one study (25%), conducted by Grammatopoulou et al., (2010) in which the two trained physiotherapists implementing the interventions were blinded to group allocation. In the study conducted by

Ho et al., (2014), the physician performing the acupuncture was the only person in the trial aware of group allocation due to the need for selection of the appropriate acupuncture needles per group intervention, but had no further involvement hereafter. In the studies conducted by Gunduz et al., (2005) and Wu et al., (2015) the interventions utilised had obvious visible differences and blinding of those delivering treatment was not possible for this reason.

4.4.1.1.3 Detection bias

Detection bias refers to the risk of how the evaluation of the outcome may bias effects and overall results. Detection bias may however be reduced via blinding of outcome assessors to treatment assigned (Probst et al., 2016).

Blinding of assessors to assigned treatment was conducted in half of the appraised RCT studies. The study conducted by Grammatopoulou et al., (2010) made use of trained research assistants who calculated measurements and were blinded to the patients' allocation. In the study conducted by Ho et al., (2014) the evaluator who collected the outcome measure and statistician who performed the final analysis were all blinded to the grouping, thus reducing the risk of detection bias. Blinding was however not documented in the studies by Gunduz et al., (2005) and Wu et al., (2015). The risk of detection bias was therefore noted in 50% of the studies.

4.4.2 Critical appraisal of cohort studies

Following review of the six cohort studies, scores following appraisal ranged from 7 (Farquhar et al., 2016) to 10 (Todd et al., 2006 & Flarity et al., 2017) out of possible score of 11. The studies conducted by Farquhar et al., (2016) and Gosnell et al., (2015) were excluded following critical appraisal. Although Gosnell et al., (2015) received a score of 9 out of 11 following appraisal, evaluation and review of the specified primary outcomes was not evaluated in the study which resulted in the study being excluded. Reasons for exclusion are detailed in Table 4.1.

Table 4.8: Cohort study detailed critical appraisal

Study	1. Were the two groups similar and recruited from the same population?	2. Were the exposures measured similarly to assign people to both exposed and unexposed groups?	3. Was the exposure measured in a valid and reliable way?	4. Were confounding factors identified?	5. Were strategies to deal with confounding factors stated?	6. Were the groups/ participants free of the outcome at the start of the study (or at the moment of exposure)?	7. Were the outcomes measured in a valid and reliable way?	8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?	9. Was follow-up complete, and if not, were the reasons to loss to follow-up described and explored?	10. Were strategies to address incomplete follow-up utilised?	11. Was appropriate statistical analysis used?	Final appraisal rating per study:
Appraisal score per question:	**100%**	**100%**	**100%**	**100%**	**50%**	**100%**	**100%**	**83.3%**	**66.7%**	**0%**	**100%**	
Curtis et al., (2016).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	N/A	Yes	9/11
Farquhar et al., (2016).	Yes	Yes	Yes	Yes	No	Yes	Yes	Unclear	Unclear	Unclear	Yes	7/11
Todd et al., (2006).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	10/11
Flarity et al., (2017).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	10/11
Sahr et al., (2013).	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	N/A	Yes	9/11
Gosnell, (2015).	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Unclear	Yes	9/11

Failure to control for confounding factors in studies may undermine credibility and internal validity (Braga et al., 2011). Although evaluation of strategies to deal with confounding factors scored 50% overall following appraisal, all studies included for final appraisal (where deemed appropriated to the study design) included strategies to deal with confounding factors: Flarity et al., (2017); Todd et al., (2006) and Curtis et al., (2016).

Loss to follow up may represent a threat to internal validity and may introduce selection bias (Howe et al., 2016). Appraisal relating to follow-up and reasons for loss to follow up scored 66.7 % overall. This was reviewed in the studies conducted by Todd et al., (2006), Flarity et al., (2017), Sahr et al., (2013) and Gosnell, (2015). This was unclear in the studies conducted by Curtis et al., (2016) and Farquhar et al., (2016). Evaluation and appraisal of strategies to address incomplete follow-up scored a rating of 0% as in four studies it was deemed not applicable to the study design (retrospective data review) and outcome evaluation (Curtis et al., 2016, Todd et al., 2006, Flarity et al., 2017 and Sahr et al., 2013). Evaluation hereof was unclear in the studies conducted by Gosnell, (2015) and Farquhar et al., (2016).

Following appraisal of the six cohort studies, the studies conducted by Gosnell, (2015) as well as Farquhar et al., (2016) were excluded as per the criteria reviewed in Table 4.1. Four cohort studies were thus carried forward for inclusion for final review. Average critical appraisal scoring for these articles was 9.5/11 (86.4%).

4.4.3 Critical appraisal of case reports

Six case reports were critically appraised. Scores for studies ranged from 1 out of 8 (Callaghan & Phelan., 2011) to 8 out of 8 (Garfield & Howard-Griffin 2000 and Papadopoulos et al., 2017).

Table 4.9: Case reports detailed critical appraisal

Study	**1. Were patient's demographic characteristics clearly described?**	**2. Was the patient's history clearly described and presented as a timeline?**	**3. Was the current clinical condition of the patient on presentation clearly described?**	**4. Were diagnostic tests or assessment methods and the results clearly described?**	**5. Was the intervention(s) or treatment procedure(s) clearly described?**	**6. Was the post-intervention clinical condition clearly described?**	**7. Were adverse events (harms) or unanticipated events identified and described?**	**8. Does the case report provide takeaway lessons?**	**Final appraisal rating per study:**
Appraisal score per question :	**100%**	**50%**	**66.7%**	**66.7%**	**66.7%**	**50%**	**33.3%**	**83.3%**	
Michelet & Boussen, (2013).	Yes	No	No	Yes	No	No	No	Yes	3/8
Callaghan & Phelan, (2011).	Yes	No	No	No	No	No	No	Unclear	1/8
Garfield & Howard-Griffin, (2000).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8/8
Linton & Sviri, (2006).	Yes	Yes	Yes	No	Yes	Yes	No	Yes	6/8

Papadopoulos et al., (2017).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8/8
Poirier & Vacca, (2013).	Yes	Unclear	Yes	Yes	Yes	No	No	Yes	5/8

Clear presentation of the patient's history and timeline inclusion was conducted in 50% of case reports except those conducted by Callaghan & Phelan, (2011), Poirier & Vacca, (2013) and Michelet & Boussen, (2013). Overall appraisal relating to clear reporting and description of the clinical condition of the patient on presentation was 66.7%. Lack of detail was noted in the study conducted by Michelet & Boussen, (2013) where scant information was provided on how the patient presented in casualty and specifics relating to his deterioration in ICU were not presented. Callaghan & Phelan, (2011) clearly described the injuries sustained by their patient however the clinical presentation relating to signs and symptoms and changes in these parameters was not clearly described, nor was evaluation of pain intensity reported or parameters constituting type or extent of respiratory distress documented.

With regards to evaluation of diagnostic tests, assessment methods and clarity of results presented, two studies were lacking with regards to this information. In the study by Callaghan & Phelan, (2011), CT and chest X-ray results were presented, however, although pain medication was administered no evaluation or assessment method relating to pain intensity or outcome measures to assess pain severity or change in intensity were documented. In addition documentation is made of improved respiratory parameters following tube thoracotomy, however what respiratory parameters or methods were utilised or how these were assessed was not presented. In the case presentation by Linton & Sviri, (2006), diagnostic investigations conducted were not reported on and information pertaining to how the patient was assessed to achieve findings, for example of reduced FRC was not documented. Due to these reasons an overall score of 66.7 % was obtained.

Clarity of description of interventions or treatment procedures utilised was conducted in all but two studies. In the study conducted by Michelet & Boussen, (2013) clarity with regards to the surgical procedure implemented as well as settings of NIV implemented, duration of use and weaning strategy utilised were lacking. The case report conducted by Callaghan & Phelan, (2011) lacked information pertaining to the intervention protocol, specifically relating to physiotherapy and mobilisation interventions. Details with regards to the modalities of chest physiotherapy and type of mobilisation strategy implemented were not documented. This accounted for the overall scoring of 66.7% following appraisal.

Clear description of the clinical condition post-intervention was documented in 50% of the included case reports. In the study conducted by Michelet & Boussen, (2013), no details were provided on the patient's condition following NIV use or on discharge from ICU. The study conducted by Callaghan & Phelan, (2011) documented no post intervention results relating to the patient's condition following chest tube removal, or physiotherapy intervention. Additionally in the study conducted by Poirier & Vacca, (2013) no results post intervention implementation were noted. Adverse events and description thereof were also not included or poorly described in the studies conducted by Michelet & Boussen, (2013), Callaghan & Phelan, (2011), Linton & Sviri, (2006) and Poirier &Vacca, (2013). This resulted in the final appraisal score of 33.3%.

Three case reports (Linton & Sviri, 2006; Garfield & Howard-Griffin, 2000; Papadopoulos et al., 2017) were carried forward following final appraisal with a mean critical appraisal score of 7.3/8 (91.7%) for these included studies.

4.4.4 Critical appraisal of systematic review and research syntheses

Table 4.10: Critical appraisal of systematic review and research syntheses

Study	1. Is the review question clearly and explicitly stated?	2. Were the inclusion criteria appropriate for the review question?	3. Was the search strategy appropriate?	4. Were the sources and resources used to search for studies adequate?	5. Were the criteria for appraising studies appropriate?	6. Was critical appraisal conducted by two or more reviewers independently?	7. Were there methods to minimize errors in data extraction?	8. Were the methods used to combine studies appropriate?	9. Was the likelihood of publication bias assessed?	10. Were recommendations for policy and/or practice supported by the reported data?	11. Were the specific directives for new research appropriate?	Final appraisal rating:
Johnson et al., (2015).	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	11/11

This study was excluded from final analysis as per the exclusion criteria reviewed in Table 4.1.

4.4.5 Critical appraisal of analytical cross sectional studies

The study conducted by Mehta, (2013) initially received an appraisal rating of 3 out of 8, as details regarding demographics, setting and measurement of the exposure were lacking. In addition omission of identification of confounding factors and management thereof contributed to this score. Clarification was provided by the author with regards to the demographics of the patients, setting as well as VAS measurement following completion of appraisal which increased the appraisal score to 5 out of 8 (62.5%).Table 4.11 provides detailed appraisal of this study.

Table 4.11: Analytical cross sectional study detailed appraisal

Study	1. Were the criteria for inclusion in the sample clearly defined?	2. Were the study subjects and the setting described in detail?	3. Was the exposure measured in a valid and reliable way?	4. Were objective, standard criteria used for measurement of the condition?	5. Were confounding factors identified?	6. Were strategies to deal with confounding factors stated?	7. Were the outcomes measured in a valid and reliable way?	8. Was appropriate statistical analysis used?	Final appraisal rating:
Mehta, (2013).	Yes	Initially :Unclear	Initially :Unclear	Yes	No (not documented)	No (not documented)	Yes	No Only averages to depict changes were utilised. No further statistical method of analysis was conducted on the results obtained.	:3/8 -> 5/8 (Clarification by author Q2 & Q3 increased final appraisal score).

4.4.6 Critical appraisal of text and opinion studies

Table 4.12: Text and opinion studies detailed appraisal

Study	1. Is the source of the opinion clearly identified?	2. Does the source of opinion have standing in the field of expertise?	3. Are the interests of the relevant population the central focus of the opinion?	4. Is the stated position the result of an analytical process, and is there logic in the opinion expressed?	5. Is there reference to the extant literature?	6. Is any incongruence with the literature/sources logically defended?	Final appraisal rating per study:
Appraisal score per question:	100%	100%	100%	80%	100%	100%	
Unsworth et al., (2015).	Yes	Yes	Yes	Yes	Yes	Yes	6/6
Easter, (2001).	Yes	Yes	Yes	Unclear The manuscript was composed in a logical manner, however it was unclear how the literature was sourced (searches conducted and databases searched).	Yes	Yes	5/6
Ekpe & Eyo., (2016).	Yes	Yes	Yes	Yes	Yes	Yes	6/6
Simon et al., (2012).	Yes	Yes	Yes	Yes	Yes	Yes	6/6
Witt &Bulger, (2017).	Yes	Yes	Yes	Yes	Yes	Yes	6/6

All articles appraised were included in final analysis. Final mean critical appraisal score for all included articles: was 5.8 out of 6 (96.7%). Detailed appraisal of the text and opinion studies can be viewed in Table 4.12

4.5 Outcomes reviewed

4.5.1.1 Outcome measures for acute pain

Pain outcomes were reviewed in five (31.3%) of the final included studies. The VAS was the most commonly utilised scale.

The VAS varying from 0 (no pain) to 10 (the worst pain) was utilised in the study conducted by Grammatopoulou et al., (2010). Pain during coughing was evaluated once daily, following physiotherapy intervention. Mehta, (2013) assessed VAS before and immediately after TENS application. In the case report conducted by Papadopoulos et al., (2017) the VAS was evaluated before and after every auricular acupuncture intervention.

The NRS was utilised for evaluation of pain in the study conducted by Ho et al., (2014). Pain was evaluated following ibuprofen use when patients performed deep breathing, coughing, or turning over in bed, before and 10 min after every acupuncture treatment.

Gunduz et al. (2005) noted verbal rating scores in the CPAP (via facemask) group, measured at 6 hourly intervals for seven days. No further detail was provided with regards to the verbal rating score.

4.5.2 Physical function outcomes

No studies were found which specifically measured physical function outcomes in the acute care setting utilising established objective outcome measures and tools.

4.5.3 Outcome measures for respiratory function

Three (17.6%) studies reviewed outcomes related to the evaluation of respiratory function in study participants.

In the study by Mehta, (2013) the PEFR was evaluated before and immediately after TENS application over the site of pain.

The study conducted by Ho et al., (2014), evaluated the effects of acupuncture and secondary outcome evaluation was that of sustained maximal inspiration (SMI) lung volumes. This was evaluated through the TriFlow incentive breathing spirometer, before and after the second and third acupuncture interventions. The number of patients with immediate increases and decreases in SMI lung volumes 10 min after the second and third acupuncture treatments were also recorded.

Grammatopoulou et al., (2010) documented use of the flow-oriented incentive spirometer Triflo for the evaluation of increase of respiratory volumes. However, no further

documentation was made with regards to these volumes or interpretation thereof. A note was made by authors that pulmonary function tests were not conducted due to pain, as patients were unable to complete six seconds of expiratory effort.

4.5.3.1 Screening measures of respiratory function

Although this review aimed to identify treatment interventions, use of respiratory interventions as screening modalities ultimately guides and directs appropriate intervention prescription and use, assisting effective intervention selection.

Flarity et al., (2017) made use of FVC as a screening measure to detect and allow for early identification of respiratory compromise and guided management required (level of care, pain management and interventions). Initial FVC measures, followed by continued serial FVC measures were utilised to direct management dependent on FVC measures obtained (FVC < 1000ml lead to institution of aggressive pulmonary toilet and pain management). It was concluded that FVC is a simple method to screen patients with rib fractures at risk for pulmonary complications, providing a physiological parameter of pulmonary function.

Todd et al., (2006) made use of incentive spirometry screening on hospital admission to ascertain which patients would require intervention via multidisciplinary clinical pathways. Inspiratory volumes were determined using an incentive spirometer, with a volume less than 15 mL/kg considered failure.

4.5.4 Outcomes of Length of stay (hospital or ICU)

Five studies (31.3%) reported on the outcome of LOS. Three (18.8%) studies reported on both ICU LOS as well as hospital LOS (Todd et al., 2006 ; Sahr et al., 2013; Flarity et al., 2017) and one study (6.3%) reported only on hospital LOS (Curtis et al., 2016) whilst Gunduz et al., (2005) reviewed only ICU LOS.

4.5.5 Incidence of pneumonia/chest infection outcome

Three studies (18.8%) reported on the incidence of pneumonia.

Gunduz et al., (2005) reported on the incidence of pneumonia relative to ET and CPAP via facemask use in patients with flail chest. Todd et al., (2006) reviewed implementation of clinical pathway intervention in patients 45 years and older with greater than four rib fractures relative to pneumonia incidence. Curtis et al., (2016) also reviewed pre and post cohorts relative to CHiP implementation and pneumonia incidence.

4.5.6 Mortality rate

Mortality rate was reported as an outcome in five (31.3%) of the included studies which reviewed interventions of:

Mechanical ventilation via ET in comparison to CPAP via facemask intervention in the management of flail chest injuries (Gunduz et al., 2005).

Pre versus post CHiP intervention, with analysis for those with greater than and less than three rib fractures (Curtis et al., 2016).

Pre compared to post clinical pathway intervention for patients with multiple rib fractures (Todd et al., 2006).

Analysis of pre-CPG to post-CPG implementation was reviewed for both the total cohort, as well as ICU cohort in mortality analysis (Flarity et al., 2017).

Mortality rate was documented relative to greater than and less than three rib fractures for post-protocol implementation which included triage protocol as well as multidisciplinary care implementation in the study conducted by Sahr et al., (2013). Although mortality incidence was recorded, it was not reported as a formal outcome measure in ascertaining or evaluating protocol effectiveness. The author specifically noted this and advised that mortality was less useful an indicator of recovery than process-oriented outcomes (such as LOS and functional outcomes), and analysis of these outcomes was deemed more appropriate. As such mortality incidence in this study as well as in the systematic review being conducted was not evaluated further, based on the reasons as provided by the author.

4.6 Narrative review

Non-pharmacological therapeutic interventions identified in providing positive effects on the primary outcomes of pain and physical function are summarised and reviewed below. In addition interventions resulting in improvements in the secondary outcomes of hospital and ICU LOS, incidence of respiratory complications and mortality rate are discussed.

4.6.1 Interventions identified for pain relief

4.6.1.1 Acupuncture

In the study conducted by Ho et al., (2014), pain evaluation (NRS) was reviewed before and after acupuncture treatment when patients performed deep breathing, coughing, or turned over in bed. Results showed that following each application of acupuncture treatment, statistically significant differences in pain intensity ($p < 0.05$) between the filiform acupuncture group and the thumb tack intradermal needle (control group) was noted under all assessed conditions except during deep breathing following the first and second treatments ($p > 0.05$). For evaluation of improvement of pain following acupuncture intervention, pain intensity in the filiform acupuncture group decreased more remarkably under every condition than in the control group ($p < 0.00$) for deep breathing after the first acupuncture intervention and for coughing and turning over after all three interventions. With regards to duration of pain relief, 81.5% of patients in the filiform acupuncture group and 40.0% in the control group revealed pain relief maintenance for at least six hours following acupuncture. It was concluded that acupuncture as an adjunct to ibuprofen use was a safe and viable therapy for pain management in patients with multiple rib fractures.

