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The Treatment of Rib Fractures with Thoracic Epidural Analgesia

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Rib fractures are detected in nearly 300,000 patients admitted to U.S. trauma centers each year. Among these patients, a mortality rate of about 10% can be expected. It is often pain, rather than structural damage, that precipitates the high risk of mortality. Focusing rib fracture care on effective pain management improves treatment outcomes. The purpose of this investigation was to explore the efficacy and cost-effectiveness of one mode of pain management – thoracic epidural analgesia (TEA) – in the treatment of patients with rib fractures. Methods: Four years of patient records were obtained from a Level II trauma center in an urban-suburban setting. There were 1,008 patients with ≥ 1 fractured rib in the registry. These patients were retrospectively analyzed, evaluating relationships between TEA and mortality, risk of complications, use of mechanical ventilation, length of stay in the hospital and intensive care unit, and total treatment cost. Results: The severity of injuries among patients receiving TEA was significantly worse, but there was no significant difference in mortality between patients treated with TEA (0.6%) and those receiving alternative treatments (2.0%; p=0.233). There was a trend that the administration of TEA decreased odds of mortality by 87% (p=0.071). Similarly, the use of TEA predicted a $12k reduction in total patient charges (p<0.001) and a $2,600 reduction in hospital expenses (p<0.001). Discussion: This investigation suggests the use of TEA can improve patient survival while reducing patient billing and hospital costs.

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The Treatment of Rib Fractures with Thoracic Epidural Analgesia

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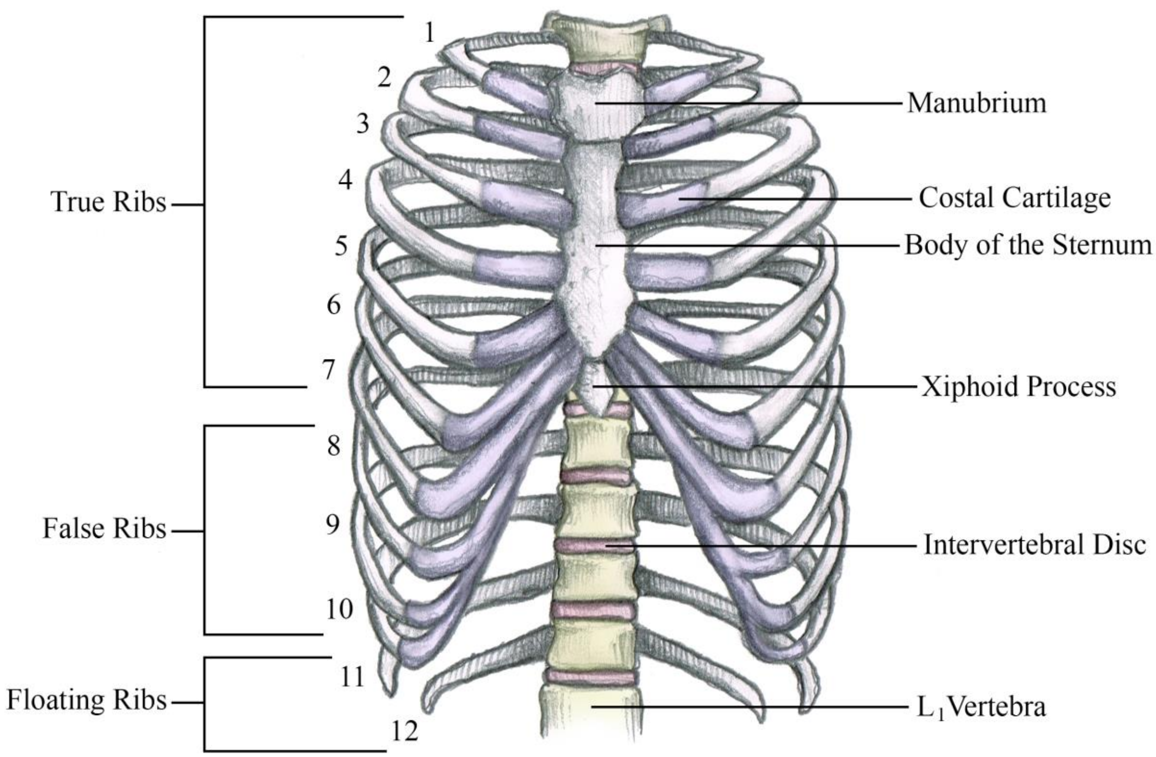
Chapter 1: Introduction

The human body has 24 ribs, comprising 12 bilateral pairs. The 7 most superior pairs are considered “true ribs” because they are connected to the sternum directly through their own costal cartilage. Pairs 8–10 are called “false ribs” because their anterior articulation is only through the cartilage of the 7th pair. Ribs 11 and 12 are known as “floating ribs” because they are not connected to the sternum at all (Figure 1.1).

Figure 1.1: Anatomy of the rib cage



In the U.S., rib fractures are the most commonly treated chest injury.[1-3] Each year, nearly 300,000 patients fracture 1 or more ribs as a result of blunt thoracic trauma.[4] The true prevalence may actually be higher as some fractures go undetected at admission.[2,3,5]

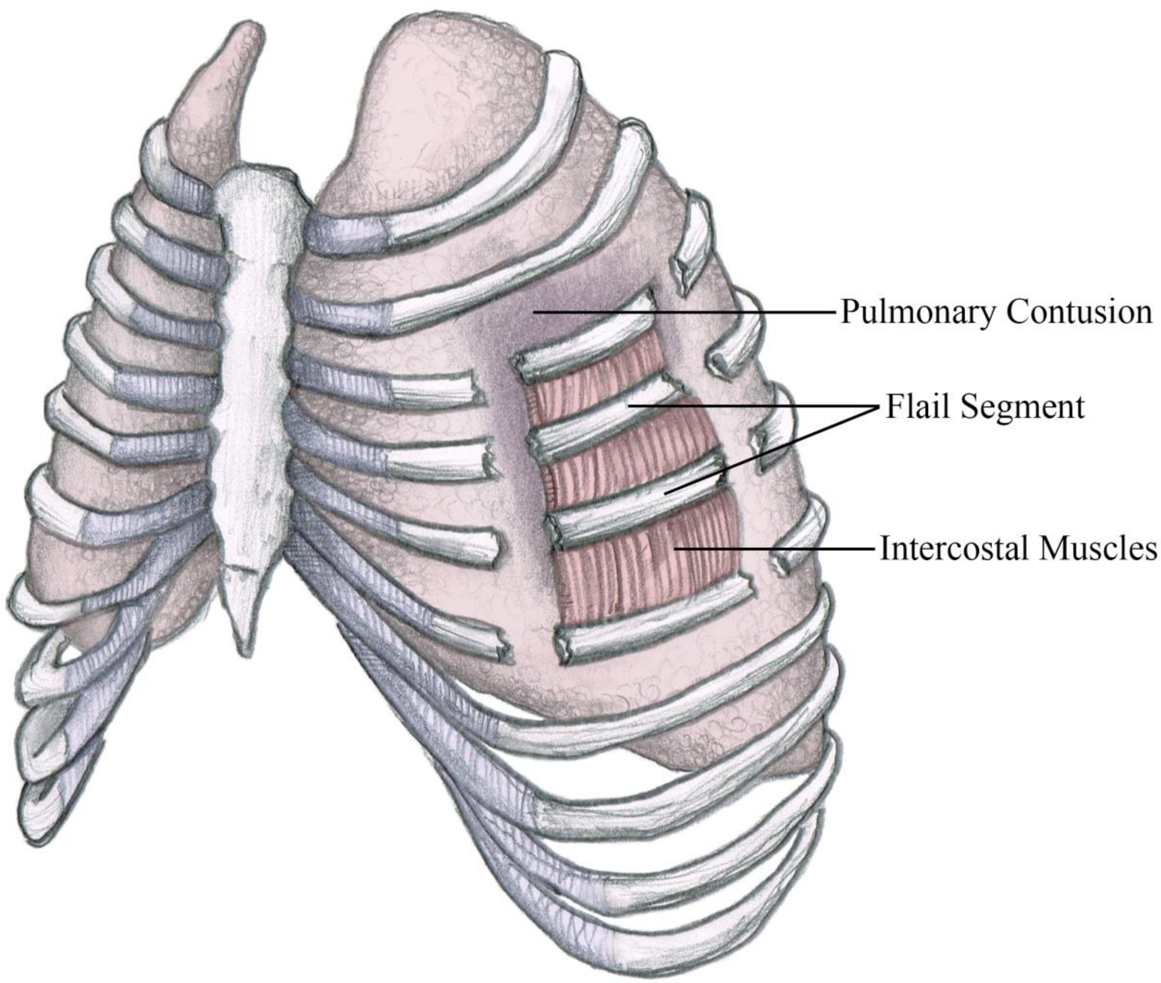
Among these patients, the characteristics of their injuries are diverse and the degree of damage is inconsistent. Although the mean number of fractures is typically 4–6 ribs[6-10], the range is broad. Additionally, forces large enough to break ribs frequently result in associated injuries such as pulmonary contusions and flail chest.[3,6,11]

A ***pulmonary contusion*** is a bruise on the lung tissue marked by capillary damage and consequent micro-hemorrhages within the alveoli.[12] The amount of bleeding depends on the severity of the contusion.[13] If enough blood and fluid accumulate, it can lead to a pulmonary edema, obstruct gas exchange, and promote hypoxic conditions.[14,15] In more severe cases, bronchorrhea (production of watery sputum) may develop.[16] The patient can also experience pulmonary consolidation (a region of compressible lung tissue filled with liquid) or atelectasis (the partial or full collapse of a lung).[17] Most studies report 27–40% of patients who fracture at least 1 rib also present with a pulmonary contusion.[3,6,7,9,11]

Flail chest is a potentially lethal condition in which a section of the rib cage becomes detached from the chest wall. For this to occur, there must be at least 3 consecutive ribs fractured in at least 2 places, creating an "incompetent" segment of the chest wall. This means that the detached segment's movement is opposite that of the intact portion.[18,19] During inhalation, while the rib cage expands outward, the flail segment moves inward, owing to the relationship between ambient pressure and the pressure inside of the lungs.[20] This motion has been coined "paradoxical respiration"[21-25], although that is technically a misnomer; it would be more appropriately called paradoxical *ventilation*, as it is not a cellular event, but a mechanical one. Some authors have found flail segments to be present in as few as 2–3% of rib fracture cases[26] while

others have reported incidences over 20%.[11,27] Typically, among patients who present with at least 1 fractured rib, the incidence of flail chest falls in between those amounts.[3,6,9,28-30] Both flail chest and a pulmonary contusion can be seen in Figure 1.2.

Figure 1.2: Illustration of a flail segment with a pulmonary contusion



Other injuries that regularly accompany rib fractures are pneumothorax and hemothorax. Pneumothorax is an accumulation of air in the pleural cavity, which separates the lung from the chest wall. This occurs in 15–40% of blunt thoracic trauma

cases and may interfere with breathing.[2,3,31-33] Hemothorax is the accumulation of blood in the pleural cavity; incidence is similar to pneumothorax. [2,3,31-33] Hemopneumothorax is a combination of both conditions.[31,32]

The number of fractured ribs as well as the presence of associated injuries affects the risk of mortality.[8,10] Among large samples of patients admitted to trauma centers with at least 1 fractured rib, the overall mortality rate is about 10%.[2,3,5,10] In the presence of 8 or more fractures, this rate can exceed 30%.[10] When pulmonary contusions and flail segments are both present, mortality may exceed 40%.[34]

The risk of mortality is influenced by the amount of pain a patient experiences. In the presence of multiple rib fractures, that pain is often exacerbated by coughing and deep breathing. To minimize these symptoms, many patients actively avoid coughing and adopt a pattern of shallow breathing (i.e., splinting).[35,36] These alterations in ventilatory behavior impede the clearance of airway secretions, which results in the retention of sputum.[11,37-39] In turn, lung compliance is commonly affected and a mismatch between ventilation and perfusion begins to develop.[37,40] Combined with insufficient clearance of airway secretions, patients are placed at an elevated risk of secondary complications (e.g., pneumonia), which increases the likelihood of respiratory failure and the need for intubation and ventilatory support.[38,41] Once patients require mechanical ventilation, the risk of mortality is drastically elevated.[42-45] Effective pain control is thus critical to the successful treatment of a patient with multiple rib fractures.[41,46,47]

There are a variety of ways to manage a patient's pain. Those who fracture 1 or 2 ribs and have minimal pain can be treated with oral analgesic drugs[47] and experience a low risk of complications and mortality.[1,10] Among patients who fracture 3 or more ribs and whose pain is greater, systemic analgesia is unlikely to be sufficient and regional modes are more likely to be used.[10,47] Thoracic epidural analgesia (TEA) is one mode of regional analgesia.[37,47]

TEA is a relatively complex procedure in which the analgesia is installed into the epidural space (Figures 1.3 and 1.4). Typically, it involves a combination of opioids (e.g., hydromorphone or fentanyl) and local anesthetic (e.g., bupivacaine or lidocaine). The synergistic effect may produce superior analgesia while helping to avoid adverse effects related to either elevated dosing of either mode of administration by itself.[48]

Figure 1.3: Transverse view of a vertebra, the articulated ribs, and the epidural space