Auricular acupuncture proved effective in pain management following two sessions of acupuncture in the management of a patient having sustained traumatic rib fractures, pulmonary contusion and pneumothorax (Papadopoulos et al., 2017). Findings revealed a

rapid reduction in pain following each acupuncture session. Initial VAS was reported as 10/10 on admission. Following the first acupuncture session the patient reported complete regression of chest pain. Deterioration was evident 22 hours later with VAS evaluation rated as 10/10. Following second acupuncture intervention VAS dropped to 3/10, with prolonged pain relief which allowed for transfer to the ward. In addition to the rapid pain relief, marked reduction in anxiety as noted by a decline in heart rate and blood pressure were documented.

4.6.1.2 Physiotherapy modalities and combination treatment

Grammatopoulou et al., (2010) documented a significant reduction in pain experienced following implementation of the ACBT intervention in patients over 45 years old with at least three rib fractures. Significant differences in pain scores between the ACBT and routine physiotherapy group was evident on day 3 ($p = 0.04$) and days 4 to 7 ($p = 0.00$), with no significant differences found on day 1 and day 2. Trend analysis revealed that pain was reduced significantly across day to day treatment, for both groups, however the ACBT group experienced faster and more linear reduction in pain than conventional treatment alone. The control group received routine physiotherapy consisting of frequent positioning, early mobilisation, supportive coughing and IS. This group also experienced a reduction in pain; however, this reduction was not as rapid and fluctuated more in their experience of pain than in the ACBT group.

4.6.1.3 TENS

Mehta, (2013) evaluated pain intensity before and immediately after TENS (BIOTECH) therapy. TENS was applied via dual channel high parameter application (frequency: 120 Hz) in a comfortable position for 30 minutes over the site of pain. Results revealed an immediate reduction in mean pain VAS scores from 6.43 to 3 following TENS application. Only descriptive analysis and mean scores were recorded for this pain outcome.

4.6.1.4 NIV (CPAP via facemask)

Gunduz et al., (2005), reviewed CPAP application via facemask in comparison to MV via endotracheal intubation in patients with flail chest injury. Results indicated a decrease in verbal rating scores and morphine consumptions with time in the CPAP group. No further information was documented with regards to VRS results, nor was comparison made with the ET group.

4.6.2 Interventions identified in improving respiratory function

4.6.2.1 Acupuncture

Ho et al., (2014) demonstrated that the use of filiform acupuncture improved SMI lung volumes. Following second acupuncture application, statistically significant improvements in the immediate SMI lung volumes were demonstrated. The filiform acupuncture group had an average immediate SMI increase of 142.60 ± 204.10 ml, while the thumb tack intradermal needle (control group) had an increase of 6.00 ± 143.10 ml ($p < 0.01$). No significant

improvement was however observed after the third treatment (filiform acupuncture group SMI 50.00 ± 124.0 ml, control group SMI 10.00 ± 35.36 ml; $p > 0.05$). Following the second acupuncture session, 55.6% of patients in the filiform acupuncture group had immediate SMI increase (average 276.7 ml) in contrast to only 12% of controls with immediate SMI increase (average 216.7 ml) with p=0.00. No significant difference was observed between the two groups in patient numbers with SMI increase after the third treatment ($p>0.05$).

Papadopoulos et al., (2017) utilised auricular acupuncture, which assisted in the restoration of deep breathing, effective cough, and normal respiratory rate, saturation and hemodynamic profile. The patient presented with a SpO_2 = 82% on 5L/min O_2 via facemask. Following the first acupuncture session saturation rose to 92% (89-97%) and $PaCO_2$ dropped from 48mmHg to 38mmHg. Primary abdominal breathing pattern settled to a thoracic breathing pattern with normal expansion and RR of 20 breaths/min. Prior to the second acupuncture intervention RR rose to 36 breaths/ min with abdominal breathing, $PaCO_2$ elevation to 45mmHg and drop in saturation to 79%. Following second acupuncture intervention VAS dropped to 3/10, with saturation increase to 97-100% and report of ABG normalising. Following auricular acupuncture the patient was able to breathe deeply and cough effectively.

4.6.2.2 TENS

Mehta, (2013) demonstrated an increase in PEFR following TENS use. Peak expiratory flow rate was evaluated before and immediately after TENS application over the site of pain. Results indicated a marked increase in average PEFR from 90 to 121.43L/min following TENS use. In addition saturation rose from 97.3% to 99% following TENS application.

4.6.2.3 Non-invasive ventilation

Linton & Sviri, (2006) demonstrated successful use of NIV utilising continuous negative extrathoracic pressure (CNEP) around the anterior chest wall and abdomen of an elderly patient who sustained a large anterior flail chest. Continuous negative extrathoracic pressure utilisation allowed for more effective cough effort, with preservation of ability to breathe freely due to the splinting effect of the CNEP on the flail segment and supported functional residual capacity.

4.6.3 Interventions identified for reducing respiratory complications

4.6.3.1 Physiotherapy techniques

4.6.3.1.1 Active cycle of breathing technique

Following implementation of the ACBT as well as routine physiotherapy (positioning, early mobilisation, effective supported coughing and flow-oriented incentive spirometry), Grammatopoulou et al., (2010), documented an absence of pulmonary complications (atelectasis or incidence of pneumonia) in both the ACBT and routine physiotherapy groups. No further analysis was provided with regards to this data.

4.6.3.2 Acupuncture

Although statistical analysis was not provided for incidence of pulmonary complications, Ho et al., (2014), documented increased ease of deep breathing as well as improved ability to cough and expectorate secretions following filiform needle acupuncture intervention. Interpretation was made that this could lead to reduced rates of pulmonary complications and increased patient compliance with ventilatory training following rib fracture injury.

4.6.3.3 Non-invasive ventilatory modalities

Non-invasive ventilation modalities were found to reduce the incidence of pulmonary complications/incidence of pneumonia following flail chest injury in the following studies:

Gunduz et al., (2005) found that non-invasive CPAP use with PCA in patients with flail chest injury led to lower nosocomial infection rates. Incidence of pneumonia between groups was 48% versus 9%, favouring CPAP intervention above IPPV with endotracheal intubation. This reduction in pneumonia incidence with CPAP use was attributed to the ability of CPAP to preserve spontaneous breathing, permitting improved bronchial hygiene and reducing pulmonary morbidity. Others have reported similar findings, with endotracheal intubation having been shown to increase the risk of pneumonia development (Kalanuria et al., 2014; Arumugam et al., 2018).

Garfield & Howard-Griffin, (2000) documented successful use of NIPPV modalities (intermittent positive pressure breathing (IPPB) via a Bird ventilator, CPAP via facemask and NIPPV via nasal mask) in the management of a patient with flail chest injury. Final case report analysis documented no evidence of systemic or pulmonary infection at any stage of acute care management.

Linton & Sviri, (2006) implemented use of CNEP following flail chest injury. Continuous negative extrathoracic pressure preserved the patients' ability to breathe and cough freely around the mandatory negative pressure applied and supported FRC. This preservation of ability to cough and breathe freely was concluded by the authors to allow for reduction in the incidence of laryngeal injury and ventilator-associated complications observed.

4.6.3.4 Multidisciplinary care and treatment pathways/bundles.

Curtis et al., (2016) implemented use of a blunt chest injury early activation protocol (CHiP) in an elderly population. Bundled protocol intervention comprised of physiotherapy, pain and trauma team review, PCA and high flow nasal prong oxygen (HFNP) use. Post CHiP implementation analysis identified earlier and increased review and management of patients by the pain management team ($p<0.00$), physiotherapy ($p=0.01$) and trauma team ($p<0.00$). Increased use of PCA ($p=0.04$) as well as HFNP oxygen ($p<0.00$) was also noted in the post protocol intervention group. Final results indicated that the odds of developing pneumonia was 56% lower in the post CHiP cohort ($p=0.03$).

Todd et al., (2006), implemented MDT intervention for patients 45 years of age and older with greater than four rib fractures. Following screening and identification of at risk patients,

patients were enrolled into the MDT care pathway. Pathway intervention involved focused efforts from respiratory therapy, pain, physical therapy, and nutrition services. Respiratory therapy constituted use of aerosolised pharmacologic therapies, EzPAP positive airway pressure system and other escalating invasive therapies as required. Pain control was maximised under the pivotal role of the pain service (oral pain medication, NSAID, intravenous pain medications and epidural analgesia as deemed appropriate). Physiotherapists involved with the physical rehabilitation of the patients, aimed to optimise mobility utilising strengthening, range of motion, and balance exercises. The MDT care also included nutritional management. Incidence of pneumonia showed a statistically significant reduction in the post pathway group ($p<0.00$). The odds of developing pneumonia were 88% lower in the post pathway MDT cohort.

4.6.4 Interventions resulting in improvements in physical function

4.6.4.1 Acupuncture

Ho et al., (2014) documented that patients reported elevated motivation to get up and move following reduction in pain after filiform acupuncture intervention. In addition, ability to turn over in bed was documented as less painful in the filiform group versus the thumb tack intradermal needle group. Sleep quality following first acupuncture intervention was significantly improved ($p<0.05$) however thereafter no significant difference was noted ($p>0.05$) after further intervention. It was concluded that acupuncture management reduced the inconvenience due to trauma and improved the QOL of patients during hospitalisation.

4.6.5 Interventions resulting in reduced LOS

4.6.5.1 Non-invasive ventilation modalities

In the study conducted by Gunduz et al., (2005) mean ICU LOS was found to be slightly but not significantly longer in the IPPV ET group versus CPAP group. Mean LOS between groups was 16 (ET group) versus 14 days (CPAP group).

4.6.5.2 Multidisciplinary pathways and care

Sahr et al., (2013) demonstrated a reduction in LOS post rib fracture protocol implementation (pre vs post protocol intervention) in elderly patients. The triage protocol facilitated a process-oriented approach, standardising care and improving accessibility to multidisciplinary care. Aggressive pain control including PCA, early mobilisation, and multidisciplinary care (physical and occupational therapy, physical medicine, rehabilitation, social work, and pharmacy) formed part of the intervention. Post protocol intervention lead to statistical differences within ICU LOS ($p = 0.03$) and hospital LOS ($p = 0.04$) when comparing the number of ribs fractured. This significance resulted as patients with three or more fractured ribs had longer lengths of stay. A statistically significant difference ($p =0.01$) favouring post-protocol intervention was also found within hospital LOS when comparing protocol phases.

Flarity et al., (2017) implemented clinical practice guidelines (CPG) and FVC screening with directed appropriate pain management and institution of early aggressive pulmonary toilet in

patients admitted to hospital or ICU having sustained rib fractures. Results indicated no difference in total LOS between the pre- post cohorts. The post CPG ICU cohort however demonstrated a reduction in ICU LOS by two days. These CPG thus allowed for early identification of respiratory compromise and appropriate triage of patients. The CPG increased ICU admission allowing for consistency in provider practice and patient management.

Todd et al., (2006) documented that following adjustment for age, ISS, and number of rib fractures, clinical pathway implementation was associated with decreased ICU LOS by 2.4 days (p=0.01) and hospital LOS by 3.7 days (p=0.02).

In the study conducted by Curtis et al., (2016), hospital LOS was not shown to be significantly different (p=0.74) between the pre-CHiP and post- CHiP cohorts. This was possibly attributed to the fact that the post- CHiP cohort had a higher median ISS. In addition, the authors noted that LOS is affected by a multitude of factors especially in the elderly.

4.6.6 Interventions resulting in reduced mortality

Mortality reduction does not necessarily equate with improved function or quality of life, but may be used as an indicator of the quality and safety of care in health care institutions (Lingsma et al., 2018). Interventions identified in reducing mortality rate include:

4.6.6.1 Non-invasive ventilation modalities

In the study by Gunduz et al., (2005), mortality rate in the management of patients with flail chest in the IPPV via endotracheal intubation group was 33.3% and that in the CPAP group was 9.1%. The CPAP group survival rate showed statistical significance ($p < 0.01$).

4.6.6.2 Multidisciplinary clinical pathways

Todd et al., (2006), reported that clinical pathway intervention was associated with reduced incidence of mortality (p=0.06) in comparison to pre-pathway intervention.

Sahr et al., (2013), did not make use of mortality as a formal outcome measure for evaluation following rib fracture protocol implementation. The author reasoned that mortality among their trauma patients in their hospital would result in too small a sample size to allow analysis and as a result, use of reduction in mortality rate as a measure of protocol effectiveness would not be diagnostic with respect to the success of the protocol. Review of mortality figures relative to this account by the authors, denoted an 11.1% mortality rate in the pre-clinical protocol cohort versus 7.5% in the post protocol implementation cohort; however, results should be interpreted in the context of the limitations described by the author.

4.6.7 Narrative review: Text and opinion studies

Easter, (2001) concluded that rapid mobilisation, respiratory support (ventilatory strategies and spirometry) and appropriate pain management (medical and pharmacological management) were essential components of care in the management of patients with multiple

rib fractures. These three components of management were identified as key practices to reduce and prevent complications and influence clinical outcomes. Appropriate pain management was identified as the component of care leading to the best outcomes in the care of patients with multiple rib fractures.

Unsworth et al., (2015) concluded that rapid mobilisation through physiotherapy is a pivotal factor in reducing respiratory complications. Pain management was essential for interventions to take place effectively. Clinical pathways were found to facilitate multidisciplinary care and standardise practice. Emphasis was placed on the need for delivery of multidisciplinary interventions and care bundles in the management of multiple rib fractures. Age, number of rib fractures and associated lung injury were factors identified for consideration for eligibility and admission to care bundles and pathways.

Ekpe & Eyo, (2016) identified and reviewed various modalities to manage pain following blunt chest injury and multiple rib fractures. Preferred modes of management identified for blunt chest trauma intervention included appropriate pain control, chest physiotherapy and mobilisation.

Simon et al., (2012) reviewed the EAST practice management guidelines for pulmonary contusion and flail chest (PC-FC) in order to present evidence-based recommendations for the treatment of PC-FC. The use of optimal analgesia and aggressive chest physiotherapy, received a level 2 evidence rating, and its implementation was recommended to minimise the likelihood of patients developing respiratory failure. A level 3 evidence recommendation of trial mask CPAP in alert patients with marginal respiratory status was advised for consideration as part of management. The bulk of evidence favoured selective use of MV, analgesia and chest physiotherapy as the preferred initial management strategies.

Witt & Bulger, (2017) reviewed evidence based therapeutic interventions including bundled clinical care pathways, pulmonary hygiene and multimodal analgesia in the management of patients with multiple rib fractures. Components of care instituted as part of Harborview rib fracture management protocol included frequent function-based scoring (PIC score) and monitoring. Early initiation of multimodal pain therapy, hourly pulmonary hygiene, and early, frequent mobilisation, elevation of head of bed, respiratory therapy, and incentive spirometry, family and patient education and respiratory therapy interventions were included in management. Respiratory therapists evaluated, reviewed and implemented care throughout the care pathway.

4.7 Results of Meta-analysis

Studies with sufficient data for the outcomes specified in this review were pooled together for meta-analysis. Meta-analysis was conducted for pre-bundle of care implementation versus post-bundle of care implementation. Outcomes evaluated in the meta-analysis for pre versus post bundle of care included those of hospital and ICU LOS, mortality rate and incidence of pneumonia.

Three studies for hospital LOS (Todd et al., 2006; Sahr et al., 2013 (two data results recorded for this outcome relative to the number of rib fractures documented) and Curtis et al., 2016) were included for analysis. The studies included for the outcome of ICU LOS were Todd et al., (2006) and Sahr et al., (2013). The study conducted by Flarity et al., (2017) measured

similar outcomes relative to intervention implementation and effect on outcomes of hospital LOS and ICU LOS. This study was considered for inclusion in the meta-analysis however the outcomes of hospital LOS and ICU LOS were expressed in median and interquartile range (IQR). For inclusion in the meta-analysis, data format was required to be expressed as means and standard deviation for data entry requirements. Best efforts were made by the researcher on numerous occasions to source this data from the author, without success. As a result the data pertaining to hospital LOS and ICU LOS included in the study conducted by Flarity et al., (2017) was excluded from meta-analysis for this reason, and was discussed in the narrative review.

For the outcomes of incidence of pneumonia, and mortality rate relative to bundle of care implementation, the studies of Todd et al., (2006) and Curtis et al., (2016), were included for each forest plot. For the outcome of mortality, Flarity et al., (2017) was also included in the forest plot.

Table 4.13: Meta-analysis: Pre-bundle of care implementation vs Post-bundle of care implementation.

Outcome	Studies included	Heterogeneity evaluation	Meta-analysis conducted:
Hospital length of stay (hospital LOS)	Sahr et al., (2013) *(2 entries relative to the two patient populations reviewed)* Todd et al., (2006) Curtis et al., (2016)	I^2= 0 with fixed effects model.	√
Intensive care length of stay (ICU LOS)	Sahr et al., (2013) *(2 entries relative to the two patient populations reviewed)* Todd et al., (2006)	I^2=63% with random effects model.	× Pooling of results not appropriate relative to I^2 %.
Incidence of pneumonia	Todd et al., (2006) Curtis et al., (2016)	I^2= 26% Tau^2= 0.05 with random effects model.	√
Mortality rate	Todd et al., (2006) Curtis et al., (2016) Flarity et al., (2017)	I^2= 50% Tau^2= 0.23 with random effect model.	√

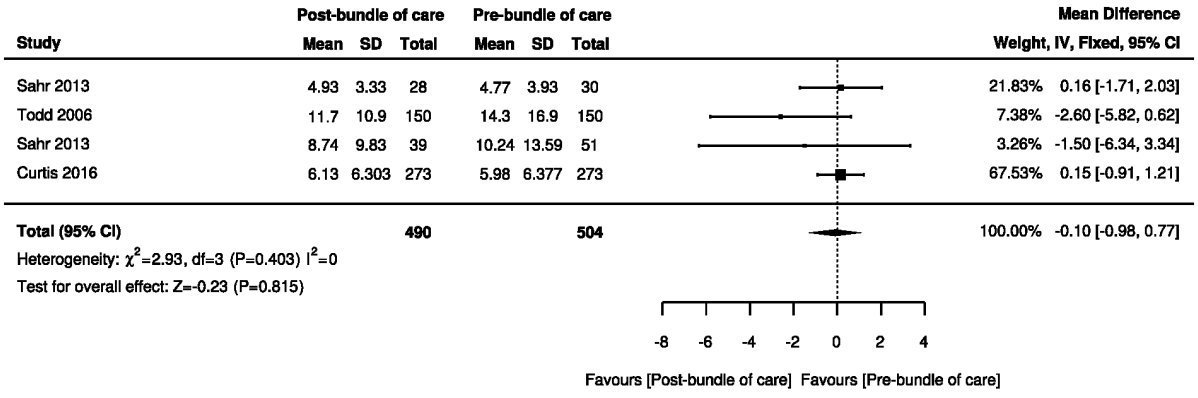


Figure 4.3: Forest plot: Meta- analysis of pre- versus post bundle of care implementation on hospital length of stay.

Three studies (Sahr et al., 2013; Todd et al., 2006; Curtis et al., 2016) were included in the meta-analysis. Two entries were recorded for Sahr et al., (2013) relative to the number of rib fractures (greater than or less than three rib fractures) and impact on hospital LOS.

Confidence intervals for all three included studies spanned the line of null effect. Forest plot analysis revealed a total of 490 patients in the post bundle of care group versus 504 in pre-bundle of care group. The final point estimate was -0.10 with its 95% confidence interval between (-0.98, 0.77). Test for overall effect yielded a p-value = 0.82 and overall results indicated no statistically significant difference in hospital LOS for those with rib fractures managed before bundle of care implementation versus those managed post bundle of care intervention.

Heterogeneity evaluation yielded an I^2= 0 with fixed effects model, indicating low heterogeneity between included studies as per heterogeneity classification established in chapter three.

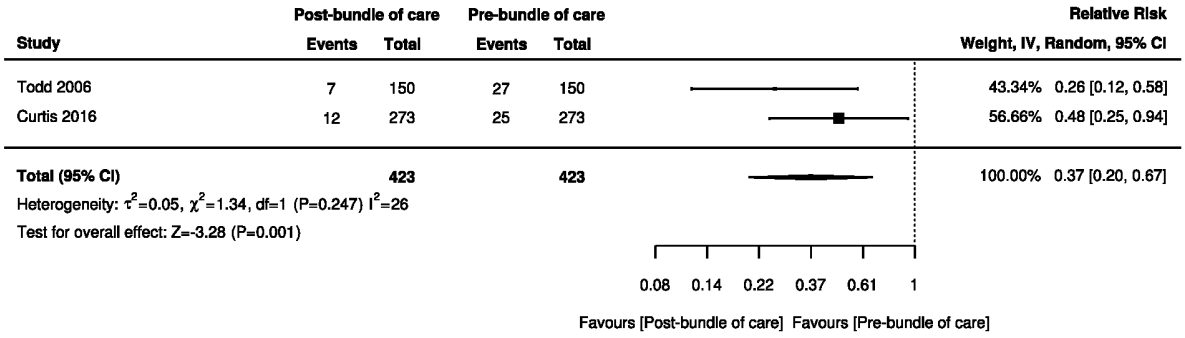


Figure 4.4: Forest plot: Meta- analysis of pre-versus post bundle of care implementation on incidence of pneumonia.

Two studies (Todd et al., 2006; Curtis et al., 2016) were included in the meta-analysis for outcome evaluation of incidence of pneumonia following bundle of care implementation. Both included studies favoured post-bundle of care implementation with the 95% CI for each study not crossing the line of null effect. Analysis revealed a total of 423 patients per group. Final result analysis revealed a relative risk (RR) (95% confidence interval (CI)) = 0.37 (0.20, 0.67) with p =0.00. This signifies a statistically significant result in favour of post bundle of care intervention. Patients managed with care bundles had a reduction of 63% in RR of developing pneumonia following rib fractures in comparison to those managed without care bundles.

Heterogeneity evaluation, revealed tau square value =0.05 and an I^2 under 30% which is considered low heterogeneity.

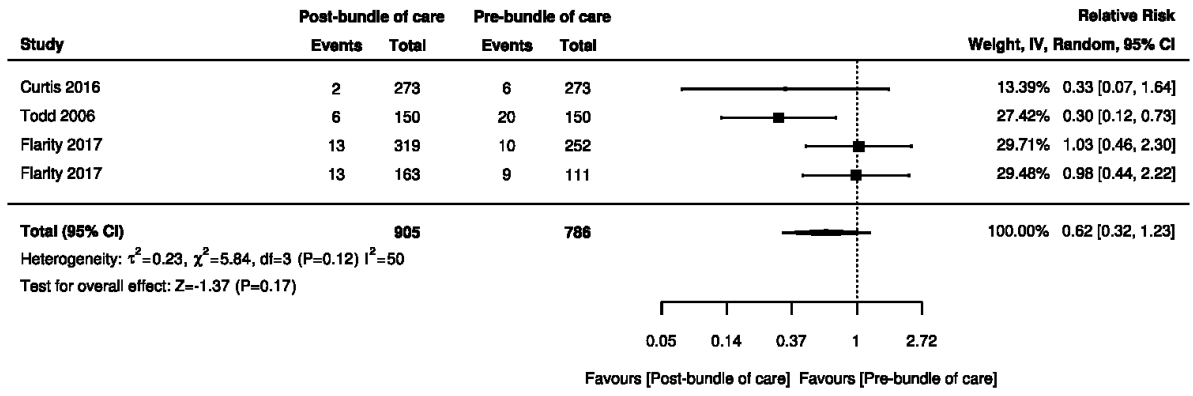


Figure 4.5: Forest plot: Meta- analysis of pre- versus post bundle of care implementation on mortality rate.

In the study conducted by Curtis et al., (2016) a large CI is noted crossing the line of null effect on evaluation of the forest plot. Curtis et al., (2016), found that mortality rates were not significantly different (p=0.29) for patients with rib fractures in the pre and post CHiP cohorts, six deaths were reported in the pre CHiP cohort versus two deaths in the post CHiP cohort**.** On forest plot analysis the study conducted by Todd et al., (2006) favoured post bundle of care intervention with the 95 % CI not traversing the line of null effect. Todd et al., (2006), reported that clinical pathway intervention was associated with reduced incidence of mortality (p=0.06) in comparison to pre -pathway intervention. Flarity et al., (2017) reviewed mortality relative to two patient populations (those admitted to hospital as well as those admitted to ICU) following pre and post CPG implementation. Each population (hospital and ICU admission), had their own mortality analysis, and is presented as such in the forest plot. When comparing pre and post CPG cohorts, no difference was noted in mortality rate in either the hospital or ICU populations reviewed following CPG intervention.

Overall result analysis revealed a total of 905 patients in the post-bundle of care intervention group, versus 786 in the pre-bundle intervention group. Final results showed a RR (95% CI): 0.62 (0.32, 1.23) with the final point estimate CI traversing the line of no effect and p=0.12. Mortality risk was thus shown not to be significantly reduced by bundled care implementation in patients with rib fractures.

Heterogeneity evaluation revealed an I^2 = 50% and Tau^2= 0.23 with the random effect model. This may represent moderate heterogeneity as per the heterogeneity classification described in chapter three.

4.8 Quality of evidence appraisal.

The summary of findings table is presented with review of the main findings for each outcome in Table 4.14.

Table 4.14: Summary of findings table.

Summary of findings:

Bundled care compared to standard/ usual care for inpatients with acute rib fractures

Patient or population: inpatients with acute rib fractures
Setting: Acute care
Intervention: bundled care
Comparison: standard/ usual care

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	№ of participants (studies)	Certainty of the evidence (GRADE)	Comments
	Risk with standard/ usual care	**Risk with bundled care**				
Hospital length of stay (LOS)	The mean hospital length of stay ranged from **4.77-14.3** days [a]	MD **0.1 days fewer** (0.98 fewer to 0.77 more)	-	994 (3 observational studies)	⨁⨁⨁◯ MODERATE [b]	Bundled care intervention indicated a possible increase or decrease in LOS by one day following intervention. Final point estimate CI were inclusive of null effect.Evidence was rated down based on imprecision criteria.
Pneumonia incidence	12 per 100	**5 per 100** (2 to 8)	**RR 0.37** (0.20 to 0.67)	846 (2 observational studies)	⨁◯◯◯ VERY LOW [c]	Overall results indicated a relative risk reduction of 63% of pneumonia following bundled care intervention versus standard/usual care. Evidence rated down based on imprecision. Inconsistency was rated not serious with I2=26%.
Mortality rate	5 per 100	**3 per 100** (2 to 6)	**RR 0.62** (0.32 to 1.23)	1691 (3 observational studies)	⨁◯◯◯ VERY LOW [d]	Overall point estimate indicated reduced relative risk of mortality by 38% following bundled care. Final CI advocated potential reduction in relative mortality risk by 32% or increased risk of 23% followed bundled care. Evidence was rated down on imprecision criteria and inconsistency was deemed not serious in the presence of explainable heterogeneity.

***The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

CI: Confidence interval; **MD:** Mean difference; **RR:** Risk ratio

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

Explanations

a. Range derived from studies included in the meta-analysis.
b. The confidence interval is inclusive of null effect, with minimally important difference demonstrated in the overall point estimate.
c. Overall sample sizes and number of events are small.
d. Relatively few events and wide confidence intervals including potential for appreciable benefit and harm.

Generated with GRADEpro GDT: GRADEpro Guideline Development Tool. (2015).

4.8.1 Mortality

Pooled analysis of the three cohort studies with 1691 participants found a RR of 0.62 (95% CI 0.32 to 1.23). There was no serious concern with regards to risk of bias or inconsistency (I^2 = 50% explainable heterogeneity) or indirectness. Publication bias was not detected. Results showed serious concern for imprecision as the CI included the potential for no effect, as well as large reduction or increase in mortality. Overall quality of evidence was thus rated as very low.

4.8.2 Pneumonia incidence

Pooled analysis of the two cohort studies yielded 846 participants. Overall results found a RR of 0.37 (95% CI 0.20 to 0.67). No serious concern with regards to risk of bias, indirectness or inconsistency (I^2=26%) was detected. Publication bias was undetected. Final results however indicated serious concern with regards to imprecision as number of participants and overall incidence were concluded as small. Overall quality of evidence was thus rated as very low.

4.8.3 Hospital LOS

Pooled analysis of the three cohort studies with 994 participants found a mean difference of -0.10 (95% CI -0.98 to 0.77). There was no serious concern with regards to risk of bias, indirectness or inconsistency (I^2=0%). Publication bias was undetected. Final results however indicated serious concern for imprecision as the CI was inclusive of the potential for no effect, with minimally important difference noted in the overall point estimate. Overall the quality of evidence was rated as moderate.

4.9 Summary of results

Following appraisal and review of the included studies in this systematic review, various non-pharmacological treatment modalities and interventions have been identified for use in the management of patients with acute rib fractures following blunt chest injury. These modalities were shown to influence the outcomes of pain, function, LOS as well as influence the incidence of pulmonary complications and mortality. The interventions and their effect on outcomes are summarised in the table on the page that follows.

Table 4.15: Modalities identified in included studies for improvement in specified outcomes:

Intervention identified	Pain relief	Improved pulmonary function	Reduced pulmonary complications	Improved physical function	Reduced HLOS	Reduced ICU LOS	Reduced mortality
Acupuncture:							
Filiform needles: Auricular:	√ √	√ √	√	√ Subjective report.			
Bundled care and MDT pathways			√√		√√	√√√	√
Physiotherapy modalities:							
ACBT	√		√				
Combination Rx:	√		√				
TENS	√	√					
NIV:							
CPAP (facemask)	√		√		√	√	√
CNEP		√	√				
CPAP (facemask) & IPPB			√				

Key: *ACBT- active cycle of breathing technique, CPAP- continuous positive pressure ventilation, CNEP- continuous negative extrathoracic pressure, HLOS- hospital length of stay, ICU- intensive care unit, IPPB-intermittent positive pressure breathing, LOS- length of stay, MDT- multidisciplinary team, NIV- non-invasive ventilation, , Rx- treatment, TENS- Transcutaneous electrical nerve stimulation.*

√ : Number of studies documenting a positive outcome

Combination Rx: conservative management including positioning, early mobilisation, supported coughing and incentive spirometry.

Multidisciplinary clinical pathways and care bundles have been identified in the vast majority of studies as an included intervention, with favourable outcomes in the management of patients with rib fractures being demonstrated. Components of care and incorporated modalities of intervention in each MDT pathway may vary between studies depending on the institution of implementation and population reviewed. As such Table 4.16 on the next page identifies and reviews components/modalities of care included in the various clinical pathways or protocols included in this review.

Table 4.16: Components of care identified in clinical pathways/ bundled care intervention.

	Components/ modalities of pathways/bundled care					
Intervention Study	**Appropriate aggressive pain management.**	**Early mobilisation**	**MDT care**	**Chest physiotherapy or respiratory therapy or pulmonary toilet or physical therapy**	**Ventilatory support or other**	**Other**
Triage protocols MDT Sahr et al., (2013)	√	√	√	√ physical therapy		
CPG Flarity et al., (2017).	√			√ pulmonary toilet		
CHiP Curtis et al., (2016).	√		√	√ physical therapy		√ HFNP
Multidisciplinary clinical pathway Todd et al., (2006).	√	√ optimise mobility	√	√ respiratory therapy (nebulisation) √ physical therapy	√ EzPAP	

Key: CHiP-chest injury protocol, CPG- clinical practice guideline, EzPAP- positive expiratory pressure system, HFNP-high flow nasal prong oxygen, MDT-multidisciplinary team.

In addition to the studies analysed, text and opinion studies included for evaluation also reviewed and recognised the value of non-pharmacological interventions utilised in the management of patients with rib fractures. Modalities and interventions identified and reviewed are presented in table format on the page to follow.

Table 4.17: Modalities identified in text and opinion studies for management of patients with rib fractures.

	Optimal Pain Management.	Mobilisation Early, Frequent, Rapid).	Respiratory support or training	MDT care/Care bundles	Physiotherapy	Other
Management of MRF Easter, (2001).	√	√	√ Ventilatory support √ IS * pain mx			
Rib fractures Unsworth et al. (2015).	√	√ (through physiotherapy)	√ Ventilatory support. √ IS * pain Mx.	√	√ Respiratory	
Rib fractures Ekpe & Eyo, (2016).	√	√			√ Chest physiotherapy.	
Pulmonary contusion & flail chest (PC-FC) Simon et al. (2012).	√		√ CPAP		√ Chest physiotherapy.	
Multiple rib fractures Witt & Bulger (2017).	√	√	√ IS	√ bundled care pathway	√ respiratory therapy √ hourly pulmonary hygiene √ positioning (elevation of head of bed)	√ Education

Key: CPAP- continuous positive airway pressure, IS- incentive spirometry, MRF- multiple rib fractures, Mx- management, PC-FC, pulmonary contusion- flail chest.

Chapter 5 will review and discuss the results presented in this chapter.

CHAPTER 5: DISCUSSION

5.1 Introduction

Non-pharmacological therapeutic interventions utilised in the management of adult patients with rib fractures in the acute care setting are by large published in isolation (no studies were found in which non-pharmacological therapeutic interventions were summarised and reviewed collectively and overall effects of these interventions simultaneously established). In addition, limited literature exists identifying these interventions and examining their overall effect on outcomes for this population.

In this systematic review, non-pharmacological therapeutic interventions utilised for acute pain management, as well as those interventions utilised to improve function following rib fractures in the acute care setting have been identified and reviewed. The effect of these non-pharmacological therapeutic interventions on the outcomes of pain as well as physical and respiratory function following acute rib fractures was evaluated. Secondary outcomes were reviewed relative to the effect of these interventions on LOS (hospital and ICU), incidence of pneumonia and mortality rate.

The rationale for use of non-pharmacological therapeutic interventions in the management of acute rib fractures is to assist pain reduction, and to promote recovery of function (respiratory and physical), with resultant effect on the incidence of respiratory complications, LOS and mortality rate. Invasive pain-relieving methods as well as pharmacological interventions carry their own risks and side effects associated with implementation and use, such as procedural risks and complications, as well as drug dependence and pharmacological side effects (Oncel et al., 2001). Non-pharmacological therapeutic interventions negate and reduce the risk of side effects or complications associated with pharmacological intervention use. These risks are especially important considerations in the management of the elderly who are more sensitive to pharmacological side effects (Davies & O'Mahony, 2015) and have also been identified as high-risk patients following rib fractures (Bergeron et al., 2003).

As already established, rib fractures are frequently encountered injuries presenting in the acute care setting following blunt thoracic trauma, with pain being the most common and debilitating symptom following injury (Karmakar et al., 2003; Dimitrov et al., 2017). Pain impacts all aspects of function and hinders recovery, as well as the patients' tolerance to treatment interventions (e.g. respiratory physiotherapy and incentive spirometry). Unmanaged acute pain leads to increased incidence or risk of complications, specifically respiratory complications (pneumonia incidence) due to an inability to breathe deeply or cough effectively, with resultant increases in LOS as well as increased morbidity and mortality rates (Easter, 2001; Witt & Bulger., 2017; Maduka et al., 2019). Pain management is thus a critical and fundamental component of care in the management of these patients if morbidity and mortality rates are to be curbed. Non-pharmacological therapeutic interventions may be

utilised for, or as an adjunct to pharmacological pain management following acute rib fractures. These non-pharmacological interventions could thus assist pain relief and promote recovery in the absence of risk associated with pharmacological interventions use.

Non-pharmacological therapeutic interventions identified in this systematic review as having positive effects on the outcomes of pain and function, following acute rib fractures managed in the acute care setting will now be reviewed in detail.

5.2 Non-pharmacological therapeutic interventions used to manage pain following acute rib fractures

Interventions identified in this review which provided pain relief to adult patients with acute rib fractures included acupuncture intervention, CPAP via facemask, physiotherapy modalities and TENS.

5.2.1 Acupuncture

Acupuncture in the form of filiform needle and auricular acupuncture were found in this review to reduce pain following implementation in patients with acute rib fractures. Filiform acupuncture intervention provided pain relief for patients with multiple rib fractures during the activities of deep breathing, coughing and turning in bed (Ho et al., 2014). Implementation of auricular acupuncture following traumatic rib fractures also lead to reduction in reported pain intensity following intervention in the case report presented by Papadopoulos et al., (2017).

Acupuncture is considered an alternative or complementary therapy that has been found to be increasingly used in the management of pain (Wilkinson & Faleiro, 2007; Kelly & Willis, 2019). As reviewed in chapter two, acupuncture aims to promote and restore the harmonious flow of energy via insertion of fine acupuncture needles into specific acupuncture points, stimulating the body's own healing response (Woo et al., 2010). Various postulated mechanisms of action have been utilised to explain the pain-relieving effects elicited by acupuncture therapy. Stimulation and release of naturally occurring opiates such as endorphins can potentially increase within the CNS leading to potent blockage or modulation of pain arising from the musculoskeletal system. In addition, similar to the mechanism of action induced by TENS, the neurogate theory may also explain the blockade of pain following acupuncture intervention. Adrenal activation and the release of endogenous corticosteroids, together with myofibrillary disentanglement may also result following acupuncture needle insertion, leading to pain reduction. Local blood flow may also increase, which could initiate and promote the healing process contributing to pain relief (Wilkinson & Faleiro., 2007). These changes induced could potentially account for the pain relieving effects observed following acupuncture intervention in patients with rib fractures in this systematic review.