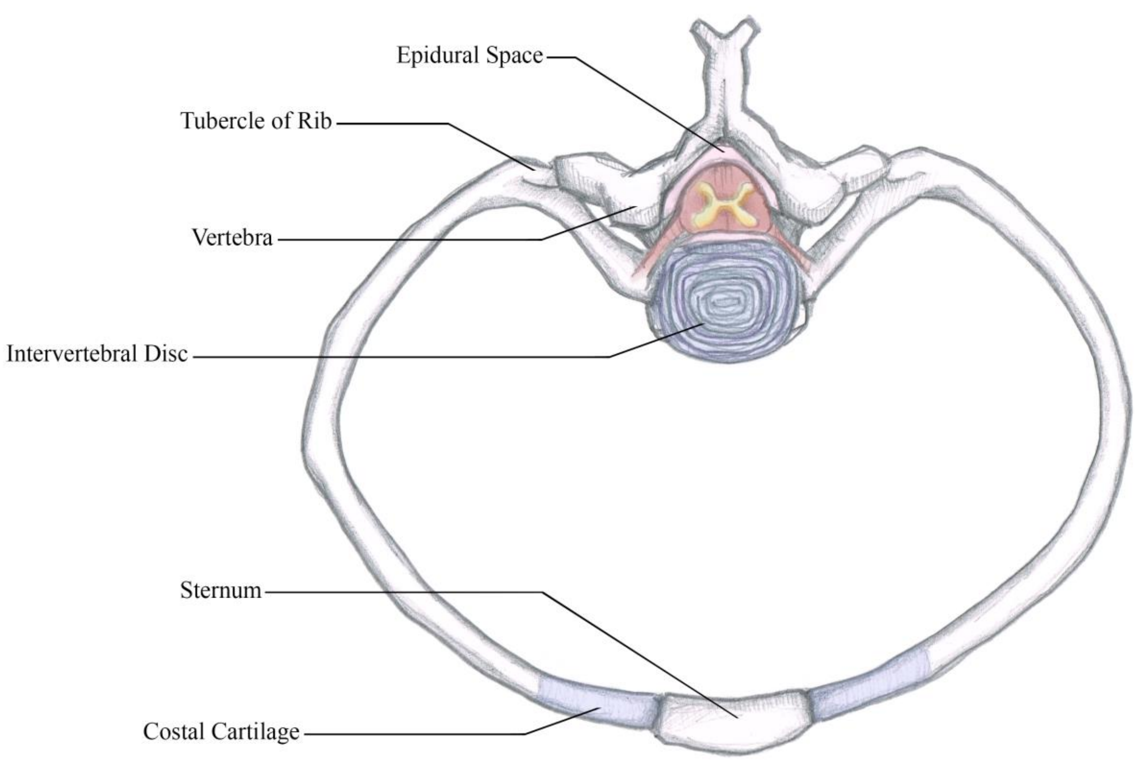
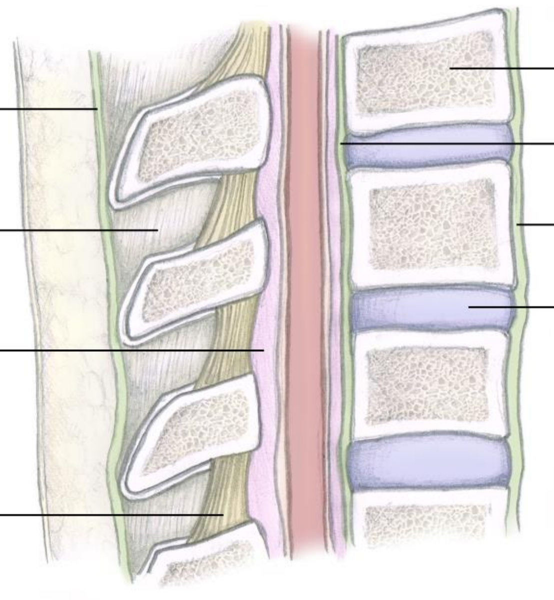


Figure 1.4: Sagittal view of a vertebral column and the epidural space



Chapter 2: *Rib fracture care: a systematic review of thoracic epidural analgesia.* This chapter includes a comprehensive search for articles related to the use of TEA in patients with rib fractures. In it, I describe the etiology and characteristics of rib fracture injuries, outline the history of their treatment, and evaluate the current body of research, appraising study quality and comparing key findings. The primary outcomes evaluated concern the efficacy of TEA in terms of mortality, length of stay (LOS) in the intensive care unit (ICU) and hospital, the use of mechanical ventilation, improvement in patient pain levels, effect on respiratory function, and incidence of complications and adverse events (e.g., pneumonia, respiratory failure). Wherever possible, comparisons are drawn to other treatments. This chapter provides further introductory material on TEA and serves and as an assessment of its clinical value.

Chapter 3: *The efficacy of thoracic epidural analgesia in the treatment of rib fractures.* This chapter evaluates clinical outcomes of TEA administration at a Level II trauma center. It describes the demographics and injury characteristics of patients admitted, assesses the effectiveness of TEA in regard to mortality, pulmonary complications, use of mechanical ventilation, and LOS in the ICU and hospital, and evaluates the relationships between predictors of mortality to provide perspective on the management of patients with rib fractures.

Chapter 4: *The cost-effectiveness of thoracic epidural analgesia in rib fracture care.* This chapter analyzes financial outcomes related to the care of patients with rib fractures, evaluating the cost-effectiveness of TEA administration. The primary outcomes are the cost of treatment both to the patient and to the hospital. It assesses the predictors of cost and identifies interrelationships between patient demographics, injury characteristics, and the mode of treatment.

Chapter 5: *Conclusion.* This chapter summarizes all important findings from Chapters 2, 3, and 4, notes limitations in the field, and advises future directions for research.

Chapter 2: Rib Fracture Care: A Systematic Review of Thoracic Epidural Analgesia *(Part 1: Abridged Version)*

ABSTRACT

Each year, nearly 300,000 patients are admitted to trauma centers with rib fractures. About 10% of these patients die and more than a third develop pulmonary complications. Much of the morbidity and mortality is a consequence of pain (and the effect pain has on pulmonary mechanics). Effective pain management is thus critical to successful treatment outcomes. There are a variety of ways to manage pain. Thoracic epidural analgesia (TEA) is one method. In this paper, we review the safety and efficacy of TEA among patients with rib fractures.

INTRODUCTION

In the U.S., 10-15% of all patients admitted to trauma centers and a quarter of all trauma-related deaths are the result of blunt thoracic trauma.[2,10] Blunt thoracic trauma commonly results in chest wall injuries; the most common of these is rib fractures.[1,2] Each year, nearly 300,000 patients with rib fractures visit U.S. trauma centers.[4] The true prevalence may be higher as not all fractures are detected upon admission.[2,5,49]

Patients who only fracture 1 or 2 ribs are typically treated with oral analgesic drugs (NSAIDs, acetaminophen, or hydrocodone)[47] and have low incidences of complications and mortality.[1,10] If pain relief is not sufficient, other systemic modes (e.g.,

intravenous narcotics or dilaudid) may be administered.[47] When a patient fractures 3 or more ribs, the risk of complication increases.[1] In this situation, the pain can be more harmful than the injury itself, as more severe pain often precipitates secondary complications.[10,19,37]

As the number of fractured ribs increases, the pain experienced with breathing is exacerbated. In an effort to avoid that pain, patients experience splinting.[35,36] This can impede chest physiotherapy and cause ineffective coughing, resulting in insufficient clearance of airway secretions and retention of sputum.[11,37-39] In turn, lung compliance is commonly reduced and patients experience a mismatch in ventilation and perfusion.[37,40] The combination of these deficits (poor lung compliance and inadequate clearance of secretions) puts patients on a course toward secondary complications (e.g., atelectasis, pneumonia) and eventually respiratory failure and the need for intubation and ventilatory support.[38,41] The ultimate consequence of this is a mortality rate of about 10% among all patients admitted with rib fractures.[2]

A primary way to prevent these complications, thus lowering the risk of mortality, is to control the patient's pain level.[41,46,47] Accomplishing this with systemic narcotics can result in over-sedation and worsening of pulmonary toilet. Thus, when multiple ribs are fractured, regional modes of analgesia often become the mainstay, with systemic deliveries used as a supplemental treatment.[47] There are several types of regional analgesia, most notably thoracic epidural analgesia, intercostal nerve block, intrapleural nerve block, and thoracic paravertebral block.[37,47] This paper focuses on thoracic epidural analgesia (TEA), comparing its safety and effectiveness to alternative treatments.

History of thoracic trauma treatment

Interest in chest wall trauma and its consequences (such as flail chest) is not new to medicine. Rudimentary descriptions appeared in the Edwin Smith Surgical Papyrus (circa 1600 BC), in the *Iliad* (circa 850 BC) and in 5th century writings by Hippocrates.[18,50] The first documented treatment, which was practiced for several centuries, was wrapping the chest wall in linens.[51] That approach didn't change until the 1930s, when physicians began inserting pins, hooks, screws, and wires to stabilize the chest wall internally (incorrectly assuming that chest wall instability was the most lethal concern). Unfortunately, these treatments failed to reduce mortality.[52,53] In the 1950s, artificial ventilation was introduced. Although initially promising, higher incidences of comorbidities (including pneumonia) were soon reported.[43,52,54] In the 1970s, more conservative techniques, such as simple pain control, were attempted. When the outcomes of these treatments were compared to the outcomes of mechanical ventilation, researchers were encouraged; it appeared to be the pain itself – more than the structural changes – that precipitated morbidity.[24,44,45,55,56] In the 1990s, researchers went a step further, investigating the efficacy of different types of pain management.[53] The question was no longer whether pain management was of paramount importance, but which modes of management were the most effective.[42]

Today, we still don't have an answer to this question, owing to the number of options as well as outcomes to consider. It is not merely life or death, but cardiopulmonary function, incidence of complications, and degree of pain relief on top of the cost, duration, and safety of the treatment. The most beneficial agent would be one

that maximizes pain control while minimizing side effects. Regional modes of pain control have emerged as the most effective interventions, but there are several methods available and no single treatment accomplishes all of the desired outcomes.[37,42,47] Despite this, TEA is often regarded as the most reliable technique to relieve pain and improve pulmonary outcomes in patients with multiple fractured ribs.[42]

Presentation of injury

The majority of patients admitted to trauma centers for rib fractures are injured in motor vehicle collisions while around a quarter of the incidence results from falls.[6,26,27,57] Regardless of the mode of injury, there is no consistent presentation of damage. In addition to differing numbers and locations of ribs fractured, the trauma commonly results in associated injuries, such as pulmonary contusions. Thus, when a patient presents with fractured ribs, the characteristics of his or her injury (e.g., unilateral or bilateral fractures, upper or lower ribs, chest tube placement, presence of associated injuries) affect the course of recovery and the likelihood of mortality.[8]

Mortality

In an assessment of 64,750 patients across 268 trauma centers in the National Trauma Data Bank (NTDB), the mortality rate among patients with rib fractures was 10%.[10] Smaller studies have reported lower mortality rates. For example, a Turkish hospital reported a mortality rate of 5.7% among rib fracture patients treated between 1999 and 2001.[58] However, this group included 68 children (age 5 to 12), 103 adolescents (age 13 to 17), 235 adults (age 18 to 59), and 142 elderly patients (age 60 to 78). No

children or adolescents died; 100% of deaths were among patients age 18 or older. Thus, the mortality rate among adults was 8.2%. Other hospitals have found success with more aggressive approaches to therapy. Using a "multidisciplinary clinical pathway", which involves respiratory therapy, physical therapy, nutrition services, and several pain management techniques (oral pain medications, IV pain medications, and epidural analgesia), one hospital decreased the mortality from 13% to 4%.[59] The treatment is extensive, however, and studies have not yet quantified the individual contribution of each component.

In general, a mortality rate of about 10% can be expected (ranging from 3% to 13%) and is often the result of secondary lung complications.[46,60,61] The best predictors of mortality include number of fractured ribs (representing injury severity)[2], presence of additional injuries (e.g., flail segments)[26], and age.[6]

Complications

Between a third and half of all patients with rib fractures experience pulmonary complications (e.g., pneumonia, pneumothorax, atelectasis, adult respiratory distress syndrome)[2,10] The risk of complication increases significantly with each additional rib fractured.[6,10] Thresholds at which morbidity significantly increases have been found at 3 or more ribs[1] and at 6 or more ribs.[10] The most commonly reported complication is pneumonia; its incidence depends on the age of the patient and severity of the injury.[10,46] In general, much higher rates can be expected among elderly patients compared to young patients (e.g., 34% vs. 17%).[6]

Pain

Pain is a primary risk factor for morbidity and mortality among patients who present with chest wall trauma.[58,62,63] In the presence of pain, patients typically alter ventilation (to avoid exacerbation of that pain) by restricting breathing and decreasing tidal volume.[35,36] This impedes chest physiotherapy and pulmonary toilet, often causing ineffective coughing, which results in insufficient clearing of airway secretions and retention of sputum.[11,37-39] In turn, this leads to atelectasis, which reduces lung compliance and functional residual capacity, resulting in a mismatch of ventilation and perfusion. Parenchymal lung infection can also develop in the presence of bacterial colonization.[37,40,57] Patients who cannot effectively cough, clear secretions, or re-inflate areas of the lung compromised with atelectasis are at a higher risk for pulmonary complications such as secondary pneumonia with pulmonary consolidation.[38,41,54,64] This leads to respiratory failure and the need for intubation and ventilatory support.[38,41] The ultimate consequence of these secondary complications is a high risk of mortality.[38] Contrarily, if the patient's pain is not exacerbated with normal ventilation and coughing (thus an adequate tidal volume is maintained and coughing can occur without exacerbation of symptoms), the risk of pulmonary complications (e.g., atelectasis, pneumonia, and the need for mechanical ventilation) is reduced.[56,65,66] For this reason, effective pain management is critical to restoration of pulmonary function and the avoidance of morbidity and mortality.[39,67,68] Pain management is accomplished through systemic and regional anesthetics and analgesics.[41] Because the relief of pain is a primary goal of treatment, it is often the severity of the pain – rather than the severity of the injury – that guides the choice of treatment. If pain can be managed with oral and/or IV

narcotics, it often is; if conservative treatments do not provide adequate pain control, patients are often treated with local analgesia.[6,11,47]

Modes of analgesia

Analgesia is the primary treatment in the management of patients with chest wall trauma.[58,69] A variety of treatment options exist; some are systemic (e.g., oral and intravenous anti-inflammatory agents, intravenous opioids, and narcotic dermal patches) while others are local agents (e.g., intercostal nerve blocks, intrapleural nerve blocks, thoracic paravertebral blocks, and TEA).[8,47,70] The 3 most effective (and commonly delivered) local treatments are: narcotic infusions and continuous local anesthetic via epidural catheter, intrapleural infusions of local anesthetic via catheter, and intercostal nerve block via injection.[42,71] Less common modes of therapy have been attempted, including intrathecal opioids[72], narcotic dermal patches[73], epidural steroid injections[74], and transcutaneous electrical nerve stimulation.[75] Because the focus of this review is on TEA, we will only mention alternative treatments briefly except when directly comparing them to TEA.

Oral non-narcotic analgesic drugs

NSAIDs, codeine, or acetaminophen may be sufficient if only 1 or 2 ribs are fractured. There is no central nervous system or cardiovascular depression, but the degree of analgesia is limited. Although there is a shortage of data regarding their use in treatment of patients who have multiple rib fractures, the common understanding is that they may be effective supplements to a treatment, but not effective when used in

isolation.[37,47]

Systemic analgesia

This is often the first line of therapy to manage pain from rib fractures.[37] There are several modes of delivery: intermittent, on-demand injections[76], intravenous (IV) patient-controlled analgesia[77,78], continuous IV infusion[36], and less commonly, dermal patches of lidocaine on the fracture site, which has proven ineffective.[47,73] While a continuous IV infusion of systemic opioids will reduce pain and improve vital capacity, it can result in cough suppression and hasten the onset of respiratory complications (e.g., respiratory depression and hypoxemia), possibly owing to paradoxical breathing, obstructive apnea, or a reduction in sigh-breaths.[36] Even when using conservative doses, morphine may still compromise pulmonary mechanics (most notably a reduction of spontaneous deep breathing).[79] Systemic use of opioids (or ketamine) can also compromise evaluations of the head and abdomen.[47] On top of the side effects, systemic analgesia remains less effective than regional techniques at controlling pain.[37] Thus, systemic opioids may be helpful in conjunction with a regional treatment, but not as a treatment for multiple fractured ribs per se.[76,77]

Regional analgesia

Regional analgesia is often supplemented with a small dose of either NSAIDs or opioids and pain reduction is typically strong and immediate.[28,47] There is little sedation, so evaluation of head and abdominal injuries is easier. A major disadvantage is the technical complexity of the procedures, leading to occasional errors in the administering

of the treatments. They can also be painful while the needle is entering (or catheter is being installed), toxicity is a possibility, and the patients require more intensive monitoring and care by the physicians and nurses.[47] There are a variety of modes; the four most common are TEA, thoracic paravertebral block, intercostal block, and intrapleural block.[37] This paper focuses on TEA.

Thoracic epidural analgesia

Narcotic infusions and continuous local anesthetic can be delivered through thoracic or lumbar epidural catheters. Opioid receptors exist in the spinal cord that can alter the perception of pain without needing stimulation of receptors in the brain.[36] Once injected, the anatomy of the epidural space restricts the geography throughout which the analgesia can spread.[42] These boundaries are made up by the dura (the outermost membrane surrounding the spinal cord) and the periosteum, which lines the bones of the vertebral canal. Superiorly (in the upper-cervical region), the dura and periosteum fuse. This prevents the analgesic from migrating above the foramen magnum. Posterior migration is limited by the ligamenta flava (ligaments that connect the vertebrae, bordering the interior of the spinal canal).[42] After inserting the catheter into this area, local anesthetics and narcotics are administered, blocking the anterior and posterior nerve roots crossing this space. The anesthetic/analgesic agents diffuse across the dura and begin to block sensory nerves. Motor nerves are affected to a lesser degree. It takes a large dose to achieve the desired effect. A possible side effect of a large dose of local anesthetics is dilation of the arteries and veins (especially the veins). There are techniques to safely avoid or treat the resulting hypotension.[68,80]

In 1982, Rawal and colleagues[81] showed thoracic epidural morphine to be a more effective treatment than intercostal nerve block following cholecystectomy. The epidural patients experienced prolonged pain relief and did not experience respiratory depression, while those receiving intercostal nerve block did. Since then, TEA has emerged as one of the most researched and seemingly effective treatments for patients who present with multiple fractured ribs.[47,70]

According to most reports, the downsides of epidural analgesia are not ineffectiveness (relative to other treatments), but risk of side effects. It has been successful in both lumbar and thoracic routes using opioids, local anesthetics, or a combination, especially in patients over the age of 60. Among this group, epidural analgesia decreases mortality and pulmonary complications.[82] Among patients with chest wall trauma, it relieves pain better than systemic opioids[36,78] and intrapleural analgesia.[83] It is an effective treatment in a variety of pulmonary measures (e.g., dynamic lung compliance, airway resistance, functional reserve capacity, vital capacity, pulmonary gasses).[84] If the patient has paradoxical chest wall movement, epidural analgesia reduces it and restores shallow breathing to near-normal levels.[85] There may also be immune system benefits, as epidural analgesia reduces plasma levels of interleukin-8, a chemokine that increases inflammation following acute lung injury.[78] Overall, patients who are treated with epidural analgesia develop fewer complications than patients who are intubated and receive mechanical ventilation[44,45,53] and they spend fewer days in the hospital and the ICU.[53]

Comparing the different treatments

Each treatment has a unique set of advantages, disadvantages, and contraindications. Patients must be treated according to what is currently regarded as the best medical practice. For this reason, controlled trials that truly randomize patients to different treatment groups are infrequently conducted. It is unlikely that a review board would approve a randomization model that distributes patients evenly throughout the treatment groups based on criteria such as the presence of upper-rib fractures. Thus, most data available are retrospective comparisons of two groups of patients who have *similar* injuries and were treated with different techniques. Among this body of research, there is wide variation in which treatment option is used.[86]

When hemodynamic and respiratory function are concerns, systemic analgesia is often avoided.[38] Systemic opioids can also impair assessment of a patient's mental status.[38] For these reasons, regional techniques are often preferred.[38] According to a 2000 meta-analysis by Rogers and colleagues[87], TEA can reduce the rate of mortality by more than 30% and decrease the incidence of comorbidities by 15% (stroke) to 55% (pulmonary embolism). Likewise, a 2003 meta-analysis by Block and colleagues[88] (which analyzed more than 100 studies) found epidural treatment to be superior to opioid treatments. More specifically, use of epidural catheter treatments (as compared to systemic opioids) has demonstrated improvements in subjective pain management[7], pulmonary function[36,78,89], and better clinical outcomes.[11,82] Despite this, in a 2003 narrative review on pain management, Karmakar and Ho[37] concluded that no single mode of analgesia could be confidently recommended. Contrasting this review, Simon and

colleagues published pain management guidelines for blunt thoracic trauma in 2005[90], stating that the preferred mode of analgesic for patients with multiple rib fractures was via epidural. The inconsistencies in recommendations may be responsible for the low rates (below 20%) of epidural use among eligible patients (patients without contraindications to epidural placement).[7,8,59] In 2005, Flagel et al.[10] found only 2% of patients with at least 1 fractured rib to be treated with epidural analgesia (1,295 of 64,750). Most recently, in 2014, Dehghan et al.[26] found epidural catheters were only used in 8% of patients who were admitted with flail injuries (263 of 3,467).

Rationale for this review

The most recent review of TEA as a treatment for patients with multiple rib fractures was published by Carrier and colleagues in 2009.[46] In it, they performed a meta-analysis of 8 studies related to TEA (7 in English, 1 in Turkish). They identified 3 studies that compared TEA with local anesthetics to parenteral opioids[78,91,92], 2 studies that compared TEA with local anesthetics to intrapleural analgesia[83,93], and 3 studies that compared epidural analgesia with opioids to parenteral opioids.[36,89,94] When analyzing those studies collectively, Carrier and colleagues reported no significant differences between epidural analgesia and other analgesic modalities in mortality, length of stay in the ICU, or length of stay in the hospital. When evaluating duration of mechanical ventilation, they found *some* benefit to using epidural anesthesia with local anesthetics. However, that treatment was associated with a greater risk of hypotension.

These findings must be interpreted cautiously. Out of the 8 studies analyzed, only 6 were randomized trials, one of which was a poster presentation. Of the remaining studies, 1 assigned treatment based on injury severity and 1 is in Turkish, with no mention of randomization in English. Furthermore, only 4 studies provided sufficient details about catheterization methods in English. Carrier and colleagues rank their 8 studies in terms of quality, admitting, “Only four of the eight studies included in our review were of high methodological quality.” These were: Bulger et al., 2004[11]; Luchette et al., 1994[83]; Moon et al., 1999[78]; and Shinohara et al., 1994.[93]

A similar admission is made in a 2007 review of the literature by Parris[95], who *also* found 4 studies to be satisfactory for inclusion. These were: Bulger et al., 2004[11]; Moon et al., 1999[78]; Mackersie et al., 1991[36]; and Ullman et al., 1989.[89] Curiously, only half of the “high methodological quality” studies overlap between the two most recent reviews.

One example of a study that Carrier and colleagues regarded as high quality and Parris did not is a 1994 investigation by Luchette et al.[83] This study did not address clinical outcomes (days in ICU, days in hospital, duration on mechanical ventilation, incidence of pneumonia) as much as variables thought to *affect* clinical outcomes (pain, pulmonary function). There is no mention of blinding and patients were permitted into the study with associated injuries that were not explained or controlled for (and would likely affect patient-perceived pain level). It is important to consider the impact such limitations might have on the validity of Carrier et al.’s conclusions.

Regarding these conclusions, although no original studies were published between the two reviews, Parris's interpretation of the data was slightly different from Carrier et al.'s: "On limited evidence from moderate quality studies, epidural analgesia/anaesthesia offers some benefits over intravenous analgesia but further studies are needed to strengthen this conclusion."

What seems consistent between the two reviews is not their interpretation of the findings, but their appraisal of the *quality* of available literature. According to Parris, "the limited quantity and quality of evidence illustrates the difficulties in studying this patient group and determining the most relevant outcomes." In terms of quantity, several studies went unreported, but in terms of quality, he makes a valid point. He elaborates on that point: "All four studies looked at slightly different patient groups, different treatment regimens and outcomes with consistently poor reporting of timing of placement of epidural catheters and administration of intravenous analgesics."

Although a new systematic review may be in order just to reconcile the conclusions of the previous attempts, it is also an ideal time to do so as new studies evaluating the safety and/or effectiveness of TEA have been published since 2009. According to our search, there are 10 studies that merit consideration, which were not considered in either of the aforementioned reviews: 4 published prior to 2009, 6 published since.

Prior to 2009: Wisner (1990)[82] compared epidural narcotics (87% lumbar, 13% thoracic) to a variety of analgesic modes, but most commonly intravenous/intramuscular (IV/IM) narcotics among patients who had sustained thoracic trauma. Wu and colleagues

(1999)[7] compared TEA to IV analgesia in patients with at least 3 fractured ribs. Bulger and colleagues (2000)[6] compared treatment outcomes of elderly Patients (≥ 65 y) with at least 1 fractured rib to younger patients (18-64 y) with at least 1 fractured rib; epidural catheters were compared to other treatment modalities (e.g., pleural block, IV/IM narcotics, oral narcotics, ketorolac, Tylenol). Kieninger et al. (2005)[96] compared epidural analgesia to IV narcotics in older patients with rib fractures.

Since 2009: Mohta and colleagues (2009)[29] compared TEA to thoracic paravertebral infusion in patients with at least 3 fractured ribs. Hashemzadeh and colleagues (2011)[61] compared TEA to intercostal block in patients with multiple fractured ribs. Kim and colleagues (2011)[97] reported the complications that arose in patients who underwent surgical reduction and fixation of fractured ribs, and were treated with TEA. Hakim & Latif (2012)[28] evaluated TEA compared to lumbar epidural analgesia (both lidocaine) in patients admitted with blunt chest trauma. Yeh and colleagues (2012)[8] compared TEA to IV and oral narcotics in patients with at least 3 fractured ribs. Waqar and colleagues (2013)[9] compared TEA to IV opioids among patients with multiple fractured ribs.

Objectives of this review

In this review, we complete a comprehensive search for articles related to the use of TEA in patients with rib fractures. In doing so, we attempt to identify the value of TEA as it relates to mortality, length of stay in the ICU and hospital, use of mechanical ventilation, improvement in subjective pain levels, effect on respiratory function, and incidence of pneumonia and other complications/adverse events (e.g., sepsis, acute

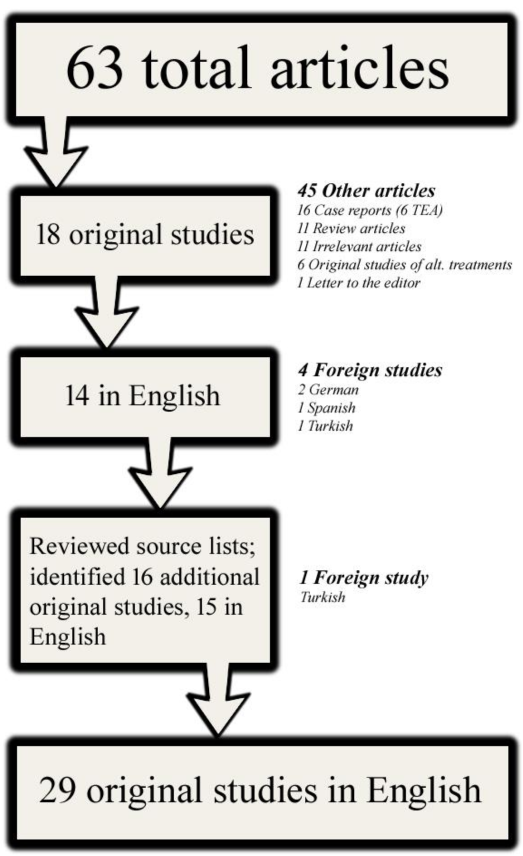
respiratory distress syndrome, respiratory failure). Wherever possible, we make comparisons to other treatments.

METHODS

Search strategy

An electronic search was conducted using PubMed on March 29, 2014. Two search terms were used:

1) (thoracic) AND (catheter* OR epideral* OR "epidural analgesia" OR "Analgesia, Epidural"[MAJR]) AND pain AND (fracture*) AND (rib OR ribs)



2) (("thoracic catheter" OR "thoracic epidural" OR "thoracic catheters" OR "thoracic epidurals" OR "thoracic paravertebral catheter" OR "Analgesia, Epidural"[MAJR] OR "epidural analgesia") AND pain AND fracture* AND (rib OR ribs))

After running each search, the PubMed Advanced Search Builder tool was used to combine their results, eliminating duplicate studies.