Following review of the literature, acupuncture has been found to be utilised for a wide array of conditions including acute and chronic pain management (Cao et al., 2009; Woo et al., 2010; Linde et al., 2016; Vickers et al., 2018; Zhang et al., 2012; Manyanga et al., 2014; Patil et al., 2016). In light of these findings however, there is scarce evaluation or review of use of

acupuncture intervention in pain management for adult patients following acute rib fractures. Acupuncture may thus hold great potential as an effective and useful non-pharmacological therapeutic modality for use in the management of rib fracture pain, based on the studies evaluated in this systematic review and pain-relieving effects achieved following application in other patient populations. Further RCT are however required to substantiate these findings in the acute rib fracture population as current results are based on evidence from one RCT (providing a level 2 evidence rating) and a case report providing level 5 (low strength evidence rating) evidence. Additionally, as acupuncture becomes increasingly utilised in the management of pain (Wilkinson & Faleiro, 2007; Kelly & Willis, 2019), health care practitioners need to be aware of potential risks associated with acupuncture use. As acupuncture involves inserting needles up to several centimetres beneath the skin, the practice of acupuncture may thus pose some potential risks to patients as well as practitioners. One of the most important complications identified is the transmission of pathogenic micro-organisms, from environment to patient or from one patient to another (Woo et al., 2010). Factors such as needle reuse and/or inadequate skin disinfection has led to transmission of infectious micro-organisms, including bacteria and blood borne viruses (Woo et al., 2010). In the context of the African setting in which the human immunodeficiency virus (HIV) / acquired immune deficiency syndrome (AIDS) have been identified as the leading cause of morbidity and mortality in sub-Saharan Africa (Dwyer-Lindgren et al., 2019), this may give rise to increased risk for both patient and health care practitioner when acupuncture is implemented. This is especially relevant in light of the finding that most needle stick injuries are seen to occur in developing countries (Matsubara et al., 2017). Strict adherence to proper infection control guidelines should thus be considered as paramount and mandatory practice, if the risk of acupuncture transmitted infections to both patients as well as healthcare practitioner is to be avoided.

5.2.2 Physiotherapy modalities

5.2.2.1 ACBT and combined physiotherapy intervention

On review of the existing literature, limited studies were retrieved in which the effects of physiotherapy modalities such as ACBT were explored relative to the outcome of pain in patients following acute rib fractures. Only one study, a RCT was retrieved from the literature reviewing ACBT versus routine physiotherapy management as interventions utilised in the management of pain following acute rib fractures (Grammatopoulou et al., 2010). Reductions in pain were demonstrated in both the ACBT group as well as routine physiotherapy intervention group following intervention use in this study. Patients managed with ACBT however experienced more significant, rapid and consistent reductions in pain in comparison to routine management. Routine treatment consisted of positioning, early mobilisation, supportive coughing and flow orientated incentive spirometry. This group also experienced a reduction in pain however this reduction was not as rapid and fluctuated more relative to the ACBT group. Relative to these findings it is difficult to however distinguish which modalities in the routine treatment group specifically lead to this improvement. The authors concluded that the pain relief induced by the ACBT may have been mediated through the potential anti-inflammatory and healing effects induced by exercise, as well as the gate control theory of pain, descending pain mechanisms and possible placebo effect.

On review of other populations in which the interventions of ACBT and routine physiotherapy have been implemented, differences in results were noted in the following studies. Savci et al., (2006) reviewed ACBT versus incentive spirometry in combination with mobilisation following coronary artery bypass graft surgery. Results indicated that pain perceptions as evaluated during a deep breath were significantly decreased throughout the postoperative days in both groups. No significant differences in pain perception between the ACBT and incentive spirometry treatment groups were however noted. Derakhtanjani et al., (2019) found that following comparison of the effect of ACBT and routine chest physiotherapy (chest wall vibrations and manual percussions) on pain and respiratory parameters after coronary artery graft surgery, both methods increased pain perception following implementation and no significant differences were observed between group comparisons for this outcome.

Physiotherapy modalities may thus assist in pain management following acute rib fractures. As such physiotherapy interventions such as ACBT and combined physiotherapy interventions may hold potential as useful adjuncts in reducing pain following acute rib fractures. Further clinical trials are however required in order for this potential finding to be substantiated, as current results are based on only one level 2 single centre RCT as conducted by Grammatopoulou et al., (2010). This will allow for more robust evidence-based recommendations to be made regarding implementation of ACBT and combined physiotherapy interventions in the management of pain following acute rib fractures.

5.2.3 TENS

Transcutaneous electrical nerve stimulation is an inexpensive nonpharmacological therapeutic intervention utilised in health care practice in the management of multiple conditions (Vance et al., 2014). In the study conducted by Vance et al., (2014) reviewing TENS use for pain control, TENS when applied at adequate intensities, was documented to be effective in the management of symptoms related to postoperative pain, osteoarthritis as well as painful diabetic neuropathy. Acute as well as chronic pain conditions have been documented to be effectively managed with TENS use (Rakel & Frantz, 2003; Vance et al., 2014; Johnson et al., 2015). As reviewed in chapter two, TENS exerts its pain-relieving effects via activation of an intricate neuronal network, with analgesic effects being mediated through peripheral, central and endogenous pathways (Vance et al., 2014).

Analysis of results of this systematic review identified only one single centre cross- sectional study (level 4 evidence rating) in which the effect of TENS on pain intensity following acute rib fractures was evaluated (Mehta, 2013). An immediate reduction in pain intensity was documented following TENS use in this study conducted by Mehta, (2013). Study results and interpretation thereof are however limited by a small sample size as well as low level of evidence rating for this cross sectional study. Mehta, (2013) concluded that TENS therapy is an effective, reliable and practical method in controlling pain following rib fractures. These results concur with findings presented by Oncel et al., (2002) who conducted a single centre RCT reviewing TENS use versus NSAID's and placebo in the management of pain following uncomplicated minor rib fractures in patients aged 11- 81 years of age. The most effective treatment was found to be TENS on days one and three ($p<0.05$). The authors concluded that TENS therapy was an effective, reliable and practical method of controlling pain, and could be utilised as an alternative method for pain control following minor (three or less) rib

fractures. These findings are also in line with results demonstrated in other populations in which TENS has led to significant improvements in pain reduction following application. As reviewed in chapter two, TENS use as an adjunct to pain medication post thoracotomy lead to consistently lower pain scores and narcotic requirements in the TENS group in comparison to the placebo TENS group (Freynet & Falcoz, 2010). This finding was also demonstrated in the single centre RCT conducted by Jahangirifard et al., (2018) in postoperative patients following coronary artery bypass graft surgery, in which TENS application in comparison to routine management, lead to statistically significant reductions in pain at rest and during coughing. Reduced narcotic utilisation was also demonstrated in this group. In a pilot study conducted by Grover et al., (2018) reviewing use of TENS for pain management in the emergency department, TENS appeared to be effective in reducing pain when added to standard treatment.

As such, the vast majority of studies reviewed point towards effective pain relief following TENS application for pain management. Transcutaneous electrical nerve stimulation therefore holds high potential for use as an effective non-pharmacological therapeutic intervention in the management of pain following acute rib fractures. Further RCT reviewing TENS use for pain relief following acute rib fractures need to be conducted in order for stronger evidence based recommendations to be made for use in this population. Additionally, further studies reviewing TENS parameters for use, (site of application and duration of use) as well as effect on various rib fracture populations (simple, multiple or flail) will assist in directing evidence based standardised management practices and recommendations for use.

5.2.4 Non-Invasive ventilation (CPAP via facemask)

The application of CPAP via facemask was shown in one single centre RCT to lead to decreased analgesic use as well as pain scores (VRS) in comparison to MV via endotracheal intubation in patients with flail chest injury (Gunduz et al., 2005). Chest wall distortion following flail chest injury has been documented to be less during spontaneous breathing with CPAP than during intermittent mandatory ventilation (Tzelepis et al., 1989). Continuous positive airway pressure ventilation may thus provide potentially more effective stabilisation following flail chest injury than other positive pressure ventilation strategies (Gunduz et al., 2005). This may account for the reduction in pain experienced in the CPAP group (Gunduz et al., 2005). As this finding was demonstrated in only one RCT study (level 2 evidence), further RCT are required in order to support this finding.

5.2.5 Outcome measures used to assess pain in patients with acute rib fractures

Following evaluation of the results of this systematic review, the outcome measure utilised most frequently to evaluate pain following acute rib fractures was that of the VAS followed by the NRS and VRS. The VAS and NRS have been found to be reliable, valid scales sensitive to change in measuring pain severity and are commonly utilised scales for assessing acute pain intensity (Bendinger & Plunkett, 2016). Additionally, the VAS is considered the gold standard technique for acute pain evaluation and is frequently utilised in pain-related research (Bendinger & Plunkett, 2016). In the study conducted by Bijur et al. (2001) reviewing the reliability of the VAS for measurement of acute pain, findings indicated that the VAS was a highly reliable instrument for acute pain measures.

Relative to the acute rib fracture population, a systematic review assessing outcome measures utilised following rib fractures documented a lack of validated outcome measures for this patient population (Craxford et al., 2019). The authors recommended that further studies are needed to provide validated outcome measures to ensure accuracy of reported findings and conclusions. This was deemed important as no clear gold standards have been established. The authors concluded that this may account for the wide variety of patient reported outcome measures being utilised by researchers, including those not originally intended for evaluation in chest trauma (Craxford et al., 2019). The NRS was found to be the most frequently used instrument in assessing pain in this population and was found to be the most commonly utilised in clinical practice. According to the authors however, the Brief Pain Index (BPI) and McGill Pain Questionnaire (MPQ) capture more detailed information about the respondent's pain than evaluation of pain intensity alone and may thus give potentially greater content validity. Authors should take these findings into consideration when outcome measures in this patient population are established for future research.

5.3 Non-pharmacological therapeutic interventions used to influence physical function in patients following acute rib fractures

Following review of all included studies in this systematic review, no studies were found which objectively measured or evaluated physical function as an outcome via standardised or established outcome measurement tools. As a result, no specific interventions were identified which objectively lead to improvements in physical function following implementation. The only subjective report of improved physical function following acupuncture intervention was the study conducted by Ho et al., (2014).

5.3.1 Acupuncture

Acupuncture therapy has shown great possibilities in this review as a potentially effective and useful non-pharmacological therapeutic modality for use in the management of pain following rib fractures, as well as in aiding improvement in respiratory function. With regards to improvements in physical function, one would expect that with increased pain relief following acupuncture therapy, potential improvements in ability to move and general physical function and capacity would be increased. In the study conducted by Ho et al., (2014), following filiform needle intervention, some patients reported elevated motivation to get up and move following pain relief from acupuncture intervention. The authors of that RCT concluded that acupuncture management reduced the inconvenience caused by trauma and improved the QOL of patients during hospitalisation. In addition, reductions in pain intensity during deep breathing, coughing and turning were also demonstrated. Pain relief during these activities should therefore theoretically have allowed for greater capacity for turning over in bed and general bed mobility in the presence of reduced pain. No objective outcome measures to assess physical function as reviewed in chapter two were utilised in this study (Ho et al., 2014) to determine the impact of acupuncture intervention on the outcome of physical function.

In other patient populations reviewed in the literature, systematic review of acupuncture effectiveness in patients with rheumatoid arthritis revealed that acupuncture intervention may have positive effects on pain relief as well as physical function and health related QOL in

these patients (Seca et al., 2019). In addition, as reviewed in chapter two, improvements in both functional mobility as well as QOL were demonstrated in the systematic review conducted on acupuncture use in patients with osteoarthritis (Manyanga et al., 2014). As such acupuncture intervention may hold potential benefit in aiding and improving physical function following acute rib fractures. Review findings however indicate that no objective validation of the impact of acupuncture intervention on physical function following acute rib fractures has yet been explored in this population. Large scale clinical trials need to be conducted in order to test the efficacy of acupuncture therapy on recovery of patients' levels of physical function utilising standardised outcome measures to evaluate any changes objectively.

5.3.2 Outcome measures used to assess physical function in patients with acute rib fractures

No studies were found which specifically measured physical function as an objective outcome in the acute care setting following intervention implementation. Only subjective improvement in pain was reported in one study in this systematic review. No established outcome measures and tools, as reviewed in chapter two, were utilised to evaluate physical function in any of the studies retrieved. As such there appears to be a void in the use of objective outcome measures to assess physical function following intervention implementation following acute rib fractures. In addition, physical function appears to be seldomly utilised as an outcome measure to ascertain intervention effectiveness in this population. As physiotherapy aims to restore and improve function, specifically physical function following injury, inclusion of physical function as an outcome measure in assessing intervention effectiveness would seem an especially meaningful consideration and component of evaluation. This would prove particularly important if evidence-based recommendations regarding the use of interventions to improve physical function and drive changes in clinical practice are to be established.

5.4 Non-pharmacological therapeutic interventions used to influence respiratory function in patients following acute rib fractures

Interventions identified in this systematic review which aided improvement in respiratory function included acupuncture (Ho et al., 2014; Papadopoulos et al., 2017), TENS (Mehta, 2013) and NIV utilising continuous negative extrathoracic pressure (CNEP) (Linton & Sviri, 2006).

In addition to identification of treatment interventions aimed at reducing respiratory complications following acute rib fractures, respiratory screening protocols were also identified as important components of care which may assist in reducing pulmonary morbidity. Respiratory screening and serial evaluation aided in early detection of patients at high risk of respiratory compromise following rib fractures. Results obtained from screening were found to guide and direct appropriate patient management (Todd et al., 2006; Flarity et al., 2017). Initial bedside assessments of FVC and incentive spirometry values lead to directed implementation of clinical pathway management strategies, with early treatment initiation (Todd et al., 2006; Witt & Bulger, 2017; Flarity et al., 2017). These respiratory screening protocols proved effective in assisting health care professionals in identifying those at high risk of respiratory compromise, directing urgent necessary management thereby preventing further deterioration of respiratory function. As such these screening protocols

may assist in reducing overall compromise to respiratory function as a result of early detection of patients at risk, and prompt initiation of appropriate management. Use of such respiratory screening measures may thus prove beneficial in clinical practice and guide management decisions, possibly leading to improved respiratory function and reduced pulmonary complications.

5.4.1 Acupuncture

Following acute rib fractures, acupuncture intervention was shown in this review to lead to improvements in respiratory function following acupuncture therapy. In the single centre RCT conducted by Ho et al., (2014), filiform acupuncture intervention resulted in statistically significant improvements in SMI lung volumes when implemented in patients with one or more rib fractures. Additionally, initiation of auricular acupuncture intervention following traumatic rib fractures was found to lead to restoration of deep breathing, effective cough, and normalisation of respiratory rate. Improvements in saturation as well as hemodynamic profile following acupuncture intervention were also documented in the case report conducted by Papadopoulos et al., (2017). Improvements in respiratory function noted after acupuncture intervention following rib fractures may possibly be attributed to increased capacity to take deep breaths and generate larger lung volumes as a result of pain relief induced from acupuncture therapy. Improvements in respiratory function, specifically PEFR and FVC, following acupuncture intervention have also been reported in various other populations as reviewed in chapter two, including management of patients with asthma as well as following cardiac bypass graft surgery (Masao et al., 2009; Maimer et al., 2013). Additionally, when utilised as an adjunctive therapy, acupuncture has been shown to lead to improvements in levels of dyspnea on exertion as well as health-related QOL in patients with COPD (Feng et al., 2016).

Acupuncture thus holds potential as an effective and useful non-pharmacological therapeutic modality for use in the management and improvement of respiratory function in adult patients following rib fractures. Only two studies one with a level 2 evidence rating and one with a low evidence rating (level 5) were identified reviewing the impact of acupuncture therapy on respiratory function in this systematic review. For more robust evidence-based recommendations to be made regarding implementation of acupuncture intervention in adult patients following acute rib fractures, further RCT's are required. In addition, standardisation of application (needle type and placement), duration of application and frequency as well as the rib fracture population (simple, multiple or flail) deriving most benefit from application, should be explored.

5.4.2 TENS

Transcutaneous electrical nerve stimulation used in conjunction with pharmacological intervention has been shown by others to reduce pain during movement leading to increased mobility (Rakel & Frantz, 2003) and improvements in respiratory function (Monisha et al, 2017; Jahangirifard et al., 2018). Transcutaneous electrical nerve stimulation could thus be of significant value in the management of patients with acute rib fractures as reduction in pain, together with increased ability to mobilise and improved respiratory function are key strategies in the management of these patients. Despite these advantageous effects, very few

recent studies were sourced in the literature relative to TENS use in the management of acute rib fractures and effect on respiratory function.

Of the studies meeting the inclusion criteria for this systematic review, Mehta, (2013) demonstrated that TENS lead to an immediate reduction in pain following application over the site of pain, with marked increases in PEFR and oxygen saturation being noted following TENS use. Improvements in PEFR and oxygen saturation may have resulted from improved capacity to take deep breaths as a result of pain relief following TENS application. This increased ability to breathe deeply would have resulted in increased lung volumes with resultant improvements in capacity for gaseous exchange, possibly accounting for the improvements in oxygen saturation observed. This cross-sectional study conducted by Mehta, (2013) however, provides a low level of evidence and as such further high-quality clinical trials are required to confirm these findings.

In relation to other studies conducted, Sloan et al., (1986) reviewed the effectiveness of TENS on patients admitted with multiple rib fractures. Transcutaneous electrical nerve stimulation therapy led to statistically significant reductions in pain and also led to statistically significant improvements in PEFR ($p=0.03$) as well as PaO_2. Improvements in these respiratory parameters were attributed to improved pain control from TENS use. This allowed for greater respiratory excursion and assisted accommodation to physiotherapy intervention thus allowing for more effective physiotherapy to take place. The use of TENS has also been found to improve respiratory function in additional populations identified in the literature.

As reviewed in chapter two, TENS application post thoracotomy together with postoperative pain medication, was found to be effective in improving forced expiratory volume in the first second (FEV_1) and FVC, as well as ability to cough during chest physiotherapy (Freynet & Falcoz, 2010). In the study conducted by Erdogan et al., (2006) reviewing the effect of TENS on post thoracotomy pain and pulmonary function, the TENS group relative to placebo TENS group demonstrated significant reductions in pain as well as statistically significant improvements in FEV_1 and FVC at specific time periods post operatively. The authors concluded that TENS lead to reductions in post thoracotomy pain and improved pulmonary function. Additionally Jahangirifard et al., (2018) also documented positive outcomes relating to respiratory function following TENS use postoperatively. Following coronary artery bypass graft surgery, TENS use in comparison to routine management lead to statistically significant improvements in pulmonary function specifically FEV_1 and FVC. Monisha et al., (2017) conducted a study reviewing the effects of TENS and respiratory physiotherapy on pain and respiratory capacity following coronary artery bypass graft surgery. Conventional chest physiotherapy (including deep breathing exercise, lung expansion exercise, secretion removal techniques, and assisted cough) together with TENS was found to significantly decrease atelectasis and improve PEFR in comparison to conventional chest physiotherapy alone.