Search results

This search yielded 63 total articles; 14 of these presented original research about the effectiveness of TEA in English.[7,8,11,25,29,39,41,61,82,83,91,93,96,98]

Additional articles

After completing the search, we reviewed the source lists of all relevant articles and found an additional 16 original trials that weren't identified by our search term; 15 of these were in English.[6,9,10,28,30,36,65,66,78,84,85,89,94,97,99]

Study Selection, Validity Assessment, and Eligibility Criteria

The quality of each study is evaluated and assigned a rating based on a 14-point scale. The instrument for assessing study quality is the Quality Assessment of Controlled Intervention Studies, available on the NIH website.[100]

Items 1 through 3 address randomization and treatment allocation. Items 4 and 5 involve blinding. Item 6 evaluates the similarity of treatment groups at baseline. Items 7 through 9 assess drop out and adherence. Items 10 and 11 address internal study validity. Item 12 evaluates power calculations/sample size. Item 13 involves pre-specification of study outcomes. And item 14 asks if all study participants are analyzed in the groups they were assigned.

All studies published in English are characterized in tables. The findings of studies with higher quality assessments are given more consideration.

Extraction and Synthesis of Data

Data were carefully extracted from all 29 articles. Tables were generated, characterizing primary outcomes where available. The outcomes are: demographic information (sex, age), type of study (RCT, review, etc.), injury characteristics (number of ribs fractured, ISS, presence of flail chest and pulmonary contusion), type of treatment (TEA, IV, etc.), mortality, ICU length of stay, hospital length of stay, use and duration of mechanical ventilation, changes in subjective pain levels, changes in respiratory function, incidence of pneumonia and other complications/adverse events (sepsis, acute respiratory distress syndrome, respiratory failure).

Principle Summary Measures

Because there are inherent differences in the type and quality of the data published, and vast differences in the methods of their acquisition, we do not attempt to meta-analyze the findings. At this stage in the research, such a summation would be little more than data alchemy, and worthy of distrust. Instead, we merely present the findings in tables, evaluate the quality of the relevant claims, and provide an overall appraisal of the state of the evidence.

RESULTS

Research supporting TEA

16 studies have reported epidural analgesia to be an effective treatment for patients with fractured ribs. Of these, 5 do not include a comparison group, 3 compare

TEA to mechanical ventilation (one is a duplicate of another study), 4 compare TEA to IV opioid treatments, and the remaining 4 compare TEA to other regional techniques.

In 2005, Flagel and colleagues[10] compared the use of epidural analgesia to all alternative treatments (they did not specify which treatments these were). In evaluating the NTDB, they found 9% of patients (n = 64,750) to present with at least 1 fractured rib. Among these patients, 2% (n = 1,295) received epidural analgesia; the rest (63,455) received alternative treatments. No information is provided about what these forms are or how they were administered. Nor were the methods of epidural catheterization (including type and concentration of analgesia) described. Inclusionary and exclusionary criteria were not reported and numerous baseline variables were absent from the results. This includes age (overall and in each treatment group), gender (overall and in each treatment group), mean number of fractured ribs (overall and in each treatment group), and the incidence of flail segments and pulmonary contusions in individual treatment groups. Among all patients with rib fractures, epidural analgesia was used in 2% of cases. The more ribs fractured, the more commonly epidural analgesia was used ($R_2 = 0.96$). Use of this treatment jumped 50% in the presence of 6 or more fractured ribs (compared to treatments of patients with 5 or fewer). Despite greater numbers of rib fractures in the group receiving epidural analgesia, ISS was slightly lower, and odds of surviving were much better (more than 96% survived, compared to a 10% overall mortality rate). Epidural analgesia had no effect on the incidence of pneumonia.

All original studies in English that support the use of TEA as a treatment for rib fractures are seen in Table 2.1.

Table 2.1: Research Supporting TEA

Author	N	Age (y)	# Ribs	ISS	Associated Trauma	Complications	Mortality	Pulmonary Outcomes	LOS (d)	Pain Relief
No Comparator										
Abouhatem et al., 1984[25]	19	53 (20–80)	5		37% flail segment; 16% pulmonary contusion	Reported bradycardia (n=2) and hypo-tension (n=3)			Treatment duration: 8 (2–17)	94.7% exp. pain relief; 42.1% exp. “excellent” pain relief.
Doss et al., 1999[41]	57	21–26								100% exp. pain relief
Govindarajan et al., 2002[39]	27	48±16	4 (2–8)			No morbidity among sample		Ventilatory markers improved	Hospital: 5 (4–7)	Improved pain relief at rest and during coughing
Johnston et al., 1980[99]	6	49	5.3±1.5			Hypotension: mean BP fall of 15 mmHg after treatment		1 patient required mechanical ventilation	7–10 (n=5)	
Worthley, 1985[30]	161	46.1±16.8			16.1% flail segment; 9.9% pulmonary contusion.	2 cardiac arrest, 1 epi infection reported.	1.2%	14 subjects needed mechanical ventilation		
Mechanical Ventilation										
Dittmann et al., 1975[85]	Epi=16; MV=32	Epi=55.1	Epi=5.4				Epi=7.1%; MV=21.9%	Epi: ventilatory markers improved; 1 patient was intubated; 1 contracted pneumonia.		Epi: pain relief claimed, but no data reported.
Dittmann et al., 1978[84]	Epi=49; MV=51	Epi=55.7; MV=44.7	Epi=6.8; MV=6.5				Epi=6.1%; MV=13.7% .	Epi: ventilatory markers improved; 3 patients needed ventilation.	Epi=4.5 (2–11); MV=9.8.	
Dittmann et al., 1982[65]	Epi=112; MV=155	Epi=57.5; MV=45.2	Epi=6.8; MV=6.6		Epi: 1% pulmonary contusion. MV: 32% pulmonary contusion		Epi=4.5%; MV=24.5%		ICU: epi=6.1, MV=13.5; Hospital: epi=16.8, MV=26.2	
IV Treatment										
Pierre et al., 2005[94]	Epi=11. IV=11.	Epi=53; IV=53	Epi=4.5, IV=3.8						Hospital: epi=10.8, IV=15.9; ICU: epi=3.1, IV=6.6	Epi had better pain outcomes at 24 and 36 hr
Ullman et al., 1989[89]	Epi=15. IV=13.	Epi=46.1± 4.6, IV=53.0± 6.0	Epi=7.3 ±0.6, IV=6.6± 1.1	Epi=19.5 ±2.0, IV=25.3 ±2.9		2 epi patients experienced urinary retention.		Epi group spent 3.1 days on ventilation; IV group spent 18.2. Epi group had better improvements in tidal volume.	Hospital: epi=14.9, IV=47.7. ICU: epi=5.9, IV=18.7	

Author	N	Age (y)	# Ribs	ISS	Associated Trauma	Complications	Mortality	Pulmonary Outcomes	LOS (d)	Pain Relief
Waqar et al., 2013[9]	Epi=47. IV=38.	Epi=54±17, IV=45±22	Epi=6.4±2.1, IV=5.2±2.5	Epi=23.6±10.3, 21.0±6.7	Epi: 19% flail segment. IV: 13% flail segment.	"Complications" were reported to be 8% among epi patients and 18% among IV patients.	Epi: 4%; IV: 2.6%	13% of epi patients contracted pneumonia; 26% of IV patients contracted pneumonia.	Hospital: epi=19±3.1, IV= 21±4.1; ICU: epi=12±2.4, IV=14±3.5	Pain relief superior in epi patients at all time points
Wisner, 1990[82]	Epi=52. IV/IM=167.	Epi=71.0±1.1, IV/IM=69.4±0.6		Epi=15.7±1.0, IV/IM=14.6±0.8			Epi=4%, IV/IM=16%	8% of epi patients contracted pneumonia. 19% of IV/IM patients contracted pneumonia.		Epi associated with improved pain control
Other Regional Techniques										
Gibbons et al., 1973[66]	Epi=27. Other=30.					Hypotension in 44% of epi patients; circulatory arrest in 7%	No reported deaths in epi; 7% mortality in other group	Epi: 22% of patients needed ventilation. Other: 43% needed ventilation		
Hashemzadeha et al., 2011[61]	Epi=30. Intercostal block=30.	Epi=45.5±15.4, Intercostal=65.5±7.2							Trauma unit: epi=5.7±2.0, intercostal=7.7±3.7; ICU: epi=1.6±1.0, intercostal=1.9±1.4	
Luchette et al., 1994[83]	Epi=9. Intrapleural cath=10.	Epi=56±18.3, Intrapleural=51±10.9		Epi=21.7±5.5, intrapleural=19.4±5.7		Mild to moderate hypotension experienced by epi subjects.		No differences in vital capacity, minute ventilation, and respiratory rate; epi patients improved more in tidal volume and negative inspiratory force. Mechanical ventilation needed in 78% of epi subjects and 70% of intrapleural subjects.		Pain management better in epi group by visual analog and lower use of supplemental morphine

Research not supporting TEA

Epidural analgesia is not always shown to be the most effective modality. Among patients admitted with rib fractures, the outcomes of TEA administration have been inconsistent.[7,82,96] Whereas 16 studies have reported positive outcomes with epidural analgesia, 10 have reported either comparable or poorer outcomes for patients with fractured ribs. Out of these, 2 were not designed to evaluate the efficacy of TEA, 6 compared TEA to IV treatments, and 2 compared TEA to other regional techniques.

Methods not designed to evaluate epidural analgesia

In 2004, Balcı and colleagues[91] evaluated patients with flail injuries. There were 3 different treatments: 13 patients received TEA (35.1%), 16 received intercostal nerve blockade (43.2%), and 8 received narcotic or nonnarcotic parenteral analgesia (21.6%). This study was not designed to assess the effectiveness of TEA; it was a side note in a protocol investigating surgical fixation. The authors report that all patients receiving epidural analgesia or intercostal nerve blockades needed additional parenteral analgesia and repeated doses to address pain. They do not report pain outcomes or data concerning treatment repetition, but note that pain control was inadequate and opioid drugs were the most commonly used option to increase the analgesic effect. Across the whole sample, mortality was 20.3%, the duration of mechanical ventilation ranged from 1.5 to 22 days, and the length of hospital stay ranged from 9 to 32 days. The authors concluded that surgical fixation was a successful treatment for patients with traumatic flail chest but thoracic epidural catheters were potentially problematic "not only because of the angle of the spinal processes and the smaller space but also because it was difficult to put patients

with flail chest in the proper position to place the catheter, thus we do not advise its routine use."

In 2000, Bulger and colleagues[6] compared outcomes of elderly Patients (≥ 65 y) with at least 1 fractured rib to younger patients (18-64 y) with at least 1 fractured rib. There were 277 elderly patients (74 ± 6 yr, 3.6 ± 2.5 fractured ribs, 17% had a flail segment, ISS = 20.7 ± 12.7) and 187 younger patients (39 ± 13 yr, 4.0 ± 2.9 fractured ribs, 11% had a flail segment, ISS = 21.4 ± 13.4). The mean duration spent in the ICU was 6.1 ± 10.0 days for elderly patients and 4.0 ± 9.4 days for young patients ($p < .05$). The mean hospital stay was 15.2 ± 16.5 days for elderly patients and 11.0 ± 13.1 days for young patients ($p < .01$). As the number of fractured ribs increased, so did the odds of contracting pneumonia, adult respiratory distress syndrome, and mortality. 22% of the elderly patients died compared to 10% of the young patients ($p < .001$). Elderly patients and patients with more severe injuries were most likely to receive epidural catheters. Despite greater chest injury in the catheter group, mortality rates were lower (11% in epidural group, 25% in those not receiving epidurals). Despite a lower mortality rate among patients receiving epidural analgesia, that treatment was associated with more pulmonary complications and longer stays in the ICU and hospital. A possible explanation for both of these outcomes is the greater injury severity of those receiving epidurals. Additionally, basic treatment logistics might explain some of the length of stay: once a catheter is applied, it is generally left in place for 4–5 days.

Compared to other treatments

To date, 6 studies have failed to find TEA to be superior to IV treatments and 2 have failed to find TEA superior to other regional techniques. In one of the studies involving regional analgesia, patients received both treatments. That study is described below. The remaining studies are characterized in Table 2.2.

Compared to other regional techniques

In 1994, Shinohara and colleagues[93] compared thoracic epidural block to intrapleural block among 17 patients with multiple unilateral rib fractures (5.7 ± 1.4) and hemopneumothorax. Both intrapleural and thoracic blocks were installed in all patients. On the first day, when a patient complained of pain, that patient received treatment through one of the two blocks (randomly chosen). On the second day, when a patient complained of pain, the other block was used. The intervention group is considered to be those who received intrapleural block prior to thoracic block and the comparison group consisted of those who received thoracic block prior to intrapleural block. There were no significant differences in pain relief; no subject required additional analgesia during treatment; there were no cases of pneumonia or mortality.

Table 2.2: Research not supporting TEA

Author	N	Age (y)	# Ribs	ISS	Associated Trauma	Complications	Mortality	Pulmonary Outcomes	LOS (d)	Pain Relief
IV Treatment										
Bulger et al., 2004[11]	Epi=22, IV=24	Epi=49±18, IV=46±16	Epi=7.2 ±3.2, IV=6.8± 3.3	Epi=26 ± 8; IV=25±8	Epi=38% flail segment; IV = 21% flail segment.	Epi=complications in 27%, IV=complications in 33%	Epi: 9.1%; IV: 4.2%	Epi=7.6 days on mechanical ventilation; IV=9.1 days on mechanical ventilation. Epi=18% pneumonia. IV=38% pneumonia.	Hospital: Epi=18 ± 16; IV=16 ± 13. ICU: Epi=10 ± 15; IV= 23 ± 26.	3 epi patients and 3 IV patients failed to experience pain relief and switched groups.
Kieninger et al., 2005[96]	Epi=53, IV=134	Epi=77.7± 10.2, IV=77.3± 10.5		Epi=10.3 ±3.6, IV=8.3± 3.9		Epi=58% experienced cardiopulmonary comorbidities, IV=68% experienced cardiopulmonary comorbidities	Epi=5.6%, IV=1.5%		Epi=8.6 ± 4.6, IV=5.6 ± 5.1	
Mackersie et al., 1991[36]	Epi=15, IV=17	Epi=49.3± 19, IV=47.8± 14	Epi=4.2 ±1.0, IV=4.8± 1.7	Epi=20± 7.6, IV=16±7 .2		Nausea/vomiting present in 46% of epi cases and 29% of IV cases.		Epi group experienced better inspiratory capacity improvement. No cases of pneumonia	Hospital: epi=8.7±4.2, IV=7.1±6.2	Epidural group experienced a trend of better pain reduction
Moon et al., 1991[78]	Epi=13, IV=11	Epi=37, IV=40		Epi=26.6 , IV=23.4				Ventilatory function was better in epi patients		Epi group experienced better pain relief while coughing; not at rest
Wu et al., 1999[7]	Epi=25, IV=39	Epi=56±17, IV=45±22	Epi=5.6 ±2.1, IV=4.4± 1.5	Epi=21.6 ±10.3, IV=21.9 ±6.7		Epi: 4% experienced cardiac complications, 4% neurologic. IV: 13% cardiac complications, 18% neurologic.	0% across total sample	Epi: 26% were intubated, 12% contracted pneumonia. IV: 5% were intubated, 10% contracted pneumonia.	ICU: epi=4.4±4.1, IV=2.5±3.5	Epi group experienced superior pain relief
Yeh et al., 2012[8]	Epi=34, IV=153	Epi=48.8± 18.4, IV=69.6± 10.1	Epi=5.0 ±2.0, IV=5.6± 2.3	Epi=23.1 ±9.3, IV=21.5 ±9.3					Hospital: epi=7, IV=5; ICU: epi=1, IV=0	
Other Regional Techniques										
Mohta et al., 2009[29]	Epi=15, Paravertebral	Epi=38.9± 14.9, para=40.4	Epi=4.9 ±1.8, para=4.9	Epi=15.9 ±7.1, para=13.	Epi=7% flail segment, para=27% flail segment	Hypotension higher in epi (40%) than para	0% both groups	Ventilatory mechanics improved comparably in both groups. Epidural	Hospital: epi=10.1, para=11.7;	No difference in visual analog

Author	N	Age (y)	# Ribs	ISS	Associated Trauma	Complications	Mortality	Pulmonary Outcomes	LOS (d)	Pain Relief
	infusion=15	±14.8	±1.4	6±5.6		(7%); fever higher in para (20%) than epi (13%); 1 patient developed anesthetic toxicity in para group		pneumonia=1, para pneumonia=2	ICU: epi=6.3, para=6.8	improvement

Study Quality

The studies evaluating the efficacy of TEA span a broad range of quality. Among the 16 studies showing TEA to be an efficacious treatment, 8 involved a comparison group. Among the10 studies that reported either poorer or comparable outcomes, 2 were not designed to evaluate the efficacy of TEA. Thus, among all studies with methods sufficient to answer this question, 8 supported the use of TEA against alternative treatments and 8 have failed to support it. The studies that favored TEA met an average of 4.9 of the 14 criteria outlined by the NIH's Quality Assessment of Controlled Intervention Studies tool.[100] Among the studies that do not favor TEA, they meet an average of 8.0 criteria (Table 2.3).

Table 2.3: Study quality of all trials evaluating TEA

Author	Random Design	Adequate Random Methods	Concealed Treatment Allocation	Subjects & Providers Blinded	Evals. of Subjects Blinded	Similar Baseline Values	Total Dropout <20%	No Group Dropout Difference	Adherence to Protocol	Confounding Treatments Controlled	Validly, Reliably Assessed	Sample Size >80% Power	Pre-Specified Measures	Analyzed in Group Assigned
Studies supporting TEA														
Abouhatem et al., 1984[25]	no	no	no	no	no	NA	**YES**	NA	**YES**	**YES**	Not Described	Not Described	**YES**	NA
Doss et al., 1999[41]	no	no	no	no	no	NA	**YES**	NA	**YES**	**YES**	Not Described	Not Described	Not Described	NA
Govindarajan et al., 2002[39]	no	no	no	no	no	NA	**YES**	NA	**YES**	**YES**	**YES**	Not Described	**YES**	NA
Johnston et al., 1980[99]	no	no	no	no	no	NA	**YES**	NA	partial	partial	Not Described	Not Described	**YES**	NA
Worthley, 1985[30]	no	no	no	no	no	NA	**YES**	NA	partial	partial	**YES**	Not Described	**YES**	NA
Dittmann et al., 1975[85]	no	no	no	no	no	Not Described	**YES**	**YES**	Not Described	no	Not Described	Not Described	**YES**	**YES**
Dittmann et al., 1978[84]	no	no	no	no	no	no	**YES**	**YES**	**YES**	partial	Not Described	Not Described	**YES**	**YES**
Dittmann et al., 1982[65]	no	no	no	no	no	no	**YES**	**YES**	**YES**	partial	Not Described	Not Described	**YES**	**YES**
Pierre et al., 2005[94]	**YES**	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	Not Described	**YES**	Not Described
Ullman et al., 1989[89]	no	no	no	no	no	No	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Waqar et al., 2013[9]	no	no	no	no	no	no	**YES**	**YES**	**YES**	partial	Not Described	Not Described	**YES**	**YES**
Wisner, 1990[82]	no	no	no	no	no	no	**YES**	**YES**	**YES**	**YES**	Not Described	Not Described	**YES**	**YES**
Flagel et al., 2005[10]	no	no	no	no	no	no	**YES**	**YES**	Not Described	Not Described	Not Described	Not Described	**YES**	**YES**
Gibbons et al., 1973[66]	no	no	no	no	no	no	**YES**	**YES**	Not Described	no	Not Described	Not Described	**YES**	**YES**
Hashemzadeh a et al., 2011[61]	**YES**	Not Described	no	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Luchette et al., 1994[83]	**YES**	Not Described	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Studies not supporting TEA														
Bulger et al., 2004[11]	**YES**	**YES**	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	partial	**YES**	**YES**
Kieninger et al., 2005[96]	no	no	no	no	no	no	**YES**	**YES**	**YES**	**YES**	Not Described	Not Described	**YES**	**YES**
Mackersie et al., 1991[36]	**YES**	**YES**	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**

Author	Random Design	Adequate Random Methods	Concealed Treatment Allocation	Subjects & Providers Blinded	Evals. of Subjects Blinded	Similar Baseline Values	Total Dropout <20%	No Group Dropout Difference	Adherence to Protocol	Confounding Treatments Controlled	Validly, Reliably Assessed	Sample Size >80% Power	Pre-Specified Measures	Analyzed in Group Assigned
Moon et al., 1991[78]	**YES**	**YES**	no	no	no	Partial	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Wu et al., 1999[7]	no	no	no	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Yeh et al., 2012[8]	no	no	no	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Mohta et al., 2009[29]	**YES**	no	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Balcı et al., 2004[91]	no	no	no	no	no	NA	**YES**	NA	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Bulger et al., 2000[6]	no	no	no	no	no	no	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**
Shinoharaet al., 1994[93]	**YES**	no	no	no	no	Not Described	**YES**	**YES**	**YES**	**YES**	**YES**	Not Described	**YES**	**YES**

NIH Quality Assessment of Controlled Intervention Studies (available online: http://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools/rct)

Risks of TEA

Treating with epidural analgesia is not without risks. It's more technically complex than the administration of IV analgesia, which puts the patient at a higher risk of complications.[38] Although infrequent, these include inadvertent dural puncture (1 in 200–526)[101-103] and spinal cord injury (when done in the thoracic region)[38,47], direct neural injury (1 in 167,000)[103,104], transient neurological injury (1 in 6,700)[103,104], catheter-related infection (1 in 770–3,300)[28,84,103,105], deep epidural infection (1 in 45,000)[30,56,103,104], hypotension (1 in 33–143)[30,47,106], cardiac arrest (1 in 10,140)[107], hematoma (1 in 150,000–190,000)[68,103,108], abscesses in the epidural space (1 in 1,000)[103,109-111], nausea, vomiting[36,37], central nervous system toxicity (1 in 833–10,000)[106], respiratory depression (1 in 63–416)[56,106], pruritis and urinary retention in the presence of an opioid[38], and motor block compromising mobilization (1 in 33).[47,106]

Individual outcomes associated with TEA

Mortality

4 studies found epidural analgesia to be associated with a lower mortality rate compared to an alternative treatment; 2 compared TEA to a variety of alternative treatments[6,10], 1 compared TEA to IV/IM narcotics[82], and 1 compared TEA to mechanical ventilation (which is not a valid comparison as patients requiring mechanical ventilation are typically regarded as having failed other treatments).[65]

No study found epidural analgesia to be associated with a higher mortality rate compared to an alternative treatment.

8 studies found no difference in mortality rate when using epidural analgesia compared to an alternative treatment: 4 compared to IV treatments[7,9,11,96], 1 to mechanical ventilation[85], 1 compared to intercostal nerve block or parenteral narcotics[66], 1 compared to thoracic paravertebral anesthesia[29], and 1 compared to intrapleural anesthesia[93]

Pain management

7 studies found epidural analgesia to be associated with better pain management compared to an alternative treatment: 4 compared to IV treatment[7,9,78,94], 1 compared to IV/IM narcotics[82], 1 compared to intercostal block[61], and 1 compared to intrapleural anesthesia.[83]

No study found epidural analgesia to be inferior at reducing pain compared to an alternative treatment.

3 studies found no difference in pain management when using epidural analgesia compared to an alternative treatment: 1 compared to IV treatment[36], 1 compared to thoracic paravertebral anesthesia[29], and 1 compared to intrapleural anesthesia.[93]

Duration of stay in the ICU

6 studies found epidural analgesia to be associated with shorter stays in the ICU compared to an alternative treatment: 3 compared to IV treatment[9,89,94], 2 compared to mechanical ventilation[65,84], and 1 compared to intercostal block.[61]

2 studies found epidural analgesia to be associated with longer stays in the ICU compared to an alternative treatment: 1 compared to oral and IV treatment[8] and 1 compared to a variety of alternative treatments.[6]

4 studies found no difference in ICU duration when using epidural analgesia compared to an alternative treatment: 3 compared to IV treatments[7,11,78] and 1 compared to thoracic paravertebral anesthesia.[29]

Duration of stay in the hospital

4 studies found epidural analgesia to be associated with shorter stays in the hospital compared to an alternative treatment: 3 compared to IV treatment[9,89,94] and 1 compared to mechanical ventilation.[65]

3 studies found epidural analgesia to be associated with longer stays in the hospital compared to an alternative treatment: 1 compared to IV treatment[96], 1 compared to oral and IV treatment[8], and 1 compared to a variety of treatments.[6]

5 studies found no difference in hospital duration when using epidural analgesia compared to an alternative treatment: 4 compared to IV treatment[7,11,36,78], 1 compared to thoracic paravertebral anesthesia[29],

Incidence of pneumonia

2 studies found epidural analgesia to be associated with a lower incidence of pneumonia compared to an alternative treatment: 1 compared to IV treatment[11] and 1 compared to IV/IM treatment.[82]

1 study found epidural analgesia to be associated with a higher incidence of pneumonia compared to a variety of treatments.[6]

6 studies found no difference in the incidence of pneumonia when using epidural analgesia compared to an alternative treatment: 3 compared to IV treatments[7,9,36], 1 compared to thoracic paravertebral anesthesia[29], 1 compared to intrapleural anesthesia[93], and 1 compared to a variety of treatments.[10]

Cardiopulmonary outcomes

Studies comparing epidural analgesia to alternative treatments have yielded variable results regarding cardiopulmonary outcomes.[36,61,78,83,89,93]

DISCUSSION

Discrepancies in findings

The treatment for rib fracture pain has not been standardized; not just mode (e.g., oral, IV, epidural, etc.), but location (e.g., lumbar vs. thoracic epidural).[7] This might be a consequence of discrepant findings in the literature. One explanation for the lesser success in many of the studies comparing TEA to other treatments is that the data often

come from retrospective reviews in which patients were not randomly assigned treatments.

Counting an abstract, there are 11 studies that randomized patients to a treatment group.[11,25,28,29,36,61,78,83,93,94,98] There are 18 studies that did not randomize patients to a treatment group.[6-10,30,39,41,65,66,82,84,85,89,91,96,97,99] Only studies in the English language have been included.

When treatment is not randomly assigned, the criteria for assignment is often based on injury severity (and sometimes age), with the more severe cases and older patients more commonly receiving epidural catheters.[6,7] For example, Flagel et al.[10] found use of epidural analgesia to increase by 50% among patients who fracture 6 or more ribs (compared to patients who fracture 5 or fewer).

In the 2012 study by Yeh et al.[8], the 34 patients who received TEA fractured more total ribs (7.1 vs. 5.0; $p < .001$), had a higher incidence of bilateral rib fractures (32.4% vs. 15.0%; $p = .026$), and showed a trend of having more common upper rib fractures (47.1% vs. 30.1%; $p = .070$). Thus, when the patients receiving TEA require longer stays in the hospital (median of 7 vs. 5 days; $p < .001$) and ICU (median of 1 vs. 0 days; $p = .001$), it seems likely to be related more to injury severity than mode of treatment.

Waqar and colleagues (2013) reported that patients who received TEA (54 ± 17 yr, 6.4 ± 2.1 fractured ribs, 19% having a flail segment, ISS = 23.6 ± 10.3) were significantly older and had significantly more fractured ribs than patients in the IV group (45 ± 22 yr, 5.2 ± 2.5 fractured ribs, 13% having a flail segment, ISS = 21.0 ± 6.7). It was

despite this severity that patients receiving thoracic epidurals had significantly shorter periods of time on analgesia (4.25 ± 1.2 days compared to 5.5 ± 3.2 days), and significantly shorter stays in the hospital (19 ± 3.1 days compared to 21 ± 4.1 days) and the ICU (12 ± 2.4 days compared to 14 ± 3.5 days).

Similarly, in the 1999 study by Wu and colleagues[7], patients assigned thoracic epidural treatment (56 ± 17 yr, 5.6 ± 2.1 fractured ribs) were significantly older and had significantly more fractured ribs than the patients who were assigned IV treatment (45 ± 22 yr, 4.4 ± 1.5 fractured ribs).