As such TENS appears to offer potential as a non-pharmacological therapeutic intervention which may be utilised to assist in restoring or improving respiratory function following acute rib fractures. Limited evidence exists documenting implementation of TENS in the adult rib fracture population for the purpose of evaluating its effect on respiratory function. Further clinical trials are thus required to investigate this possible relationship of TENS use in the adult rib fracture population and potential benefit on the outcomes of their respiratory function. This is especially important as the cross-sectional study conducted by Mehta, (2013)

generated a low evidence rating and as such further high quality trials are required to confirm these findings.

5.4.3 Non-invasive ventilation

Continuous negative extrathoracic pressure is an alternative, non- invasive form of respiratory support (Shah et al., 2013). As reviewed in chapter two, CNEP is applied to the external thorax utilising a negative pressure chamber which produces lung expansion. A case report documenting the successful use of NIV utilising CNEP around the chest wall of an elderly patient having sustained a large anterior flail segment was demonstrated by Linton & Sviri, (2006). A more effective cough effort, together with preservation of spontaneous breathing was demonstrated following use, together with effective support of FRC, provided by the splinting effect of CNEP. Various other studies have documented positive outcomes on respiratory function following use of CNEP ventilation in other populations.

A large proportion of studies reviewing use of negative pressure ventilation have however been conducted in the pediatric population (Shah et al., 2013; Shime et al., 2006) and in the treatment of adults with obstructive sleep apnea (Kram et al., 2017; Blackman et al., 2019). As such further clinical trials reviewing use of CNEP following acute rib fractures need to be conducted to establish conclusive results regarding the effects of CNEP on clinical patient outcomes in this specific population. The current level of evidence rating for the case report conducted by Linton & Sviri, (2006) is level 5 (low evidence rating) and as such more robust clinical trials are required to guide evidence-based practice.

5.4.4 Outcome measures used to assess respiratory function in patients with acute rib fractures

Outcome measures found to be utilised in the evaluation of respiratory function following intervention implementation after acute rib fracture injury included PEFR (Mehta, 2013) and SMI lung volumes as evaluated through the TriFlow incentive spirometer (Ho et al., (2014).

Evaluation of lung volumes to assess efficiency of intervention effectiveness on respiratory function has been documented in various other populations. Freynet & Falcoz, (2010) reported improvements in respiratory function as documented by increases in both FEV_1 and FVC following TENS application post thoracotomy. Improvements in PEFR were also documented in the study conducted by Monisha et al., (2017) following TENS therapy in post-operative patients after coronary artery bypass graft surgery, indicating functional improvements in respiratory capacity. As such documentation of improvements in respiratory volumes, PEFR and capacities are frequently utilised to assess changes in respiratory function following intervention implementation. Outcome measures utilised to assess respiratory function such as PEFR, FEV_1 and FVC, appear to be measures frequently utilised to evaluate changes in respiratory function following intervention implementation. This appears to be the trend in evaluation of respiratory function in patients having sustained acute rib fractures as well as in other patient populations reviewed.

5.5 Factors associated with patients' clinical outcomes following acute rib fractures

Non-pharmacological therapeutic interventions influencing patient outcomes of LOS, mortality rate and incidence of pneumonia will now be reviewed in detail. These outcomes as reviewed in the literature to follow may often be affected by factors other than the intervention implemented. Additionally, associated injuries have been identified as factors exerting significant influence and impact on management implemented, as well as morbidity and mortality rates following rib fractures (Dimitrov et al., 2017; Witt & Bulger., 2017; Maduka et al., 2019). These associated injuries are therefore important considerations and components to identify and consider when management is instituted. Associated injuries identified in this systematic review occurring in conjunction with rib fractures documented from increasing to decreasing prevalence included: pneumothorax, pulmonary contusion, haemothorax, haemopneumothorax, sternal fractures and tension pneumothorax. These findings are in line with other studies documenting associated thoracic injuries encountered in combination with rib fractures (Dimitrov et al., 2017, Maduka et al., 2019).

The incidence of associated chest injuries has been shown to occur with increasing frequency in patients with three or more rib fractures in comparison to those patients with two or less rib fractures (Dimitrov et al., 2017). On evaluation of the studies reviewed, multiple rib fractures were more commonly documented than isolated fractures following injury and may account for the extent of associated injuries noted in this systematic review. With the main mechanism of injury across studies being identified as that of motor vehicle accidents, this may account for the extent of rib fractures (multiple versus simple) observed due to the major force and trauma associated with MVA's. In addition to the presence of associated injuries, factors influencing overall management and outcome identified in this review included age, gender, ISS, weight or BMI, mechanism of injury, smoking history, tube thoracotomy and number of ribs fractured. In the elderly population, age, fall from a higher ground level as well as recent use of anticoagulant or antiplatelet medications were factors specifically used to identify high risk patients to assist and direct management of these patients (Sahr et al., 2013). These factors aid in identification of those patients at greatest risk of deterioration and appropriate management strategies can thus be implemented early on (i.e. appropriate analgesic intervention or direct admission to an ICU). Additionally, comorbidities have been shown to impair patient recovery after traumatic injury (Gabbe et al., 2016). As such factors affecting patient management and clinical outcomes as identified in this systematic review should be identified early on so that high risk patients can be appropriately managed, in order that positive effects on patients' clinical outcomes can be achieved.

5.5.1 Interventions impacting incidence of pulmonary/respiratory complications

Following narrative review of study results, incidence of pneumonia and pulmonary complications were found to be reduced by implementation of NIV modalities (Garfield & Howard-Griffin, 2000; Gunduz et al., 2005; Linton & Sviri, 2006). Physiotherapy modalities specifically ACBT (Grammatopoulou et al., 2010) and interventions such as acupuncture therapy (Ho et al., 2014) were also shown to lead to positive effects on this outcome. Multidisciplinary care and treatment pathways/bundles were also found to lead to reduced risk of pneumonia following review of meta-analysis conducted in this systematic review. Text and opinion studies identified early mobilisation as an important intervention in reducing

respiratory complications (Unsworth et al., 2015; Easter, 2001). Interventions identified in reducing incidence of pulmonary complication following acute rib fractures will now be reviewed in detail.

5.5.1.1 Acupuncture

Only one study in this systematic review reported on the possible effects of acupuncture on incidence of pulmonary complications. Subjective reports of increased capacity to breathe deeply, cough and expectorate secretions as well as increased compliance with physiotherapy intervention were documented following acupuncture intervention (Ho et al., 2014). The pain relief provided by acupuncture intervention could account for these findings and could understandably facilitate improved respiratory hygiene, via increased capacity to breathe deeply and cough and expectorate secretions effectively. As this was a subjective analysis based on the results of one RCT, future clinical trials reviewing measurable changes in objective outcomes are however required to substantiate these findings in order for evidence-based recommendations to be made.

5.5.1.2 Physiotherapy modalities

Physiotherapy interventions have been identified in this systematic review as integral components of patient management following acute rib fractures. Physiotherapists were identified as vital members of the MDT, and physiotherapy was identified as an important treatment intervention as well as component of bundled care pathways in managing patients following acute rib fractures (Easter, 2001; Gunduz et al., 2005; Todd et al., 2006; Sahr et al., 2013; Unsworth et al., 2015; Curtis et al., 2016; Ekpe & Eyo, 2016). Physiotherapy interventions identified and implemented in this systematic review to address respiratory function and prevent respiratory deterioration included progressive mobilisation strategies and positioning, chest physiotherapy techniques and active deep breathing exercises. These findings concur with physiotherapy modalities identified and reviewed as part of treatment modalities utilised by physiotherapists globally in the management of patients with major chest trauma (van Aswegen et al., 2019).

In the RCT conducted by Grammatopoulou et al., (2010) patients 45 years of age and older with at least three rib fractures were allocated to ACBT or routine physiotherapy intervention. These physiotherapy interventions were reviewed relative to their effect on the incidence of pulmonary complications following implementation. Results indicated that both ACBT and routine physiotherapy intervention (positioning, early mobilisation, supportive coughing and incentive spirometry) led to no pulmonary complications being observed in either group following intervention implementation. These results indicate that physiotherapy interventions may thus assist in reducing the incidence of pulmonary complications following multiple rib fractures. Further trials are required to substantiate these findings, as current results are based on one RCT. In addition, studies that investigate which combination of physiotherapy modalities may have led to this outcome will further guide recommendations for evidence-based interventions. Relative to other patient populations, implementation of similar physiotherapy modalities led to comparable results being noted in these populations. Savci et al., (2006) evaluated the efficacy of incentive spirometry and ACBT together with mobilisation following coronary artery bypass graft surgery. Results indicated that both

modalities had similar beneficial effects on rate of atelectasis, pain perception, and functional capacity following surgery.

Chest physiotherapy and rapid mobilisation through physiotherapy were also identified as pivotal components to include in the management of patients following acute rib fractures in review of text and opinion studies included in this systematic review. These interventions were recommended to prevent respiratory complications and minimise the likelihood of respiratory failure from ensuing after injury (Easter, 2001; Simon et al., 2012; Unsworth et al., 2015). Respiratory therapists were also involved in bundled clinical care pathway implementation in the study conducted by Witt & Bulger, (2017) and were responsible for identification and screening of patients for respiratory deterioration. Ekpe & Eyo, (2016) additionally identified chest physiotherapy and mobilisation together with appropriate pain control as preferred modes of management for patients with blunt chest trauma. Chest physiotherapy along with selective use of MV and analgesia was also recommended following review of the EAST practice management guidelines for pulmonary contusion and flail chest management, as initial management strategies for these patients (Simon et al., 2012).

As such on evaluation of the results of this systematic review, respiratory physiotherapy or chest physiotherapy appears to play a potentially vital role in managing patients following acute rib fractures in reducing the incidence of pulmonary complications in this population. As the goals of respiratory therapy in critical care patients are aimed at promoting secretion clearance, maintenance and recruitment of lung volumes, optimisation of oxygenation and prevention of respiratory complications in both the intubated and spontaneously breathing patient (Berney et al., 2012), this may account for the possible reduction in incidence of respiratory complications observed following physiotherapy intervention in the included studies. Respiratory physiotherapy interventions which may be in the form of airway clearance techniques as well as lung expansion exercises (e.g. ACBT) as identified in this review may thus be considered important components of management in the treatment of patients following rib fractures. These interventions aim at restoring and maintaining respiratory function and may therefore aid in reducing the incidence of pulmonary complications observed following acute rib fractures.

In addition to identification of interventions leading to reduction in the incidence of pulmonary complications, this systematic review also highlights the importance of screening protocols to detect early deterioration in respiratory function. Serial screening and evaluation of respiratory function allowed for prompt detection of respiratory compromise and appropriate management to be implemented timeously as a result. This may result in reduced overall incidence of pulmonary morbidity due to early detection and management. Witt and Bulger, (2017) documented continued evaluation and assessment of patients with multiple rib fractures as well as their inspiratory spirometry levels (by respiratory therapists) as an important aspect of their multidisciplinary bundled care pathway. The pathway utilised a PIC scoring tool (referring to pain, inspiratory capacity, and cough effort evaluation) to serially evaluate and monitor patients. Management interventions were thereafter instituted dependent on overall scores achieved. Serial screening measures to guide care were also documented in other studies included in this systematic review (Todd et al., 2006; Flarity et al., 2017).

Physiotherapists' roles in the management of patients following acute rib fractures are therefore not only confined to implementation of treatment modalities, but also in respiratory

screening and evaluation as demonstrated by Witt & Bulger (2017). As such this emphasises the role of physiotherapists as well as other health care practitioners in not only implementing treatment but also highlights the importance of continued evaluation and reassessment of patients' respiratory function following rib fractures. Serial evaluation enabled guided management and intervention implementation based on objective parameters, which may assist in reducing the incidence of respiratory complications observed. Kourouche et al., (2018) also documented the importance of early identification of potential respiratory compromise following blunt chest injury and correlation with outcome. Strong evidence was found supporting low vital capacity or incentive spirometry effort on initial assessment being associated with worse outcomes in patients having sustained blunt chest trauma. Incentive spirometry thus appears to be a useful modality for evaluation and screening of respiratory function following blunt chest injury and was also utilised as a treatment intervention in some studies included in this systematic review.

5.5.1.2.1 Incentive spirometry

Incentive spirometry was utilised or recommended for use in the management of patients following acute rib fractures in a few studies included in this systematic review (Easter, 2001;Todd et al., 2006; Grammatopoulou et al., 2010; Curtis et al., 2016; Witt & Bulger, 2017). In these studies, incentive spirometry was used as part of combined treatment interventions as in the study conducted by Grammatopoulou et al., (2010) in which incentive spirometry was utilised as part of treatment in the routine physiotherapy management group. Like the ACBT group the routine physiotherapy intervention group had no documented respiratory complications post intervention implementation. It is however uncertain which modality/modalities in the combined intervention group led to this outcome.

Curtis et al., (2016) also documented use of incentive spirometry as part of initial management in combination with HFNP oxygen and multimodal analgesia as did Todd et al., (2006) in which incentive spirometry and PCA were utilised on admission. Easter, (2001) included use of spirometry as part of respiratory support alongside rapid mobilisation and appropriate pain management as key practices in the management of patients with multiple rib fractures. Witt & Bulger, (2017) included incentive spirometry as part of management in their MDT care bundle instituted for the management of patients with multiple rib fractures. For the most part in the studies reviewed, incentive spirometry served greater purpose as an important screening intervention, as did early bedside FVC, aiding early detection of patients at risk of respiratory compromise and guiding appropriate management and treatment interventions to be implemented (Easter, 2001; Todd et al., 2006; Flarity et al., 2017; Witt & Bulger et al., 2017). Kourouche et al., (2018) also documented that complication prevention in blunt chest injuries requires means of identification of potential for respiratory deterioration. Incentive spirometry or vital capacity was utilised in assessment of the patient's inspiratory effort to guide management of these patients and identify those at risk of deterioration. Incentive spirometry appears to be a potentially useful modality in screening respiratory function and directing management of patients following acute rib fractures.

Incentive spirometry as a treatment intervention in managing patients following acute rib fractures was only utilised as part of a combined management strategy (Todd et al., 2006; Grammatopoulou et al., 2014; Curtis et al., 2016). As such it is difficult to ascertain its individual effectiveness as a treatment intervention in reducing the incidence of pulmonary

complications on its own. Further clinical trials reviewing incentive spirometry as an intervention would therefore need to be conducted in order to establish the effects of this individual modality on the incidence of pulmonary complications following acute rib fractures. In the blunt chest injury population, use of incentive spirometry was not supported by sufficient evidence for use in all blunt chest injury patients in reducing pulmonary complications and mortality (Kourouche et al., 2018). Instead volume-driven incentive spirometers were deemed to be appropriate for use in alert motivated patients as a means of reminding and prompting patients to perform regular deep breathing exercises (Kourouche et al., 2018).

In relation to other patient populations, incentive spirometry has been utilised in an attempt to improve pulmonary capacities and volumes and prevent associated respiratory complications especially following surgery (Naz et al., 2014; Tripathi et al., 2017; Singh et al., 2017). In the pilot study conducted by Tripathi et al., (2017) deep breathing exercise together with incentive spirometry improved respiratory function and lung capacity and prevented postoperative pulmonary complications following abdominal surgery. In addition, in a study reviewing the effectiveness of incentive spirometry in preventing post-operative pulmonary complications following laparotomy, Naz et al., (2014) found that in comparison to breathing exercises alone, incentive spirometry together with deep breathing exercises lead to significant improvements on the BORG scale ($p=0.00$) and FEV_1/FVC ratio ($p=0.00$) in comparison to the deep breathing group alone. A small sample size was however utilised in this study and further validation of these results with larger sample sizes may be required. In the clinical practice guideline evaluation conducted by Restrepo et al., (2011) reviewing incentive spirometry, the following recommendations were made following appraisal utilising the GRADE scoring system. Incentive spirometry alone was not recommended for routine use in the preoperative and postoperative setting to prevent postoperative pulmonary complications. Additionally, recommendation was made that incentive spirometry be used with deep breathing techniques, directed coughing, early mobilisation, and optimal analgesia to prevent postoperative pulmonary complications. It was also suggested that deep breathing exercises provide the same benefit as incentive spirometry in the preoperative and postoperative setting to prevent postoperative complications.

The results of this systematic review therefore indicate that incentive spirometry may be implemented as a useful screening measure to assist identification of those patients at risk of respiratory compromise following acute rib fractures. In addition, incentive spirometry, when used in combination with other management interventions, led to positive effects on the incidence of pulmonary complications in some studies. No studies were found in which incentive spirometry was utilised in isolation and its effects on pulmonary function evaluated. Further clinical trials reviewing incentive spirometry use in this population as a treatment modality are thus required in order for robust evidence based recommendations to be made.

5.5.1.3 Non-invasive ventilatory modalities

Non-invasive ventilation has been identified as a ventilatory modality utilised in the management of trauma patients, specifically following blunt thoracic trauma (Chiumello et al., 2013; Karcz & Papadakos, 2015). Non-invasive ventilation provides a means of supporting ventilation whilst avoiding intubation and the associated complications as well as side effects associated with invasive ventilatory means (Chiumello et al., 2013; Duggal et al.,

2013; Karcz & Papadakos, 2015). This has been identified as a major driving force behind the increasing use of NIV (Mehta & Hill, 2001). There are a number of methods available of providing NIV as reviewed in chapter two, including positive pressure ventilation such as CPAP or continuous negative pressure ventilation such as CNEP.

Non-invasive ventilatory modalities were found in this systematic review to reduce the incidence of pulmonary complications/incidence of pneumonia following flail chest injury in three studies reviewed. Non-invasive ventilatory modalities identified included CPAP use together with PCA in the RCT conducted by Gunduz et al., (2005) as well as IPPB via a Bird ventilator, CPAP via facemask and NIPPV via nasal mask (Garfield & Howard-Griffin, 2000) and CNEP (Linton & Sviri, 2006), both latter studies being case reports. These modalities were found to reduce the incidence of pulmonary complications or avoid pulmonary morbidity completely following implementation.

In the RCT conducted by Gunduz et al., (2005) results indicated non-invasive CPAP use together with PCA resulted in lower nosocomial infection rates in comparison to the endotracheal intubation group. Preservation of spontaneous breathing during CPAP allowing for improved pulmonary hygiene possibly accounted for the reduction in pulmonary morbidity observed in the CPAP group. These findings concur with other studies which show that endotracheal intubation is associated with increased risk of development of pulmonary complications such as pneumonia (De Souza et al., 2014). Ventilator-associated pneumonia (VAP) has been found to be the second most common nosocomial infection in the ICU and the most common in mechanically ventilated patients (Kalanuria et al., 2014; Arumugam et al., 2018). As such if patients can be effectively managed by non-invasive ventilatory means, incidence of VAP may be reduced. In the case reports presented in this review in which NIV modalities included CPAP (Garfield & Howard-Griffin, 2000) and CNEP (Linton & Sviri, 2006) in the management of respective patients with flail chest injury, Garfield & Howard-Howard-Griffin, (2000) documented no evidence of systemic or pulmonary infection at any stage of acute care management in which IPPB via a Bird ventilator, CPAP via facemask and NIPPV via nasal mask were utilised. Additionally, Linton & Sviri, (2006) implemented use of CNEP following flail chest injury which preserved the patients' ability to breathe and cough freely around the mandatory negative pressure applied and supported FRC. This preservation of ability to cough and breathe freely was concluded by the authors to allow for reduction in the incidence of laryngeal injury and ventilator-associated complications observed. Due to preservation of airway integrity, ability to maintain spontaneous breathing and ability to cough freely, NIV modalities such as CPAP and CNEP use in patients with flail chest injuries may thus lead to a reduction in the incidence of respiratory complications observed. These factors together with avoidance of invasive ventilator-associated complications may account for reduced pulmonary morbidity noted (Linton & Sviri, 2006). As these results were derived from two case reports which possess a low evidence rating of 5 (Garfield & Howard-Griffin, 2000; Linton & Sviri, 2006) and only one RCT, further clinical trials need to be conducted in order for these results to be to be substantiated.

Continuous positive airway pressure via facemask thus appears to be a potentially useful non-invasive ventilatory means in the management of patients having sustained rib fractures following blunt thoracic trauma who require ventilatory support (Gunduz et al., 2005; Simon et al., 2012). Non-invasive ventilatory modalities such as CPAP may aid in reducing the incidence of pneumonia and pulmonary complications associated with invasive ventilatory means.

In comparison to previous studies conducted, Chiumello et al., (2013) in their systematic review and meta-analysis indicated that the early use of NIV in chest trauma patients facilitated stabilisation of the chest and promoted recruitment of collapsed lung regions. Non-invasive ventilation instituted consisted of CPAP or BiPAP or non-invasive intermittent pressure support ventilation. This led to significantly reduced mortality and intubation rates, ICU LOS, as well as lower infection rates when integrated with medical intervention. Additionally, Duggal et al., (2013) reviewed the use of NIV modalities in patients following blunt chest trauma. Non-invasive ventilation was considered by the authors to be either CPAP or NPPV. The authors concluded that use of these NIV modalities may be considered for patients with blunt chest trauma who are neurologically intact, hemodynamically stable and prior to the development of overt respiratory failure.

Inclusion of NIV in care bundles for use in the management of patients following blunt thoracic trauma was recommended as possible management interventions in the study conducted by Kourouche et al., (2018) and were also identified in this systematic review as possible modalities for inclusion in care bundles following acute rib fractures (Todd et al., 2006).

5.5.1.4 Mobilisation

In the text and opinion studies included in this systematic review (Easter, 2001 and Unsworth et al., (2015)), early mobilisation was advocated as a pivotal intervention in reducing respiratory complications following multiple rib fractures. Easter (2001) identified early mobilisation as a key factor in successfully preventing hypoventilation, atelectasis and retained secretions which may lead to pneumonia, respiratory failure and ARDS in patients having sustained rib fractures. Recommendation was made that following rib fractures patients should be encouraged to sit up and walk short distances in order to maintain adequate ventilation and lung perfusion (Easter, 2001). Additionally, in the study conducted by Grammatopoulou et al., (2010), early mobilisation formed part of the routine physiotherapy intervention which also resulted in no pulmonary complications being observed alongside the ACBT intervention group. Ekpe & Eyo, (2016) likewise identified mobilisation as a preferred modality in the management of patients with blunt chest trauma.

Findings of this systematic review indicate that early mobilisation is an important intervention to implement in the management of patients following acute rib fractures (Easter, 2001; Unsworth et al., 2015; Ekpe & Eyo 2016; Witt & Bulger., 2017). Furthermore, early mobilisation has been identified as an important component of rib fracture care bundles (Todd et al., 2006; Sahr et al., 2013). This conclusion is in line with early mobilisation being established as a vital component of bundled care intervention identified for inclusion in blunt chest injury care bundles as established by Kourouche et al., (2018). In addition, mobilisation activities have been shown to be widely used by physiotherapists globally to optimise both respiratory and musculoskeletal function in the management of patients with major chest trauma (van Aswegen et al., 2019). Emphasis on early mobilisation as a vital principle of care in blunt chest trauma patients regardless of injury severity was reiterated by Battle et al. (2013). Further studies have also identified mobilisation as an important management intervention in the care of patients following blunt chest trauma and rib fractures (Easter, 2001; Todd et al., 2006; Battle et al., 2013; Witt & Bulger, 2017).

In relation to other populations reviewed, mobilisation has also been shown to reduce the risk of developing hospital-acquired pneumonia in patients admitted to the ward following abdominal injury or trauma (Stenlund et al., 2017). Additionally, early mobilisation of patients in the trauma and burns ICU resulted in decreased incidence of pneumonia and DVT, as well as airway, pulmonary, and vascular complications (Clark et al., 2013). Reductions in respiratory complications following mobilisation intervention in this population was attributed to likely improvements in ventilation/perfusion matching, lung compliance, mucociliary clearance as well as reduced work of breathing (Clark et al., 2013). This may also account for the reduction in incidence of pulmonary complications observed following mobilisation strategies in patients with acute rib fractures as observed in this systematic review.

When viewed in light of the findings of this systematic review and relative to results demonstrated in other populations, mobilisation thus appears to offer potential benefit as a non-pharmacological therapeutic modality which may assist in reducing the incidence of pulmonary complications. As such mobilisation may be considered an important component of care in the prevention of respiratory complications following acute rib fractures. As physiotherapists are frequently involved in the evaluation and implementation of mobilisation in the acute care setting (Stiller et al., 2013) and as members of the MDT, physiotherapists should therefore encourage and drive mobilisation strategies in the management of patients following rib fractures. Stiller (2013) advocated that ICU physiotherapists should prioritise interventions aimed at early progressive mobilisation.

5.5.1.5 Multidisciplinary care and treatment pathways/bundles.

Bundled care pathways and CPG are a set of three to five evidence-based practices which have been identified as essential components of care for specific healthcare conditions. These evidence-based practices together, when implemented, consistently and reliably, may lead to improved patient outcomes and quality of care according to Lavallée et al., (2017).

Studies identified in this systematic review have found that multidisciplinary care and treatment pathways/bundles are essential components in the management of patients following acute rib fractures (Todd et al., 2006; Sahr et al., 2013; Unsworth et al., 2015; Curtis et al., 2016; Flarity et al., 2017; Witt & Bulger, 2017). Evidence advocates use of bundled care and clinical pathways in the management of patients following rib fractures, to facilitate multidisciplinary care and standardise practice (Unsworth et al., 2015; Witt & Bulger, 2017).

In this systematic review appropriate aggressive pain management, early mobilisation, MDT care, chest physiotherapy or respiratory therapy including pulmonary toilet or physical therapy and ventilatory support were identified as components of bundled care intervention which may be utilised in the management of adult patients with rib fractures. Physiotherapy intervention was documented in various pathways as an integral part of MDT care in bundled pathway management (Todd et al., 2006; Sahr et al., 2003; Curtis et al., 2016). Both respiratory therapy as well as physical therapy in the form of mobility, muscle strengthening and range of movement and balance exercises directed at rehabilitating the musculoskeletal system was identified as part of bundled care interventions. In some studies, additional modalities such as positioning, incentive spirometry as well as family and patient education

were included in bundled care pathways for management of these patients (Easter, 2001; Unsworth et al., 2015; Witt & Bulger, 2017).

Continued evaluation and management of the respiratory system was also identified as a crucial component of care when identifying patients for entry into care pathways, as well as in directing management of patients with acute rib fractures (Todd et al., 2006; Witt & Bulger, 2017; Flarity et al., 2017). This is as a consequence of respiratory deterioration and ensuing respiratory complications often being identified as a source of increasing morbidity and mortality following rib fractures (May et al., 2016; Unsworth et al., 2015; Witt & Bulger, 2017). As such bundled care pathways across all included studies examining clinical pathway intervention, included respiratory care as a critical step in the management pathway. These results concur with the interventions identified for inclusion in care bundles following blunt chest injury as recommended by Kourouche et al., (2018). Respiratory support, analgesia, complication prevention strategies (including chest physiotherapy, active deep breathing and directed coughing techniques, early mobilisation and patient education) as well as surgical fixation (when indicated) were included in the blunt chest injury care bundle. Since there are no systematic reviews which specify exact components of rib fracture care bundles, as has been conducted for blunt chest injury, the results of this current study were compared to the care bundle established for blunt chest injury management by Kourouche et al., (2018).

Review of meta- analysis conducted in this systematic review for bundled care intervention showed a statistically significant risk reduction of 63% for incidence of pneumonia following bundled care implementation. The populations for which bundled care intervention proved effective in reducing the incidence of pneumonia relative to these findings included patients 45 years of age and older with greater than four rib fractures (Todd et al., 2006), and in elderly patients having sustained rib fractures from blunt thoracic trauma (Curtis et al., 2016). Pooled analysis however only included two cohort studies and interpretation of results should be reviewed with this limitation in mind. Additionally, following appraisal of the evidence, overall quality of evidence evaluation according to the GRADE approach was rated as very low due to the study design as well as rating down of evidence due to serious concern for imprecision (number of participants and overall incidence/events was concluded as small). Results of this meta-analysis should thus be interpreted in light of these findings.

The reduction in pneumonia incidence demonstrated in this systematic review may be attributed to enhanced delivery of healthcare services such as faster and increased access to pain and physiotherapy intervention and respiratory and ventilatory support in comparison to those who did not receive bundled care intervention. With more timely pain control and implementation of respiratory physiotherapy and pulmonary toilet techniques as well as mobilisation, resultant respiratory compromise and subsequent deterioration could thus have been minimised. This may account for the reduction in incidence of pneumonia demonstrated in meta-analysis conducted. Other studies reviewing incidence of hospital acquired pneumonia found a reduction in incidence of pneumonia in patients following abdominal injury and trauma, as a possible result of physiotherapy intervention implemented, in which mobilisation and respiratory training were utilised (Stenlund et al., 2017).

Bundled care intervention may thus reduce the risk of pneumonia incidence in patients with acute rib fractures based on the results of this systematic review. Further clinical trials are required to substantiate these findings to increase the strength of evidence-based recommendations for this outcome.

5.5.1.5.1 Education

Education was included as part of the multidisciplinary bundled care pathway for the management of patients with multiple rib fractures in the study conducted by Witt and Bulger, (2017). This was the only study in this systematic review which included education as part of treatment intervention implemented following acute rib fractures. The authors documented family and patient education, specifically regarding attainment of incentive spirometry goals as part of management practices implemented in their care pathway. Relative to the blunt chest injury care bundle established by Kourouche et al., (2018) patient education regarding deep breathing exercises, directed cough as well as analgesia, were included components of complication prevention strategies in the care bundle identified. Concerning global physiotherapy practice evaluation of the management of patients following major chest trauma, education was identified as the most commonly used pain management strategy, however, this approach was not widely used (van Aswegen et al., 2019). Following review of these findings, patient education therefore appears to be a potentially important component of care to implement following blunt chest trauma in reducing pain and incidence of respiratory complications.

Educational intervention was seldomly utilised in the treatment of patients following acute rib fractures in this systematic review. This is an unfortunate finding especially when the positive effects of education intervention specifically relating to pain relief are reviewed in relation to other patient populations (Turk &Wilson, 2010; Louw et al., 2011). In light of the fact that pain has been identified as the most limiting symptom following rib fractures alongside respiratory compromise, implementation and evaluation of educational strategies targeting these problematic symptoms may potentially assist in patient management and prevention of respiratory complications. Future studies should thus aim to incorporate educational intervention into treatment practices following acute rib fractures to ascertain their effectiveness in the management of pain and impact on respiratory complications in this population. In addition, the experience of pain is multifactorial in nature and may be affected by anxiety and traumatic stress symptoms. This may be especially prevalent following road traffic crashes and may lead to fear-avoidance behaviour, with limitation of activity, disuse, and disability presenting (Fitzharris et al., 2006). As such awareness by all healthcare professionals in all disciplines regarding these interactive factors on the experience of pain and the importance of patient education has been identified as essential for holistic patient management (Woo, 2010).

5.5.2 Length of stay and mortality rate

For the outcomes of LOS as well as mortality rate, these outcomes may be affected by a number of factors (including age, injury severity, underlying co-morbidities and associated injuries) independent of the intervention implemented (Sahr et al., 2013). Interventions affecting patient outcomes of LOS as well as mortality rate will now be reviewed.

5.5.2.1 Interventions influencing LOS

Following narrative review of results, NIV via CPAP in comparison to IPPV via ET, lead to a

slightly but not significantly lower LOS in the CPAP intervention group in the RCT conducted by Gunduz et al., (2005). These results concur with findings in the systematic review and meta-analysis conducted by Chiumello et al., (2013). Results indicated that early use of NIV (CPAP or BiPAP) in chest trauma patients resulted in reduced length of ICU stay as well as mortality, with improved oxygenation and reduced requirement for tracheal intubation when integrated with other medical and surgical therapies.

Multidisciplinary pathways and care bundles were also reviewed relative to their effect on the outcome of LOS. Meta-analysis was conducted and these results will be discussed further.

5.5.2.1.1 Bundled care and effect on LOS

Meta-analysis conducted in this systematic review for pre-versus post bundle of care intervention for the outcome of hospital LOS, revealed no statistically significant difference in LOS between groups. Although two of the three cohort studies included in the forest plot showed significant reduction in LOS in their populations reviewed e.g. in patients 65 years of age and older with three or more fractured ribs (Sahr et al., 2013) and in patients greater than 45 years of age with greater than four rib fractures (Todd et al., 2006), Curtis et al., (2016) demonstrated no difference in hospital LOS in their elderly population reviewed. Curtis et al., (2016) attributed this to the possibility that the post CHiP cohort possessed higher comorbid disease and higher ISS than the pre CHiP cohort. The authors concluded that LOS may thus be affected by a multitude of factors other than the management implemented. This was especially evident in elderly individuals with rib fractures where underlying co-morbidities, injury severity and associated injuries may impact outcomes. This was an especially relevant consideration in reviewing results of the meta-analysis conducted in this systematic review as the population included in this meta-analysis was predominantly an older population. This may account for the overall non-significant difference in LOS observed. This outcome was also documented in the study conducted by Flarity et al., (2017), not presented in meta-analysis due to incorrect data format. Results indicated no difference in LOS between total pre versus post CPG cohorts, however the pre-CPG cohort was younger ($p = 0.02$) whilst the CPG cohort had more total rib fractures ($p = 0.00$) and lower rib fractures ($p = 0.00$), whilst upper rib fractures occurred more frequently in the pre-CPG cohort ($p = 0.01$).

The elderly therefore appears to be more vulnerable to complications following acute rib fractures and extended LOS may thus be anticipated based on these considerations. Dalton et al., (2019) confirmed these findings, and concluded that increased age was the only variable that predicted with statistical significance, failure to achieve expedited discharge in patients having sustained multiple traumatic rib fractures. In addition, Sharma et al. (2008) concluded that increasing age and number of ribs fractured were inversely related to the percentage of patients discharged home. Extended LOS and delays in discharge may thus be attributed to the finding that the elderly are more prone to complications and have an increased morbidity and mortality risk following rib fractures than younger patients with similar injuries (Bulger et al., 2000; Bergeron et al., 2003).

Risk of pneumonia has also been found to increase in the elderly with each additional rib fractured (Bulger et al., 2000), and acute respiratory failure as well as pleural effusions are reported to be more common in the elderly after rib fractures (Wardhan, 2013). Additionally the elderly may be at increased risk of respiratory compromise due to changes elicited as a

result of the normal aging process. Loss of lung elasticity and resultant pulmonary compliance together with reduction in the number of alveoli and small blood vessels around the lung may account for the resulting respiratory impairments observed in the elderly (Easter, 2001; May et al., 2016). In addition, loss of vertebral height together with subsequent disc space narrowing and weakening of the muscles of respiration lead to resultant reductions in lung expansion and lung volumes (Easter, 2001). Poor respiratory reserve, reduced lung volumes and lung function as well as impaired gaseous exchange may ensue as a result of these age-related changes (May et al., 2016). These factors together with underlying co-morbidities and decreased physiological reserve therefore place the elderly at increased risk of secondary respiratory complications, as well as at heightened risk of mortality following rib fractures (Bergeron et al., 2003; May et al., 2016). Since the elderly are more susceptible to pulmonary deterioration and respiratory complications due to the aforementioned factors, increased duration of LOS may thus be anticipated in this population. These findings have been noted in rib fracture populations in various studies (Bulger et al., 2000; Chrysou et al., 2017). Based on the predominantly elderly population included for review for the outcome for LOS, this may account for results obtained from meta-analysis conducted.

In light of these findings and from the studies reviewed it becomes evident that LOS may be affected by factors other than the intervention implemented. Authors reviewing factors which may influence overall LOS have included the primary medical condition of the patient, age, ethnicity, payment status (workers compensation, private or publically funded), employment, marital status and type of treatment received as factors influencing general hospital LOS (Liu et al., 2001; Khosravizadeh et al., 2016). As a consequence results relating to LOS should be reviewed with these contributing factors in mind. Researchers should thus aim to match/review study populations relative to these factors (age, injury severity and co-morbidities) to negate possible factors affecting LOS other than the intervention under review. This will assist in determining for which populations LOS may truly be influenced by the intervention being implemented, as combined analysis of different ages and injury severity (rib fractures number, flail and associated injuries) may thus influence outcomes achieved.

Although results were considered statistically insignificant in this review, a possible reduction in LOS by one day may however be of clinical and financial significance both to the patient and institution of care especially in countries where these resources may be limited. In the study conducted by Dalton et al., (2019) the effects of expedited discharge of patients with multiple traumatic rib fractures relative to cost-effectiveness were reviewed. Results demonstrated that the average cost of hospitalisation for those who achieved expedited discharge was less than half of the average cost for those who did not. In addition to cost reduction, patients received additional benefits from rapid discharge including earlier return to their normal activities and spent less time in hospital which reduced their risk of acquiring nosocomial infections. As such reductions in LOS may produce beneficial outcomes with regards to costs incurred, as well as reduce the risk associated with prolonged hospital LOS.