Additionally, the methods of catheterization are not always described, so one cannot know how differences in administration technique might impact outcomes. There are 11 studies that describe the methods of catheterization thoroughly.[7,25,28-30,39,78,83,85,89,93] There are 16 studies in which the methods of catheterization are either absent or incompletely described.[6,8-11,36,41,61,65,66,82,94,96-99] Dittmann et al.'s 1978 study[84] provides minimal detail concerning methods, but cite their 1975 paper[85] for further methodological instruction. However, in the brief details they do provide (namely bupivacaine concentration), the methods between the two papers are incongruent. Balci et al.[91] do not discuss catheterization methods, but they only discuss methods of analgesia briefly as a tertiary outcome. Studies not in the English language have been omitted from these lists.

Lastly, confounding variables such as age are often, but not always accounted for. Among the studies evaluating TEA outcomes in English, 2 failed to report age[41,66] and other researchers claim age to be insignificant despite very large differences (Hashemzadeh et al.'s groups had differences of 20 years; p = .19).[61]

Summary of evidence

To date, 16 studies have shown TEA to be effective at improving treatment outcomes in patients with rib fractures; 8 of these involved a comparison group. Opposing these findings, 10 studies have reported either poorer outcomes or comparable outcomes associated with TEA use; 2 of these were not designed to evaluate the efficacy of TEA. Thus, out of all studies with methods sufficient to answer this question, 8 have supported the use of TEA against alternative treatments and 8 have failed to show a benefit of TEA. Studies that favor TEA scored 4.9 out of the 14 criteria outlined by the NIH's Quality Assessment of Controlled Intervention Studies tool.[100] Among the studies that do not favor TEA, they meet an average of 8.0 criteria.

A trend that appeared consistently was a low mortality among TEA patients despite a relatively large number of ribs being fractured. Much of the remaining outcomes are too inconsistent to characterize.

Owing to the complexity of administration, TEA may put the patient at a slightly elevated risk of treatment-associated complications such as dural puncture, epidural infection, abscesses in the epidural space, and hematoma. Nausea, vomiting, and hypotension have also been seen.

Limitations

Much of the available literature either evaluates the NTDB or quantifies groups of patients from individual hospitals. Little of this work controls for influential variables

such as injury severity; less of it randomizes the treatment options. In general, greater injury severity associates with more likely use of TEA. Groups are analyzed accordingly and described incompletely.

Conclusions

Based on limited evidence, TEA may lower mortality among patients with multiple fractured ribs. As a first step, more hospitals should quantify their data registries, controlling for injury severity (particularly number of fractured ribs, presence of flail segment, and injury severity score), and evaluate the effectiveness and safety of TEA among patients with rib fractures.

Disclaimers

This study is associated with no source of funding. It is a collaboration between St. Vincent Hospital in Indianapolis, Sum Integral in Chicago, and The University of Connecticut.

Chapter 2: Rib Fracture Care: A Systematic Review of Thoracic Epidural Analgesia *(Part 2: Unabridged Version)*

ABSTRACT

Each year, nearly 300,000 patients are admitted to trauma centers with rib fractures. About 10% of these patients die and more than a third develop pulmonary complications. Much of the morbidity and mortality is a consequence of pain (and the effect pain has on pulmonary mechanics). Effective pain management is thus critical to successful treatment outcomes. There are a variety of ways to manage pain. Thoracic epidural analgesia (TEA) is one method. In this paper, we review the safety and effectiveness of TEA among patients with rib fractures. We describe the pathophysiology of rib fracture injuries, outline the history of their treatment, and evaluate the current body of research. In doing so, we appraise the quality of all studies published concerning TEA for rib fractures, compare key findings between studies, integrate all relevant outcomes in tables, describe the implications of those outcomes, and note limitations in the field. This paper is meant to serve both as an introduction to TEA for rib fractures and as an updated assessment of its clinical value.

INTRODUCTION

In the U.S., as many as 10-15% of all patients admitted to trauma centers are the result of blunt thoracic trauma.[2] Blunt thoracic trauma commonly results in chest wall injuries, with the most common injury being rib fractures.[1,2] Rib fractures result in nearly

300,000 annual admissions to trauma centers in the U.S.[4] Patients who have only fractured 1 or 2 ribs are typically treated with oral analgesic drugs (NSAIDs, acetaminophen, or codeine)[47] and have low incidences of complications and mortality.[1,10] If pain relief is not sufficient, other systemic modes (e.g., intravenous morphine or dilaudid) may be administered.[47] When a patient fractures 3 or more ribs, there is an increased risk of comorbidities.[1] In this situation, the pain may be more harmful than the injury itself, as more severe pain often precipitates secondary complications.[10,19,37]

In the presence of 3 or more fractured ribs, the pain experienced with breathing frequently alters pulmonary mechanics. In an effort to avoid that pain, the patients' breaths become shallow.[35,36] This can impede chest physiotherapy and cause ineffective coughing, which results in insufficient clearance of airway secretions and retention of sputum.[11,37-39] In turn, lung compliance is commonly reduced and the patients experience a mismatch in ventilation and perfusion.[37,40] The combination of these deficits (poor lung compliance and inadequate clearance of secretions) puts patients on a course toward secondary complications (e.g., atelectasis, sepsis, pneumonia) and eventually respiratory failure and the need for intubation and ventilatory support.[38,41] The ultimate consequence of this is a mortality rate that may exceed 10% among all patients admitted with rib fractures.[2]

A primary way to avoid these complications, thus lowering the risk of mortality, is to control the patient's pain level.[41,46,47] When multiple ribs are fractured, regional modes of analgesia generally become the mainstay, while systemic deliveries are used as supplemental treatments.[47] There are several types of regional analgesia, most notably

thoracic epidural analgesia, intercostal nerve block, intrapleural nerve block, and thoracic paravertebral block.[37,47] This paper focuses on thoracic epidural analgesia (TEA), comparing its safety and effectiveness to alternative treatments.

History of thoracic trauma treatment

Interest in chest wall trauma and its consequences (such as flail chest) is not new to medicine. Rudimentary descriptions appeared in the Edwin Smith Surgical Papyrus (circa 1600 BC), in the *Iliad* (circa 850 BC) and in 5th century writings by Hippocrates.[18,50] The first documented treatment, which was practiced for several centuries, was wrapping the chest wall in linens.[51] That approach didn't change until the 1930s, when physicians began inserting pins, hooks, screws, and wires to stabilize the chest wall internally (assuming chest wall instability was the most lethal concern). Unfortunately, these treatments failed to reduce the risk of mortality.[52,53] In the 1950s, artificial ventilation was introduced. Although initially promising, higher incidences of comorbidities (including pneumonia) were soon reported.[43,52,54] In the 1970s, more conservative techniques, such as simple pain control, were attempted. When the outcomes of these treatments were compared to the outcomes of mechanical ventilation, researchers were encouraged; it appeared to be the pain itself, more than the structural changes, precipitating morbidity.[24,44,45,55,56] In the 1990s, researchers went a step further, investigating the efficacy of different types of pain management.[53] The question was no longer whether pain management was of paramount importance, but which modes of management were the most effective.[42]

Today, we still don't have an answer to this question, in part owing to the number of outcomes to consider. It is not merely life or death, but cardiopulmonary function, incidence of comorbidities, and degree of pain relief on top of the cost, duration, and safety of the treatment. The most beneficial agent would be one that maximizes pain control, blocks the phrenic nerve response, and minimizes side effects. Regional modes of pain control have emerged as the most useful interventions, but there are several methods available and no single treatment accomplishes all of the desired outcomes absent the accompaniment of risk.[37,42,47] However, TEA is often regarded as the most reliable technique to relieve pain and improve pulmonary outcomes in patients with multiple fractured ribs.[42] In this review, we discuss the use of TEA on patients with rib fractures, including the etiology and characteristics of rib fracture injuries, the risk of morbidity and mortality, and the differences between treatment options.

Admission to the trauma unit

Mayberry and colleagues[19] found blunt thoracic trauma to account for 8% of all trauma admissions while Zeilgler and Agarwal[2] estimate that it accounts for 10 to 15% as well as 25% of all trauma-related deaths in the U.S. (supported by Flagel et al.[10]). Among patients admitted with chest wall trauma, 55% require immediate surgery and 94% of them present with associated injuries.[2] As many as 39% of patients admitted for blunt thoracic trauma[112] and 7%[113] to 10%[2] of all patients admitted to trauma centers can be expected to have fractured ribs, making it the most common chest injury.[1,2] The prevalence of rib fractures in trauma patients may be higher as not all fractures are detected upon admission.[2,5]

The majority of patients admitted to trauma centers for rib fractures are injured in motor vehicle collisions while upwards of a quarter of the incidence results from falls.[2,5,6,19,26,34,82,114] Regardless of the mode of injury, there is no consistent presentation of damage. In addition to differing numbers and locations of ribs fractured, forces large enough to break them commonly result in associated injuries, such as pulmonary contusions. Thus, when a patient presents with fractured ribs, the characteristics of his or her injury (e.g., unilateral or bilateral fractures, upper or lower ribs, chest tube placement, presence of associated injuries) affect the course of recovery and likelihood of mortality.[8]

Among all patients who present with blunt thoracic trauma, 24% are admitted to the intensive care unit (ICU); among blunt thoracic trauma patients who present with rib fractures, 44% are admitted to the ICU.[5] On average, the patients who are admitted with rib fractures stay in the ICU for 4 to 8 days and remain in the hospital for 7 to 16 days; durations of each increase per rib fractured.[2,5,10] There ceases to be a relationship for longer ICU and hospital stays with 8 or more fractures ($p = 0.19$).[10] Among patients with 1 or more rib fractures, 60% require mechanical ventilation for an average duration of 13 days; as more ribs are fractured, the odds that this treatment will be necessary increase.[10]

Mortality

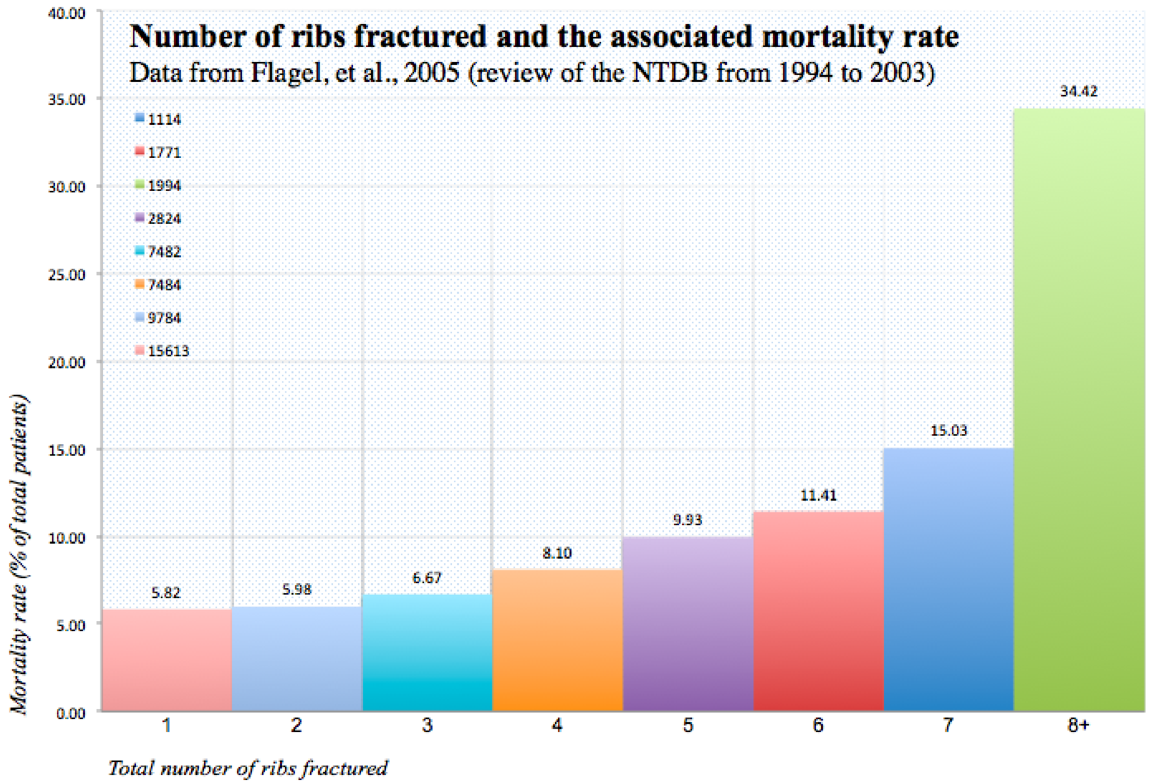
Cameron and colleagues[5] evaluated data from 25 Australian hospitals from 1992 to 1993, finding 2,584 patients who had sustained blunt trauma, 21% of whom had fractured ribs. Of the patients with rib fractures, 9.8% died (compared to 7.6% in all

trauma patients; p = .07). In a sample of 711 patients with fractured ribs admitted to the York Hospital Trauma Center between 1987 and 1992, there was an 11.8% mortality rate.[2] Among 64,750 patients with rib fractures in the National Trauma Data Bank (NTDB; 268 trauma centers from 1994 from 2003), the mortality rate was 10%.[10] Predictors of mortality include number of fractured ribs (as a surrogate measure for injury severity)[2], presence of additional injuries (e.g., flail segments)[26], and age.[6]

Number of fractured ribs

The risk of mortality is greatly affected by the number of ribs fractured, significantly increasing with each additional rib.[10] In the sample by Ziegler and Agarwal[2], mortality was 5% among patients with 2 or fewer fractured ribs and 27% among patients who fractured 7 or more ribs. Flagel and colleagues[10] found a similar threshold, in which 2 or fewer fractured ribs associated with 6% mortality while 7 ribs associated with 15% and 8 or more associated with more than 34% (Figure 2.1).