5.5.2.2 Effect of bundled interventions on ICU LOS

Bundled care intervention for the outcome of ICU LOS was not presented in meta-analysis due to the presence of high heterogeneity. Todd et al., (2006) however demonstrated that following implementation of multidisciplinary pathways in patients greater than 45 years of

age with more than four rib fractures the clinical pathway demonstrated decreased ICU LOS by 2.4 days.

In the study conducted by Flarity et al., (2017) although the overall study hospital LOS with CPG implementation did not change, patients admitted directly to the ICU were found to have marked benefit following CPG implementation. The CPG allowed for early identification of respiratory compromise resulting from rib fractures, and early stratification and triage of patients resulted in appropriate directed management based on this risk evaluation. This early recognition of patients at risk for treatment failure as identified by FVC evaluation led to increased ICU admissions in the CPG cohort. In addition, resultant reduction in LOS by over two days in the ICU cohort on multivariable analysis was demonstrated, despite this cohort being significantly older with more rib fractures.

Sahr et al., (2013) demonstrated that patients with greater than three rib fractures had longer lengths of stay in both hospital and ICU in comparison to those patients with less than three rib fractures. Even following protocol intervention these patients still experienced longer LOS in ICU due to the severity of the injury. Once again LOS was shown to be affected by factors other than the protocol or clinical pathway implemented, with the number of rib fractures being shown to increase LOS.

Following review of these findings it would appear that bundled care intervention may produce reductions in ICU LOS or assist in identifying which patients may require direct admission to ICU following screening procedures implemented as part of bundled care protocols. This may assist in guiding treatment interventions and implementation of bundled care pathways, which in turn may lead to improvements in directed appropriate care, and resultant reductions in LOS observed.

5.5.2.3 Interventions influencing mortality rate

Following narrative review of the literature, only one intervention was identified which influenced mortality rate. Gunduz et al., (2005) demonstrated that CPAP use in comparison to endotracheal ventilation in the treatment of patients with flail chest injury lead to a significant reduction in mortality rate ($p < 0.01$) for those managed with CPAP therapy. In comparison to other studies, in the systematic review and meta-analysis conducted by Chiumello et al., (2013), early use of NIV (CPAP or BiPAP) in chest trauma patients also resulted in reduced mortality when integrated with other medical and surgical therapies. As the results of this systematic review are based on only one RCT, further studies reviewing this outcome are required to substantiate this finding.

Meta-analysis was conducted in this systematic review to establish the effects of multidisciplinary clinical pathways and bundled care on the outcome of mortality rate. These results will be discussed in further detail

5.5.2.3.1 Effect of bundled care on mortality rate

Meta-analysis conducted for bundled care intervention showed no significant difference in mortality rate following bundled care intervention in this systematic review. Pooled analysis of the three cohort studies for bundled care intervention, demonstrated a RR of 0.62 (95% CI

0.32 to 1.23). Overall quality of evidence as reviewed by the GRADE approach was rated as very low due to serious concern for imprecision as the confidence interval included the potential for no effect, as well as a large reduction or increase in mortality. Mortality rate like LOS may be affected by a number of factors (number of rib fractures, presence of associated injuries, co-morbidities, injury severity and age) independent of the intervention implemented (Lin et al., 2016). Results should thus be interpreted in light of these findings and future studies should take these considerations into account when meta-analysis is conducted. Further clinical trials are recommended to explore the effects of bundled care pathways on mortality rate so that more robust evidence-based recommendations can be made relative to this outcome.

5.6 Conclusion to the discussion

Non-pharmacological therapeutic interventions which may be utilised to address pain and rehabilitate function following acute rib fractures in adult patients have been identified and discussed in detail in this chapter. Non-pharmacological therapeutic interventions identified were shown to aid pain relief, improve respiratory function and reduce the incidence of pneumonia in the acute care setting following acute rib fractures. These interventions should be considered as viable treatment options in clinical practice in the management of patients with rib fractures, and have the added benefit of negating the potential side effects associated with pharmacological intervention use.

Bundled care pathways were shown to be important management strategies in the treatment of patients following acute rib fractures. Pain and respiratory management were identified as vital components of care to include in these pathways, with physiotherapy intervention being deemed essential in MDT management of these patients. Meta-analysis conducted for bundled care intervention demonstrated statistically significant reductions in risk of pneumonia development following pathway implementation, however LOS and mortality rate showed no statistically significant changes following bundled care intervention. Mortality rate and LOS were shown to be affected by factors other than the pathway implemented and results achieved may have been influenced by these factors.

The chapter to follow will examine and consolidate the above evidence and review the implications relative to clinical practice, providing recommendations for future research. In addition, limitations of the studies, meta-analysis and heterogeneity analysis will be outlined in chapter 6.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusion

In this systematic review non-pharmacological therapeutic interventions utilised by health care professionals in the management of pain in the acute care setting following rib fractures were identified and reviewed in detail. In addition, the effects of these interventions on pain, function (physical and respiratory), and incidence of pneumonia, LOS and mortality rate were reviewed.

Acupuncture, bundled care involving MDT pathways, physiotherapy and physiotherapy modalities e.g. ACBT, incentive spirometry, TENS, NIV, early mobilisation and patient education were identified as non-pharmacological interventions which may be utilised in the management of patients following rib fractures in the acute care setting. These non-pharmacological therapeutic interventions were discussed relative to their effects on the outcomes of pain and function and secondary outcomes of LOS, pneumonia incidence and mortality rate where appropriate.

Use of multidisciplinary clinical pathways and the components included in these rib fracture care bundles were identified and reviewed. Care bundles and clinical triage protocols assist in identifying early respiratory compromise and in streamlining and promoting standardisation of care in the management of patients following acute rib fractures. The importance of early respiratory screening procedures and protocols for use in identification of early respiratory deterioration and patients defined as high risk e.g. the elderly and those with multiple rib fractures and flail chest injuries was highlighted. These screening measures allow for directed appropriate implementation of care pathway interventions in patient management.

Early optimal pain management as well as pulmonary care in the form of respiratory interventions including chest physiotherapy, pulmonary toilet techniques and active breathing exercises were identified as important components in rib fracture bundled care pathways. Together with respiratory support in the form of NIPPV, these components of bundled care were deemed vital in the management of patients following rib fractures and in bundled care interventions. Modalities aimed at improving physical function and functional ability were lacking in this review. Combined modalities in the form of regular mobilisation, and physiotherapy interventions aimed at improving function are components of care identified that should also be included in these pathways.

Objective outcome measures are needed to evaluate the effectiveness of non-pharmacological therapeutic interventions on the outcome of physical function, as no objective assessment of physical function as an outcome was conducted in any of the included studies. As a result, non-pharmacological interventions for this outcome were not identified nor could any

recommendations for use be made in this population. Non-pharmacological therapeutic interventions utilised to assist pain relief, improve respiratory function and aid in reducing LOS as well as incidence of pneumonia and mortality rate were only therefore identified in this systematic review.

Results of the meta-analysis conducted for bundled care intervention showed non-significant statistical differences for LOS with a moderate quality of evidence grading. Possible LOS reduction by one day may have clinically important relevance to utilisation of healthcare costs and resources. Mortality rate also showed non-significant differences following bundled care intervention, with the quality of evidence being rated as very low based on the GRADE rating system. Risk of pneumonia was shown to be significantly reduced by 63% following bundled care intervention, however overall quality of evidence was graded as very low for this outcome. Bundled care pathways in the context of this review, may thus provide favourable outcomes on incidence of pneumonia when implemented in the acute care setting following rib fractures. Consideration to the level of evidence grading regarding these outcomes together with the small number of studies included for meta-analysis should however be borne in mind when reviewing these results.

This review fits into the growing body of research regarding identification of modalities to assist and manage acute pain and improve function following rib fractures. Very few studies currently exist which identify and review non-pharmacological therapeutic interventions and evaluate the effects of these interventions on pain and function following acute rib fractures. A great need therefore exists for further clinical trials to be conducted in this field which will allow for more robust evidence based recommendations to be made. This will guide appropriate intervention selection and drive evidence-informed practice with regards to intervention selection and use in clinical practice.

6.2 Limitations

6.2.1 Limitations of the Studies

Where patient numbers were small as in the study conducted by Sahr et al., (2013) or only conducted at a single institution (Sahr et al., 2013; Curtis et al., 2016; Flarity et al., 2017), generalisability of the results to other health care settings and populations may be reduced.

In retrospective studies (Sahr et al., 2013; Curtis et al., 2016), all contributions to variability could not be systematically controlled for as integrity of the data would be dependent on the accuracy with which it was initially recorded. These authors would thus not have been able to control for inaccuracies in the data retrieved.

Definitions and classification of pneumonia across retrospective studies may have varied as well as diagnostic criteria and resultant documentation thereof. This may have made extraction of consistent data relating to incidence more difficult (Curtis et al., 2016).

For the outcome measure of pain, very few studies evaluated pain in analysis of intervention effectiveness. In addition, different pain outcomes were utilised to record changes in pain intensity. Standardisation of outcome scales utilised for pain measures were not conducted across studies and thus did not allow for comparative analysis to take place. In addition pain, evaluation relative to when the intervention was implemented and during which activity it

was recorded (i.e. during coughing, deep breathing or at rest) varied between studies and standardisation of when the pain measure is evaluated is necessary if comparative analysis is to take place.

Respiratory outcomes reviewed were assessed via varied measures (PEFR, SMI and FVC lung volumes). Due to lack of standardisation of assessment measures and interventions utilised, pooled analysis and review of results was not possible.

No studies were found which objectively measured or evaluated physical function as an outcome (via standardised or established outcome measures and tools). This made recommendation of interventions directed at improving physical function following acute rib fractures difficult. As such interventions directed at achieving improvements in physical function and functional independence should be objectively evaluated in future studies. This will allow for assessment of intervention effectiveness on the outcome of physical function, allowing for evidence-based recommendations to be made, as well as to objectively track patients' progress.

Only patients with radiological rib fractures were included as part of the inclusion criteria to standardise diagnosis. This may have led to exclusion of a number of studies as a large proportion of rib fractures have been shown to be missed following chest X-ray evaluation (Sano, 2018).

Studies reviewed for possible inclusion, had large variances in the age groups included for review. Differences in the populations included (inclusion criteria ranges) varied significantly and as a result a number of articles were excluded from analysis based on this reason.

Although patients 18 years and older were included in the study, some search engines (PubMed) filter option did not allow for specific selection of 18 yrs. + but rather 19 yrs. + or 13-18 years of age. Resultantly the most appropriate filter of 19 yrs. + was selected, which may have allowed for some studies to be missed, as a result of this age restriction filter.

6.2.2 Limitations of the meta-analysis

6.2.2.1 Data and study design

Different methods of reporting data lead to difficulty obtaining the required information for meta-analysis, and consequently studies such as Flarity et al.,(2017) for the outcome of LOS were excluded from the meta-analysis for this reason.

All included studies in the meta-analysis were cohort studies. Observational studies are at higher risk of bias than RCT's (Lavallée et al., 2017) and as such meta-analysis conducted should be reviewed with this in mind.

6.2.2.2 Heterogeneity analysis

Studies brought together in meta-analysis are known to naturally differ, and some degree of variance between studies is expected. In all forest plots conducted for bundled care intervention, a small number of studies were included for each analysis. Heterogeneity, I^2 evaluation and review should therefore be interpreted with caution, as in the presence of a

small number of included studies, low I^2 values may not necessarily indicate the absence of heterogeneity.

Multidisciplinary pathways and care bundles reviewed were composed of various modalities and interventions across studies, differing from one institution to another. This offered a source of heterogeneity into study analysis as the components of management of the care bundles thus varied between studies. No identical pathway was implemented as no standardised care pathway specifically for the management of rib fractures has yet been established. In addition, the ages of the population reviewed for bundled care intervention varied across included studies, as did severity of injury included for review, thus contributing to possible heterogeneity observed.

Studies did not differ considerably in terms of methodological heterogeneity (differences in study design and risk of bias) or statistical heterogeneity, but more so with regards to clinical heterogeneity (ages, number of rib fractures, protocol use, implementation and types of interventions utilised). These differences could account for the heterogeneity outcomes achieved.

6.3 Implications for practice

Urgent adequate pain control has been identified as a necessity in the management of patients following acute rib fractures. Poor acute pain control compromises respiratory function and all aspects of recovery. Inadequate pain control may also lead to chronic pain states and reduced QOL with high disability levels (Fabricant et al., 2013; Gordy et al., 2014). Non-pharmacological therapeutic interventions have been shown to address some of these concerns leading to reductions in pain, improved respiratory function, reduced incidence of pneumonia and mortality rates as well as reductions in LOS. Non-pharmacological therapeutic interventions can thus be considered as modalities for use in pain management and to improve function following acute rib fractures. These non-pharmacological therapeutic interventions are generally considered inexpensive, safe treatment options in comparison to pharmacological interventions and their associated side effects. Health care professionals should thus familiarise themselves with these interventions as possible adjuncts to pharmacological management in the treatment of these patients.

Pharmacological interventions do however still have their place in the management of these patients especially with regards to implementation of respiratory interventions. Non-pharmacological therapeutic interventions (respiratory physiotherapy and incentive spirometry) which may assist in reducing the incidence of respiratory complications require adequate pain control prior to implementation which may include appropriate pharmacological management. Early aggressive pain relief via multimodal analgesia has been shown to be an essential component in pain management following rib fractures. Modalities such as chest physiotherapy, mobilisation or use of incentive spirometry depend upon adequate pain relief in order for these interventions to be effective and to be tolerated by the patient. Health care professionals should thus ensure that pain control is adequate prior to implementation of these interventions, if respiratory modalities implemented are to prove effective.

Interventions utilised to assist pain relief such as acupuncture, reduced pain levels as well as improved respiratory function following implementation. Acupuncture, however, is not a skill set in all health care professionals' training, and as such may not be implemented as readily. Further training and education may be required for greater application in clinical practice.

Bundled care interventions assist in standardising care, ensuring MDT collaboration and allow for early identification of those patients at risk of respiratory compromise in a timeous manner. Incidence of pneumonia was found to be decreased following bundled care implementation, with possible reduction in LOS being demonstrated. Bundled care pathways should thus be instituted and utilised in the management of patients following rib fractures in the acute care setting to improve patient outcomes. Acute care institutions should thus aim to incorporate these pathways into their care practices. This will aid recognition of high-risk patients and guide management of these patients. Components of bundled care pathways specific to rib fractures have not yet been established, however these care pathways should all include aggressive appropriate analgesia and respiratory care (physiotherapy and pulmonary toilet) as well as MDT involvement. These three components were deemed essential across studies reviewed and on evaluation of the blunt chest injury care bundle established by Kourouche et al., (2018). In addition, early mobilisation, respiratory therapy, patient education and NIV support were also identified as possible modalities for inclusion in rib fracture care bundles and may be included as part of management pathways in the care of these patients.

Prevention of deterioration in respiratory function and associated pulmonary complications is considered vital in the management of patients with rib fractures in the acute care setting. Clinical practice should therefore include and implement early ongoing screening protocols to allow for rapid detection of high-risk patients allowing for guided and informed interventions to be implemented timeously. Patients with compromised respiratory function can thus be promptly identified, and steps to remediate further deterioration can be implemented early on. Incentive spirometry was found to be regularly utilised in the assessment and evaluation of respiratory function following rib fractures in this review. Incentive spirometry provided a means of serially evaluating and screening patients' respiratory efforts, allowing for identification of those patients with compromised respiratory function and directing further management required. Health care professionals should thus not neglect the importance of early regular screening of respiratory capacity, which may assist in directing management and implementation of appropriate intervention strategies. Incentive spirometry thus provides a viable option for the purpose of respiratory screening in this setting.

Transcutaneous electrical nerve stimulation provided effective pain relief as well as improved respiratory function following use. In addition, TENS is easy to apply and health care professionals should consider this non-pharmacological therapeutic intervention as a treatment strategy following acute rib fractures.

Non-invasive ventilatory modalities identified and utilised in this review demonstrated successful results in the ventilatory management of patients following rib fractures. These modalities should thus be considered as supportive ventilatory options in these patients (in the absence of overt respiratory failure). Non-invasive ventilatory modalities negate the complications associated with invasive ventilation, and should be considered feasible options for ventilatory support in these patients.

Education strategies appear to be vastly overlooked in the implementation of treatment and management of pain following acute rib fractures. Education strategies with regards to pain and complication prevention have been found to produce positive outcomes in other populations reviewed. This aspect of care should therefore not be overlooked by HCP in the management of patients' following rib fractures.

Associated injuries and co-morbidities impact patient management and outcomes. The elderly have been identified as a specifically vulnerable and high risk population following rib fractures. Increased morbidity, mortality and risk of complications often result due to an increased prevalence of underlying co-morbidities, reduced physiological reserve and associated frailty in this population (Battle et al., 2012; Schmoekel et al., 2019). A low threshold for hospitalisation together with close screening and evaluation of these patients is therefore recommended in the care of the elderly following rib fractures (Vana et al., 2016; Kuo & Kim, 2019). Health care professionals should thus implement screening procedures into practice in the clinical setting so that possible deterioration can be detected and managed timeously. In addition, preventative strategies and education campaigns on fall prevention are important considerations in reducing fall related thoracic injury and rib fractures in this population. This becomes increasingly important when the high morbidity and mortality rates associated with this injury in the elderly are reviewed (Bulger et al., 2000). Clinical practice should thus strive to promote preventive education programs in an attempt to reduce rib fracture incidence in this population.

Non-pharmacological therapeutic interventions identified in this review may thus assist pain control, support respiratory function, reduce the incidence of respiratory complications and possibly decrease LOS. These interventions should be considered as feasible treatment options by health care professionals in the management of patients following acute rib fractures.

6.4 Recommendations for future research

Outcome measures utilised to assess pain need to be standardised across studies so that comparative analysis can take place. When a variety of outcome measures are utilised across studies and interventions, comparison of results and effect sizes is made difficult. Of the included studies reviewing pain as an outcome, three utilised the VAS, one utilised the NRS and one utilised a VRS. Evaluation of pain was also conducted during different activities as well as at rest and at varying time frames relative to intervention implementation. Standardisation of these factors will aid comparable analysis of outcomes.

Future clinical trials should aim to identify which combination of physiotherapy modalities may lead to improvements in pain and reduction in the incidence of pulmonary complications following acute rib fractures. As identified in the study by Grammatopoulou et al., (2010) in the routine physiotherapy group, positioning as well as early mobilisation, supportive coughing and incentive spirometry together lead to improvements in these outcomes. Identification of the specific physiotherapy modalities leading to these improvements may allow for more efficient treatment to be implemented based on evidence-based outcomes.

Few recent studies were sourced in the literature reviewing the effects of TENS on pain or respiratory function following acute rib fractures. Further trials exploring pain relief induced

following TENS application and effects on respiratory function will increase the strength of evidence for use of this non-pharmacological intervention following rib fractures in the acute care setting. Standardisation of outcome measures utilised for evaluation of pain as well as physical function following TENS therapy also needs to be conducted if pooling of results for meta-analysis is to be achieved in future studies.

Objective outcome measures evaluating the effects of non-pharmacological therapeutic interventions on the outcome of physical function are undoubtedly required following evaluation of the results of this systematic review. No studies were retrieved in which physical function was reviewed via objective outcome measures. Consequently identification of non-pharmacological therapeutic interventions which may be utilised or directed towards improving physical function of patients with acute rib fractures were not identified. The lack of evaluation or use of objective measures to evaluate physical function as an outcome in this review is specifically concerning as improvements in physical function (strength, mobility and functional independence) as well as restoration of overall function are vital outcomes to evaluate and rehabilitate in the management of these patients. Restoration of function and resultant improvement in physical capacity and integration into activities of daily living are important rehabilitation goals to achieve in the treatment of patients following rib fractures as well as for complication prevention. This is an especially important consideration for health care professionals, particularly physiotherapists, who are involved with restoration of function (physical and respiratory) and management of patients following rib fractures in the acute care setting. Subsequent research should thus be directed towards utilising objective outcome measures to assess the effectiveness of non-pharmacological therapeutic interventions reviewed such as acupuncture, TENS, physiotherapy modalities, NIV as well as bundled care pathways on the outcome of physical function. This will allow for non-pharmacological interventions aimed at improving physical function to be identified, and evidence based recommendations to be made concerning their use. Identification of interventions directed at achieving improvements in physical function and functional independence as measured by objective analysis is therefore strongly encouraged in future studies.

Future clinical trials exploring the effects of acupuncture on the outcomes of pain, respiratory function and incidence of pulmonary complications are recommended as very few studies were retrieved in the literature exploring these outcomes following acupuncture therapy. In addition, different acupuncture methods specifically auricular and filiform needle acupuncture were implemented in the studies reviewed and different outcomes measures were utilised to evaluate these outcomes. This resulted in an inability to pool results. Future studies should thus aim to establish the most effective method of acupuncture application as well as which rib fracture population (simple, multiple or flail) would derive the most benefit from acupuncture therapy as assessed via standardised outcome measures. This will provide valuable information directing evidence-based application in clinical practice regarding method of application as well as rib fracture pattern for which most benefit will be obtained.

Care bundles have been identified as important management pathways to be implemented in the acute care setting for the treatment of adult patients with acute rib fractures. Only a few studies were retrieved reviewing bundled care pathway management in the acute rib fracture population. This was one of the limitations identified in interpretation of meta-analysis results conducted in this systematic review. As such further studies reviewing the effects of bundled care intervention on hospital and ICU LOS, incidence of pneumonia and mortality rate following acute rib fractures are recommended to increase the strength of evidence. This in

turn will lead to more robust recommendations when meta-analysis is conducted. No studies were identified in which the effects of bundled care were evaluated relative to pain relief in this population. Future clinical trials evaluating the effects of bundled care pathways on pain perception following implementation could provide valuable information regarding use of this intervention for pain relief. Subsequent studies should also be directed towards identifying and establishing the components of rib fracture care bundles which when implemented lead to the most effective outcomes. Standardisation of bundled care components implemented may allow for greater standardisation of comparison in meta-analysis, which may result in lower heterogeneity being observed between studies. In addition, patient ages and number of rib fractures of patients included for management with care bundles needs to be standardised if more rigorous results are to be obtained.

Strapping and taping intervention appear to confer possible pain relief following application in the rib fracture population, as well as in other populations evaluated as reviewed in chapter two. No reliable studies have however been conducted in which taping intervention has been accurately implemented in the acute care setting following rib fractures to determine the effects on pain relief, as well as to establish possible effects on respiratory function. Future prospective trials reviewing use of this potentially useful non-pharmacological therapeutic intervention in this setting would prove beneficial and remediate the gap in the current literature regarding use of this modality in the acute rib fracture population.

In conclusion this systematic review has identified evidence based non-pharmacological therapeutic interventions which may be utilised to manage pain and aid recovery of both physical and respiratory function in adult patients with acute rib fractures. This is the first systematic review conducted to date where these non-pharmacological therapeutic interventions have been identified and reviewed together and overall conclusions established with regards to what these interventions are, as well as their effects on pain and function. Gaps in the literature were also identified with regards to the lack in number of studies identifying non-pharmacological therapeutic interventions utilised to address pain management and function (especially physical function) following acute rib fractures. Future prospective clinical trials addressing these concerns may broaden the number of non-pharmacological therapeutic intervention options available for use in this setting, so aiding identification of interventions with positive effects on the outcomes of pain and function.

In closing, based on the findings of this systematic review, non-pharmacological therapeutic interventions have been identified as effective interventions in the management of adult patients with rib fractures in the acute care setting. Implementation of these evidence-based non-pharmacological interventions in clinical practice may thus lead to more effective pain relief and improvement in function following utilisation in patients having sustained acute rib fractures.

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APPENDIX A: ETHICAL CLEARANCE WAIVER

Human Research Ethics Committee (Medical) 50 years 1966 – 2016

Research Office Secretariat: Faculty of Health Sciences, Phillip Tobias Building, 3rd Floor, Office 301,
29 Princess of Wales Terrace, Parktown, 2193 Tel +27 (0)11-717-1252 /1234/2656/2700
Private Bag 3, Wits 2050, email: zanele.ndlovu@wits.ac.za
Office email: hrec-medical.researchoffice@wits.ac.za
Website: www.wits.ac.za/research/about-our-research/ethics-and-research-integrity/

Ref: W-CJ-170419-1 19/04/2017

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigators: Beverley Weinberg (student no 0000297T).

Project title: **The effects of therapeutic interventions on pain and physical function in adults with rib fractures: a systematic review.**

Reason: This study uses information in the public domain for a systematic review. There are no human participants.

Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

UNIVERSITY OF THE WITWATERSRAND
PROF PE CLEATON-JONES
HREC (MEDICAL)
2017 -04- 19
JOHANNESBURG

Copy – HREC (Medical) Secretariat: Zanele Ndlovu, Rhulani Mkansi, Lebo Moeng.

APPENDIX B: EXTENSIVE SEARCH KEYWORDS

Filters utilised for all search strategies included: Publication date from 2000/01/01 to 2017/12/31; Humans; English; Adult: 19+ years (where 18 years and older filter was not available for selection).

#1 Search :(rib fractures") OR ("rib fracture") OR "flail chest") OR ("flail segment") OR "thoracic injury") OR "chest injury") OR "chest trauma") OR "thoracic trauma") OR "blunt chest trauma") OR "blunt thoracic trauma

Search strategy #1 was combined with keywords as presented in each search strategy recorded in Table 1 below:

Table 1:

Search	Keywords/Search String
7	#1 AND "intensive care" OR "critical care" OR "acute care" OR hospital OR ward.
8	#1 AND "non- pharmacological management" OR "conservative management" OR " non-operative".
9	#1 AND spirometry OR ("incentive spirometry")
10	# 1 AND "active cycle of breathing" OR "breathing exercise" OR "deep breathing"
11	#1 AND (Physiotherapy) OR "physical therapy") OR "breathing exercises") OR rehabilitation OR spirometry) OR "respiratory techniques") OR "deep breathing")
12	#1 AND "transcutaneous nerve stimulation" OR "TENS" OR " electrotherapy"
13	#1 AND "acupuncture
14	# 1 AND ("rib belts") OR braces) OR straps)
15	#1 AND "taping" OR (kinesiotape) OR ("dynamic tape") OR "strapping"
16	#1 AND Therapeutic OR Rehabilitation OR therapy OR "Physical Therapy" OR "Physiotherapy" OR "Occupational Therapy" OR Mobilization OR Mobility OR "Physical activity" OR Exercise OR "Functional activity" OR Function OR Multidisciplinary
17	#1 AND ("care bundles" OR "clinical pathways" OR " multidisciplinary pathways" OR "bundled care")

APPENDIX C: STUDIES EXCLUDED FROM THE REVIEW BASED ON FULL TEXT RETRIEVAL.

Table 1: Studies excluded from the review based on full text retrieval.

Study	Reason/s for exclusion
Ahn et al. (2013) Case scenario: pain-associated respiratory failure in chest trauma.	Population: moderate head injury (exclusion criteria for this systematic review) Outcomes: relative to pain, function or secondary outcomes were not evaluated or reviewed.
Amital et al. (2009) Long-term pulmonary function after recovery from pulmonary contusion due to Blunt chest trauma.	Population: too broad and not all patients evaluated had sustained rib fractures. Setting: exercise laboratory and not an acute care facility. Evaluations: not acute (conducted after 12–48 months).
Bastos et al. (2008) Flail chest and pulmonary contusion.	Interventions: background information, reviewing medical and surgical management and recommendations for overall management. Outcomes: primary outcomes of pain or function or secondary outcomes of hospital or ICU length of stay were not included or evaluated.
Battle et al. (2013) Blunt chest wall trauma: A review.	Population: blunt chest trauma population (Not specific to rib fractures). Interventions: holistic background information relating to assessment, management and broad treatment strategies for patients with blunt chest wall trauma, not specific to interventions of interest.
Battle (2013) PhD Submission. The development and validation of a prognostic model that assists in the management of blunt chest wall trauma patients.	Objectives: did not evaluate primary or secondary outcomes identified or objectives set for evaluation in this review. Identifies risks for development of complications.
Bellone et al. (2017) Factors associated with ICU admission following blunt chest trauma.	Population: head injuries were included in the study population reviewed.
Bilalee et al. (2017) Pain, pain management and pain management outcomes in chest trauma patients: the preliminary study.	Population: blunt and penetrating injuries were included
Brasel et al. (2017) Western Trauma Association Critical Decisions in Trauma: Management of rib fractures.	Intervention: recommended management algorithm for patients with rib fractures. Background information regarding classification, monitoring, surgical and medical pain management. Objectives: set objectives and interventions

	specified were not evaluated or reviewed.
Cannon et al. (2012) Flail chest injury: are we making any progress?	Population: head injuries were included.
Chrysou et al. (2017) Lessons from a large trauma center: impact of blunt chest trauma in polytrauma patients—still a relevant problem?	Population: not specific to rib fractures, broadly considered blunt chest trauma. Patients from 16 years of age and spinal injuries and head trauma were included in patients reviewed.
Cohen et al. (2004) Pain management in trauma patients.	Population: not specific to rib fractures (e.g. burns, pediatric and blunt chest wall trauma). Intervention: general overview of pain management
Curtis et al. (2017) Implementation evaluation and refinement of an intervention to improve blunt chest injury management: a mixed-methods study.	Objectives: factors influencing uptake and implementation of a chest injury protocol (ChIP) were evaluated. Not relevant to systematic review Outcomes: primary and secondary outcomes were not evaluated.
Fitzgerald et al. (2017) Rib fracture fixation in the 65 years and older population: a paradigm shift in management strategy at a level I trauma center.	Intervention: non-operative management related more specifically to medical management. Pulmonary toilet mentioned however specific details regarding this intervention were omitted. Outcomes: pneumonia incidence relative to readmission incidence, not acute care incidence. Evaluation: functional outcomes assessed post-acute care. Sent for review by third reviewer (HvA). Third reviewer aligned with exclusion suggestions.
Germanovich & Ferrante (2016). Multi-modal treatment approach to painful rib syndrome: case series and review of the literature	Population: rib dysfunction/syndromes: not specific to rib fractures Setting: not acute care
Granetzny et al. (2005) Surgical versus conservative treatment of flail chest. Evaluation of the pulmonary status.	Population age: 12-60 years.
Hamid & McManus (2011) Blunt thoracic trauma.	Population: non- specific to rib fractures Intervention: basic management of blunt chest trauma, overview of investigations and management.
Karmakar & Ho. (2003) Acute Pain Management of Patients with Multiple Fractured Ribs.	Interventions: analgesic techniques reviewed (pharmacological and medical management). Study reviewed on TENS use by Sloan et al., (1986), outside prescribed time period of the review.

Kerr-Valentic et al.(2003) Rib fracture pain and disability: can we do better?	Interventions: pharmacological management only. Evaluation: SF-36 survey results fell outside acute care analysis.
Majercik & Pieracci. (2017) Chest wall trauma.	Interventions: not specific to non-pharmacological modalities. General overview (medical and surgical management, anatomy and investigations utilised in chest trauma).
Nyangena & Bruce. (2000) Profile of care given to patients with blunt chest injuries within the first 48 hours.	Population: too broad (blunt chest injuries), inclusion criteria not met. Outcomes: pain and function were not specifically evaluated or reviewed in relation to rib fractures.
Nyland et al. (2016) A preventative respiratory protocol to identify trauma subjects at risk for respiratory compromise on a general in-patient ward.	Population: trauma patients (not specific to rib fractures). Interventions: not specific to non-pharmacological intervention criteria (prophylactic respiratory protocol for screening and intervention implementation)
Oncel et al. (2002) Transcutaneous electrical nerve stimulation for pain management in patients with uncomplicated minor rib fractures.	Population age: 11 to 81 years (inclusion criteria not met).
Pettiford et al. (2007) The management of flail chest.	Interventions: not specific, overview of management of flail chest, pathophysiology, surgical intervention, medical management and prognosis reviewed. Interventions and outcomes : not evaluated. Studies relating to discussion and management relating to NIV have already been sourced and appraised individually.
Sareen et al. (2015) Immediate effect of kinesiology taping in treating undisplaced rib fracture pain.	Setting: not an acute care facility.
Schuurmans et al. (2017) Operative management versus non‐operative management of rib fractures in flail chest injuries: a systematic review.	The articles retrieved from the systematic review conducted by Schuurmans et al. (2017) included the studies by: **Marasco et al. (2013):** surgical versus invasive mechanical ventilation in flail chest outcomes. Intervention: two invasive interventions included. **Tanaka et al. (2002):** already sourced and reviewed **Granetzny et al. (2005)**: already sourced and reviewed.

Sesperez et al. (2001) Trauma case management and clinical pathways: prospective evaluation of their effect on selected patient outcomes in five key trauma conditions. **Wilson et al. (2001)** Clinical pathways — can they be used in trauma care. An analysis of their ability to fit the patient.	Inclusion criteria: rib fractures not all diagnosed radiologically. Population: not specific to rib fractures. Intervention: focus is on the development and stages of implementation of the clinical pathways and areas in need of remedial action in the implementation. Same article reviewed as above.
Stewart. (2014) Blunt chest trauma.	Interventions: identified, however no detail with regards to implementation or frequency was documented. Outcomes: outcome measures relating to the primary or secondary outcomes specific to the systematic review were not evaluated or reviewed.
Sullivan et al. (2016) Exploring opioid-sparing multimodal analgesia options in trauma: a nursing perspective.	Population: general trauma pain, non- specific to rib fractures. Article reviewed herein (Ho et al., 2014) relating to acupuncture had already been sourced for full text inclusion.
Tanaka et al.(2001) Pneumatic stabilization for flail chest injury: an 11-year study.	Population age: 14 to 82 years of age.
Wardhan. (2013) Assessment and management of rib fracture pain in geriatric population: an ode to old age.	Objectives: focus on assessment tools in managing the elderly. Interventions: pharmacological interventions and medical management reviewed. Outcomes: donot measure or evaluate outcomes as specified in the systematic review conducted.
Wanek & Mayberry. (2004) Blunt thoracic trauma: flail chest, pulmonary contusion, and blast injury.	Objectives: provides background information regarding pathophysiology and overall management. Outcomes: no outcomes (primary or secondary) are evaluated.
Wilson & Bonnie. (2001) Where We Have Been, Where We Are Now, and Where We Are Going Preliminary Results With Operative Fixation of Flail Chest	Intervention: the focus of the review is on operative fixation of flail chest.
Winters. (2009) Older Adults With Traumatic Rib Fractures: An Evidence-Based Approach to Their Care.	Objectives: clinical guidelines for the assessment and medical management of pain in older adults. Outcomes: no outcomes were assessed or evaluated. Interventions: nonpharmacological treatment interventions are not reviewed.

Wyen. (2013) Rotational bed therapy after blunt chest trauma: a nationwide online-survey on current concepts of care in Germany.	Population: non- specific to rib fractures (blunt chest trauma including pulmonary contusions). Outcomes: specified primary or secondary outcomes were not evaluated or reviewed.
Xirouchaki et al. (2005) Noninvasive Bi-level Positive Pressure Ventilation in Patients with Blunt Thoracic Trauma.	Population: non-specific to rib fractures (acute respiratory failure due to blunt thoracic trauma).
Zeckey et al. (2015) Kinetic therapy in multiple trauma patients with severe blunt chest trauma: An analysis at a level-1 trauma center	Population: patients were mechanically ventilated and included all severe blunt chest trauma patients.
Zhang et al. (2015) Comparison of surgical fixation and nonsurgical management of flail chest and pulmonary contusion.	Population: all included patients were mechanically ventilation.

Studies excluded following the updated PubMed Search.

Study	**Reason/s for exclusion**
Carrie et al. (2018) Bundle of care for blunt chest trauma patients improves analgesia but Increases rates of intensive care unit admission: a retrospective case-control study.	Population: Co-existing injuries including patients with craniofacial trauma, spinal fractures, abdominal trauma, pelvic fractures as well as limb fractures and underlying cardiovascular disease were included.
Kourouche et al. (2019) Designing strategies to implement a blunt chest injury care bundle using the behaviour change wheel: a multi-site mixed methods study.	Intervention: non-pharmacological interventions not reviewed or relative to specified outcomes
Lee et al. (2018) Comparison of the effectiveness in pain reduction and pulmonary function between a rib splint constructed in the ER and a manufactured rib splint.	Setting: Patients managed in an Emergency department not admitted.
Peek et al. (2019) Comparison of analgesic interventions for traumatic rib fractures: a systematic review and meta-analysis.	Population: Included patients 16 years and older. Intervention: analgesic therapy focused on epidural, intravenous, paravertebral and intercostal interventions for patients with traumatic rib fractures.

APPENDIX D: TURNITIN REPORT

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THE EFFECTS OF NON-PHARMACOLOGICAL THERAPEUTIC INTERVENTIONS ON PAIN AND PHYSICAL FUNCTION IN ADULTS WITH RIB FRACTURES:

A SYSTEMATIC REVIEW.

Beverley Joan Weinberg

A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirments for the degree of Master of Science (Physiotherapy).

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2	Submitted to University of Southern Queensland Student Paper	<1%
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