Figure 2.1



Among 464 patients across the lifespan, Bulger and colleagues[6] found an odds ratio for mortality of 1.19 for each additional rib fractured ($p < .001$). Overall, mortality typically ranges from 3% to 13% and is often the result of secondary lung complications.[46,60,61]

Presence of a flail segment

Among patients who present with flail injuries, the mortality rate may be as high as 16% (when flail injuries are combined with pulmonary contusions, risk of mortality increases to 42%).[34] Balcı and colleagues[91] analyzed 1,069 patients who were admitted to a Turkish trauma center for blunt thoracic trauma between 1991 and 2000. Of those patients, 688 had rib fractures and 64 had flail injuries. According to these records, 6% of

all blunt trauma and 9.3% of all rib fractures result in flail injury. These percentages may be uncharacteristically high. Dehghan and colleagues[26] evaluated medical records in the NTDB from 2007 to 2009. They included men and women age 16 or older who were treated at Level 1 or Level 2 trauma centers, had been admitted for blunt thoracic trauma, and had injury severity scores of 9 or greater. This resulted in a sample of 354,945 patients, of whom only 3,467 (1%) had a documented flail injury. The severity of the injury is still to be noted however: 59% of patients in this sample required intubation and mechanical ventilation, 44% required chest tubes, 21% required tracheostomy, and 16% died (agreeing with Clark et al.[34]).

Age

In addition to injury severity, age is another variable that affects the likelihood of mortality. In a sample of 541 patients, Cameron et al.[5] found the mean age of patients admitted for rib fractures to be 47.5 years, the mean age of survivors to be 46.6 years and the mean age of patients who died to be 55.2 years. Although the age differences did not reach significance, it is a trend that appears regularly in the literature. This trend was duplicated by Flagel and colleagues[10] when they reviewed the NTDB from 1994 to 2003. Although the discrepancy was narrower (mean age of survivors was 47 years while the mean age of non-surviving patients was 52 years), their larger sample (64,661 men and women with at least 1 fractured rib) led to significance ($p = .02$). Bulger et al.[6] analyzed the trauma registry of Harborview Medical Center for patients with rib fractures admitted between 1986 and 1996. Patients were separated by age: those 65 and older ($n = 277$, 74 ± 6 years, 3.6 ± 2.5 fractured ribs) were compared to a control group of patients age 18 to

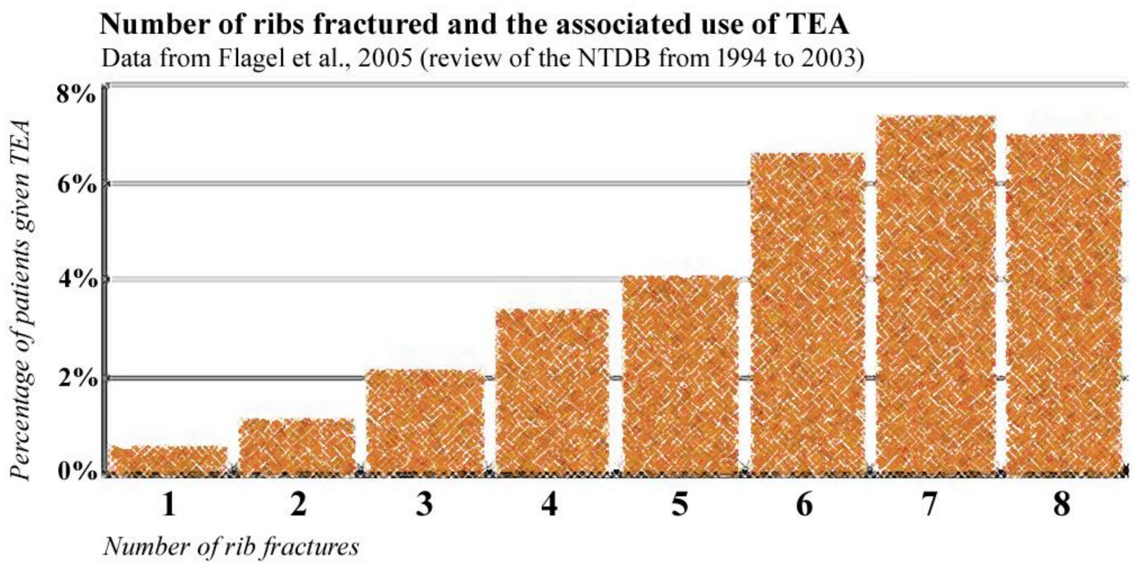
64 (n = 187, 39 ± 13 years, 4.0 ± 2.9 fractured ribs). They found patients in the elderly group to have more than twice the risk of mortality than patients in the control group (22% compared to 10%; $p < .001$). Sharma and colleagues[3] found a similar trend when they analyzed 1,475 records of patients admitted to a trauma center with blunt chest trauma between 1995 and 2004. Rib fractures were present in 56% of adults (age 18 to 64), and 65% of elderly patients (age 65 and older) and mortality was found in 9% of adults and 18% of elderly patients. Wisner[82] found age to be a significant predictor of mortality among 307 elderly patients (70.1 ± 0.4 years) admitted to the University of California, Davis medical center between 1980 and 1987. There was a 13% mortality rate in the sample and for each additional year of age, the odds of mortality increased by a factor of 1.15 ($p < .0001$). The only predictor more significant was injury severity score. Similarly, Yeh et al.[8] found age to be among the strongest predictors of complications ($p = .05$) in a sample of 187 men and women with multiple fractured ribs admitted to a trauma center between 2004 and 2009. Of note, injury severity score was not a significant predictor ($p = .89$).

Morbidity

Ziegler and Agarwal[2] found 35% of patients with fractured ribs experienced pulmonary complications (e.g., pneumonia, pneumothorax, atelectasis, adult respiratory distress syndrome) while nearly half of all patients with rib fractures in the NTDB developed pulmonary complications.[10] The risk of complication increases significantly with each additional rib fractured.[6,10] For each additional rib, Bulger and colleagues[6] found the odds ratio for pneumonia to be 1.16 among their total sample (n = 464) and

1.27 among elderly patients (age ≥ 65; n= 277) ($p < .001$). Lee and colleagues[1] found a threshold in which morbidity increased significantly when 3 or more ribs were fractured. Flagel and colleagues[10] found thresholds for pneumonia at 6 or more fractures and acute respiratory distress syndrome at 7 or more. Flagel and colleagues also found an inflexion point for the use of epidural catheters at 6 fractures. Although epidural analgesia was only used in 2% of cases, and was related to the total number of ribs fractured (R_2 = 0.96), its use increased by 50% at 6 rib fractures (as seen in Figure 2.2).

Figure 2.2



The most commonly evaluated pulmonary complication is pneumonia, which can be expected in 3% to 60% of patients[10,46] depending on the number of fractured ribs and the age of the patient. The risk of pneumonia is typically higher among elderly patients. Bulger et al.[6] found pneumonia to occur in 31% of their elderly cohort and 17% of their younger control group ($p < .01$).

Pain

Pain is a primary risk factor for morbidity and mortality among patients who present with chest wall trauma.[58,62,63] In the presence of pain, patients typically alter ventilation (in an effort to avoid exacerbation of that pain) by restricting breathing (particularly decreases in tidal volume; breaths become more shallow).[35,36] This impedes chest physiotherapy and pulmonary toilet, often causing ineffective coughing, which results in insufficient clearing of airway secretions and retention of sputum.[11,37-39] In turn, this leads to atelectasis (collapse or closure of the lung), which reduces lung compliance and functional residual capacity, resulting in a mismatch of ventilation and perfusion. Parenchymal lung infection can also develop in the presence of bacterial colonization.[37,40,57] Patients who cannot effectively cough, clear secretions, or re-inflate areas of the lung compromised with atelectasis are at a higher risk for pulmonary complications such as aspiration, acute hemopneumothorax, and secondary pneumonia with pulmonary consolidation.[38,41,54,64] This respiratory failure leads to the need for intubation and ventilatory support.[38,41] The ultimate consequence of these secondary complications is a high risk of mortality.[38] Contrarily, if the patient’s pain is not exacerbated with normal ventilation and coughing (thus an adequate tidal volume is maintained and coughing can happen without exacerbation of symptoms), the risk of pulmonary complications (e.g., pneumonia, atelectasis, sepsis, and the need for mechanical ventilation) is reduced.[56,65,66] For this reason, effective pain management is critical to restoration of pulmonary function and the avoidance of morbidity and mortality.[39,67,68] Pain management is accomplished through systemic and regional anesthetics and analgesics.[41] Because the relief of pain is a primary goal of treatment, it is

often the severity of the pain – rather than the severity of the injury – that guides the choice of treatment. If pain can be managed with oral and/or IV narcotics, it often is; if conservative treatments do not provide adequate pain control, patients are often treated with local analgesia.[6,11,47]

Modes of analgesia

Analgesia is the primary treatment in the management of patients with chest wall trauma.[58,69] A variety of treatment options exist; some are systemic (e.g., oral and intravenous anti-inflammatory agents, intravenous opioids, narcotic dermal patches); others are local agents (intercostal nerve blocks, intrapleural nerve blocks, thoracic paravertebral blocks, and TEA.[8,47,70] The 3 most effective (and commonly delivered) local treatments are: narcotic infusions and continuous local anesthetic via epidural catheter, intrapleural infusions of local anesthetic via catheter, and intercostal nerve block via injection.[42,71] Less common modes of therapy have been attempted, including intrathecal opioids[73], epidural steroid injections[74], and transcutaneous electrical nerve stimulation (TENS).[75] All forms of analgesia will be discussed, beginning with systemic approaches.

Systemic narcotics

As we established earlier, breathing in the presence of pain often alters pulmonary mechanics. Muscle spasms and voluntary splinting can lead to the development of atelectasis and prevent the normal function and mobilization of secretions.[78,82,83,115] Systemic opioids may assist in reducing these problems, but there are other complications

they do not address. For example, although there is a limited body of research on this, it appears that function of the phrenic nerve can be compromised by an afferent intercostal nerve reflex. In the presence of such a reflex, there would be a reduction in the contractility and tone of the diaphragm.[42] When the intercostal muscles are stimulated, messages get sent to respiratory neurons in the medulla (via proprioceptive afferent neurons). These respiratory neurons are responsible for activity of the phrenic nerves. The messages being sent (via stimulation of the intercostal muscles) are inhibitory; they inhibit the activity of the respiratory neurons in the medulla. The consequence of this is dysfunction of the diaphragm.[116] Again, the literature investigating this is limited, but if the analgesic treatment is opioids per se, that regimen does not appear to prevent this from occurring. However, local anesthetics appear to block the relevant afferent nerves, thus inhibiting the reflexive blockade of phrenic nerve activity. Function of the diaphragm is thus improved (or rather, dysfunction is avoided).[42] Ultimately, systemic narcotics can help relieve pain, but may contribute to other problems (e.g., hypoxia, atelectasis) and result in the necessitation of mechanical ventilation. Systemic narcotics can be taken orally, intravenously, or through dermal patches.

Oral non-narcotic analgesic drugs

NSAIDs, codeine, or acetaminophen may be sufficient if only 1 or 2 ribs are fractured. There is no central nervous system or cardiovascular depression, but the degree of analgesia is limited. Although there is a shortage of data regarding their use in treatment with patients who have multiple rib fractures, the common understanding is that they may be effective supplements to a treatment, but not effective when used in

isolation.[37,47]

Other systemic analgesic drugs

These are often the first-line therapy to manage pain from rib fractures.[37] There are several modes of delivery: intermittent, on-demand injections[76], intravenous (IV) patient-controlled analgesia[77,78], continuous IV infusion[36], and less commonly, dermal patches of lidocaine on the fracture site, which has proven ineffective.[47,73] While a continuous IV infusion of systemic opioids will reduce pain and improve vital capacity, it can result in cough suppression and hasten the onset of respiratory complications (e.g., respiratory depression and hypoxemia), possibly owing to paradoxical breathing, obstructive apnea, or a reduction in sigh-breaths.[36] Even when using conservative doses, morphine may still compromise pulmonary mechanics (most notably a reduction of spontaneous deep breathing).[79] Systemic use of opioids (or ketamine) can also compromise evaluations of the head and abdomen.[47] On top of the side effects, systemic analgesia remains less effective than regional techniques at controlling pain.[37] Thus, systemic opioids may be helpful in conjunction with a regional treatment, but not as a treatment for multiple fractured ribs per se.[76,77]

Regional analgesia

When treating multiple fractured ribs, regional analgesia is the mainstay. Often supplemented with a small dose of either NSAIDs or opioids, pain reduction is typically strong and immediate. There is little sedation, so evaluation of head and abdominal injuries is easier. Among the downsides, the procedures are technically complex, leading

to occasional errors in the administering of the treatment, they can be painful while the needle is entering (or catheter is being installed), toxicity is a possibility, and they require more intensive monitoring and care by the physicians and nurses.[47] There are a variety of modes; the four most common (thoracic epidural analgesia, thoracic paravertebral block, intercostal block, and intrapleural block)[37] are discussed below.

Thoracic epidural analgesia

Narcotic infusions and continuous local anesthetic can be delivered through thoracic (or lumbar) epidural catheters. Opioid receptors exist in the spinal cord that can alter the perception of pain without needing stimulation of receptors in the brain[36] and the anatomy of the epidural space restricts the geography in which analgesics can spread.[42] These boundaries are made up by the dura (the outermost membrane surrounding the spinal cord) and the periosteum, which lines the bones of the vertebral canal. Superiorly (in the upper-cervical region), the dura and periosteum fuse. This prevents the analgesic from migrating north of the foramen magnum. Posterior migration is limited by the ligamenta flava (ligaments that connect the vertebrae, bordering the interior of the spinal canal).[42] The catheter is inserted into this area. Local anesthetics and narcotic analgesics are administered, which block the nerve roots (anterior and posterior) crossing this space. The anesthetic/analgesic agents diffuse across the dura and begin to block sensory nerves. Motor nerves are affected to a lesser degree. It does take a large dose to achieve the desired effect. And a side effect of the dose of local anesthetics is dilation of the arteries and veins (especially the veins). There are techniques to safely avoid or treat the resulting hypotension however.[68,80]

In 1982, Rawal and colleagues[81] showed thoracic epidural morphine to be a more effective treatment than intercostal nerve block following cholecystectomy (upper-abdominal surgery) as measured by: postoperative pain (magnitude and duration), number of patients requiring supplemental narcotics (40% of patients receiving the epidural compared to 100% of patients receiving the nerve block), pre- and post-surgery peak expiratory flow (10% reduction in performance among patients receiving epidurals; 25% reduction in those receiving the intercostal block), and blood gas analyses (P_aO_2-P_aCO_2 profile was best in epidural patients). Overall, the longer duration of pain relief absent of the degree of respiratory depression experienced by the intercostal block made epidural analgesia a more favorable therapy among patients who were admitted with thoracic trauma. Since then, TEA has emerged as one of the most researched and seemingly effective treatments for patients who present with multiple fractured ribs.[47,70]

According to most reports, the downsides of epidural analgesia are not ineffectiveness (relative to other treatments), but risk. It has been successful in both lumbar and thoracic routes using opioids, local anesthetics, or a combination, especially in patients over the age of 60. Among this group, epidural analgesia decreases mortality and pulmonary complications.[82] Among patients with chest wall trauma, it relieves pain better than systemic opioids[36,78] and intrapleural analgesia.[83] And it is an effective treatment in a variety of pulmonary measures (e.g., dynamic lung compliance, airway resistance, functional reserve capacity, vital capacity, pulmonary gasses).[84] If the patient has paradoxical chest wall movement, epidural analgesia reduces it and restores shallow breathing to near-normal levels.[85] There may also be immune system benefits, as epidural

analgesia reduces plasma levels of interleukin-8, a chemokine that increases inflammation following acute lung injury.[78] Overall, patients who are treated with epidural analgesia develop fewer complications than patients who are intubated and receive mechanical ventilation[44,45,53] and they spend fewer days in the hospital and the ICU.[53] All studies that compare the effectiveness of TEA to another treatment (as well as the risk profile associated with use of TEA) will be discussed later in this review.

Thoracic paravertebral block

In this procedure, a local anesthetic (i.e., bupivacaine) is injected alongside the thoracic vertebrae, producing a "multidermatomal ipsilateral somatic and sympathetic nerve blockade in contiguous thoracic dermatomes".[37] Use of the procedure in patients with multiple fractured ribs was first characterized in 1979 by Eason and Wyatt.[117] To date however, few researchers have evaluated its use on these patients.[70,118-123] There are several ways of conducting a thoracic paravertebral block: repeated injections[118], scheduled dosing through an indwelling catheter[117,123], and continuous infusion.[70,122] This treatment is successful in improving arterial blood gases and respiratory parameters[70,118] and is not as technically challenging to perform as some of the alternate treatments.[117,121] Although very few studies have been published on the use of this treatment, the data that are available suggest a low risk of complications (including a low risk of hypotension compared to thoracic epidural.[118,124] Other possible side effects are vascular puncture, pleural puncture, and pneumothorax.[37,124] Overall, this has been found to be as good of an analgesic as TEA[29] and is also less technically complex, with minimal hemodynamic disturbance and no concern of urinary retention or pruitis.[125] However, there is a small

risk for pneumothorax and a possibility of toxicity owing to the rapid absorption of local anesthetic.[47]

Intercostal nerve block

In 1966, Ablondi and colleagues[126] were the first to suggest continuous intercostal nerve blocks. The anatomy of the ribs and posterior intercostal membrane allow injected solutions to be contained around the intercostal nerve and spread to the superior and inferior intercostal spaces. This is a very effective method to control pain and improve respiratory dynamics[66,127], but results are short lived. Improvements in respiratory measurements such as forced expiration begin to wane 6 hours after treatment[128] and the analgesic effect only lasts 4-8 hours (if the long-acting anesthetic is used)[47], thus necessitating repeated injections to sufficiently control pain.[129] Typically, as a matter of preference, patients are averse to routine injections and the likelihood of experiencing pneumothorax, aesthetic toxicity, or intravascular injection is a product of the number (and total volume) of injections.[47] This can be remedied with the installation of catheters so that the nerve block can be administered continuously, and this has been seen to control pain from multiple fractured ribs effectively.[76,77,130] But catheter placement is a challenge and they're misplaced regularly.[130-132] According to work done by Mowbray and colleagues[133], only 54.5% of the catheters were installed properly. Thus, multiple injections remains the common delivery system, which is painful, time-consuming, and puts the patient at risk of anesthetic toxicity (owing to rapid absorption of local anesthetics from the intercostal space and the large doses needed for effectiveness).[47] Use of intercostal nerve block in patients with multiple rib fractures associates with a 1.4%

incidence of pneumothorax for each individual block and 5.6% when multiple blocks are administered simultaneously.[134]

Intrapleural block

This technique was characterized first by Reiestad and Kvalheim in 1984[135] as a mode of post-operative pain management, and furthered by Reistad and Stromskag in 1986[136] as a method of managing pain following upper-abdominal surgery and mastectomy. In 1987, Rocco, Reiestad and colleagues[137] discussed continuous intercostal nerve block and intrapleural analgesia for pain from fractured ribs. And the following year, Stromskag, Reiestad and colleagues[138] described its value in controlling pain in patients who had multiple fractured ribs. A catheter is placed in the intrapleural space and local anesthetic agents are infused through it. The treatment can be administered through continuous administration or by an intermittent bolus. The mechanism of pain relief is not clear, but it's likely to involve the prevention of intercostal nerve transmission.

In regional anesthetic trials involving patients undergoing thoracic surgery, the least consistent method of administering anesthesia/analgesia is through intrapleural infusion.[42] Shafei and colleagues[127] found intermittent intrapleural bupivacaine to be a superior treatment (in terms of postoperative pain management) to intercostal blocks (and to the cryofreezing of intercostal nerves). But Bachman-Mennenga and colleagues[139] did not find this to be true when comparing intrapleural local anesthetics to intercostal nerve block, thoracic local epidural analgesia, and systemic opioids. Instead, they found 70% of patients receiving the intraplueral anesthetic to need supplemental opioids to manage pain (significantly worse than the alternative treatments, in which 1-2 patients in each group

required supplemental opioids). Short and colleagues[140] found intrapleural analgesia to be comparable to systemic opioids in pain reduction among patients who had sustained blunt chest trauma and Shinohara and colleagues[93] found it to be comparable to epidural analgesia. But Luchette and colleagues[83] found intrapleural analgesia to be less effective than epidural analgesia in patients with chest wall trauma (in terms of both pain relief and pulmonary function). In their findings, the epidural analgesia demonstrated improvements in inspiratory force and tidal volume, which suggests the intercostal afferent nerve messages (those which inhibit the respiratory neurons in the medulla) are interrupted. Part of the benefit may come from avoiding dysfunction of the diaphragm in this way. Even if there's no interruption to the intercostal-phrenic nerve arc, the pulmonary improvements are significant. Luchette and colleagues suggested that epidural anesthetic may be a more dependable option than intrapleural administration.

Today, intrapleural blocks are less commonly used in treating multiple rib fractures not just because of the inconsistency of their effectiveness, but because of side effects. One notable side effect is the possibility of a chest drain, which can cause loss of local anesthetic.[141,142] Furthermore, it's a difficult procedure to perform.[143] Instillation of the anesthetic can result in paralysis of the phrenic nerve and/or aggravate bronchospasm.[144,145] There is a risk for symptomatic pneumothorax.[130,146] If blood is in the pleural space, the local anesthetic will be diluted, resulting in a poor block.[37] The rate of absorption may be rapid (leading to a high plasma concentration and thus a potential risk for anesthetic toxicity)[143,147], but the effect is unpredictable, and thus larger doses may be necessary.[37] Toxicity is also a possibility. If the anesthetic is combined with epinephrine, it is not toxic; without epinephrine, toxic serum levels may result regardless

of administration technique.[127,148,149] Lastly, the technical complexity results in possible side effects (parenchymal injection, etc.).[37,47]

Alternative treatments

Less common treatment options have been attempted, including intrathecal opioids[72], narcotic dermal patches[73], transcutaneous electrical nerve stimulation[75], and epidural steroid injections.[74]

Intrathecal opioids

The pain from multiple fractured ribs can be treated by administration of intrathecal morphine through the lumbar route, which some researchers have found to be effective[72] and others haven't.[150] In addition to inconsistent findings on effectiveness, intrathecal morphine is associated with a high risk of complications. Nausea, headaches, drowsiness, urinary retention, and respiratory depression were all common in Dickson and Sutcliffe's 1986 study.[150]

Narcotic dermal patches

Ingalls and colleagues[73] evaluated the effectiveness of a dermal lidocaine (5%) patch on 58 adult patients with traumatic rib fractures in a randomized, double-blind, placebo-controlled trial. Patients in the intervention group (n = 33, 72.7% male, 54.8 ± 3.1 years, 5.3 ± 0.4 fractured ribs, ISS = 17.3 ± 1.3) had a lidocaine patch placed on the skin directly over the fracture site within 24 hours of admission. Patches were replaced every 12 hours for 72 hours (or until the patient was discharged). Patients in the control

group (n = 25, 76% male, 49.7 ± 4.0 years, 4.9 ± 0.4 fractured ribs, ISS = 17.9 ± 1.3) received the same treatment, but were given placebo patches. Patients in both groups were allowed morphine and hydrocodone/acetaminophen as needed to control pain levels. Although the lidocaine group did have better pain scores (5.6 ± 0.4 vs. 6.0 ± 0.3; p =. 39), lower supplemental IV narcotic use (0.23 units vs. 0.26 units; p = .56), lower supplemental oral narcotic use (4 units vs. 7 units; p = .11), and a shorter length of stay (7.8 ± 1.1 days vs. 6.2 ± 0.7 days; p = .28), none of these achieved statistical significance.

Transcutaneous Electrical Nerve Stimulation (TENS)

The electrical stimulation causes endorphins to be released in the spinal cord. Among patients with multiple fractured ribs, Sloan and colleagues[75] found subjective pain relief (as well as improvements in arterial blood gases and peak expiratory flow rates) in TENS treatment compared to NSAID administration. Otherwise, the data on use of TENS is very limited.

Thoracic epidural steroid injection

Epidural steroids have been used in patients suffering from numerous sources of pain (e.g., discogenic or radicular spinal pain, spinal compression fractures, pelvic pain, zoster-related pain, postherpetic neuralgia).[74,151,152]

Rauchwerger and colleagues[74] investigated a single-shot thoracic epidural steroid injection in 2 patients who presented with pain from rib fractures. It was presented as a treatment option in hospital settings in which long-term treatment is unavailable. Both patients were in their 50s (one man, one woman) and both were initially treated with

morphine. After ineffective pain relief, both were treated with .125% bupivacaine injections combined with 80 mg triamcinolone. Both patients experienced pain relief.

Intercostal nerve blocks have a short duration of pain relief, require multiple injections, and put the patient at a risk of pneumothorax.[153,154] The use of intrapleural and paravertebral blocks is typically limited to patients with unilateral fractures.[74] Epidural catheter use is limited to inpatients/hospital settings where continuous support for catheter management is available (to avoid hypotension, anesthetic toxicity, etc.).[74] Epidural steroid injections may be a good alternative, and the analgesia may outlast the durations of local anesthetics, but no data exist that compare this therapy to any of the aforementioned typical treatments.[74]

Comparing the different treatments

Each treatment has a unique set of advantages, disadvantages, and contraindications. And patients must be treated according to what is currently regarded as the best medical practice. For this reason, controlled trials that truly randomize patients to different treatment groups are infrequently conducted. It is unlikely that a review board would approve an urn randomization model that distributes patients evenly throughout the treatment groups based on criteria such as the presence of upper-rib fractures. Thus, most data available are retrospective comparisons of two groups of patients who have *similar* injuries and were treated with different techniques. Among this body of research, there is wide variation in which treatment option is used.[86]

When hemodynamic and respiratory function are concerns, systemic analgesia is

often avoided.[38] Systemic opioids can also impair assessment of a patient's mental status.[38] For these reasons, regional techniques are often preferred.[38] According to a 2000 meta-analysis by Rogers and colleagues[87], TEA can reduce the rate of mortality by more than 30% and decrease the incidence of comorbidities by 15% (stroke) to 55% (pulmonary embolism). Likewise, a 2003 meta-analysis by Block and colleagues[88] (which analyzed more than 100 studies) found epidural treatment to be superior to opioid treatments. More specifically, use of epidural catheter treatments (as compared to systemic opioids) has demonstrated improvements in subjective pain management[7], pulmonary function[36,78,89], and better clinical outcomes.[11,82] Despite this, in a 2003 narrative review on pain management, Karmakar and Ho[37] concluded that no single mode of analgesia could be confidently recommended. Contrasting this review, Simon and colleagues published pain management guidelines for blunt thoracic trauma in 2005[90], stating that the preferred mode of analgesic for patients with multiple rib fractures was via epidural. The inconsistencies in recommendations may be responsible for the low rates (below 20%) of epidural use among eligible patients (patients without contraindications to epidural placement).[7,8,59] In 2005, Flagel et al.[10] found only 2% of patients with at least 1 fractured rib to be treated with epidural analgesia (1,295 of 64,750). And most recently, in 2014, Dehghan et al.[26] found epidural catheters were only used in 8% of patients who were admitted with flail injuries (263 of 3,467).

Rationale for this review

The most recent review of TEA as a treatment for patients with multiple rib fractures was published Carrier and colleagues in 2009.[46] In it, they performed a meta-

analysis of 8 studies related to TEA (7 in English, 1 in Turkish). They identified 3 studies that compared TEA with local anesthetics to parenteral opioids[78,91,92], 2 studies that compared TEA with local anesthetics to intrapleural analgesia[83,93], and 3 studies that compared epidural analgesia with opioids to parenteral opioids.[36,89,94] When analyzing those studies collectively, Carrier and colleagues reported no significant differences between epidural analgesia and other analgesic modalities in mortality, length of stay in the ICU, or length of stay in the hospital. When evaluating duration of mechanical ventilation, they found *some* benefit to using epidural anesthesia with local anesthetics. However, that treatment was associated with a greater risk of hypotension.

These findings must be interpreted cautiously. Out of the 8 studies analyzed, only 5 are known to be randomized trials. Of the remaining studies, 1 assigned treatment based on injury severity, 1 is a poster presentation which does not specify randomization (or whether it was prospective or retrospective), and 1 is in Turkish, with no mention of randomization in English. Furthermore, only 4 studies provided sufficient details about catheterization methods in English. Carrier and colleagues rank their 8 studies in terms of quality, admitting, “Only four of the eight studies included in our review were of high methodological quality.” These were: Bulger et al., 2004[11]; Luchette et al., 1994[83]; Moon et al., 1999[78]; and Shinohara et al., 1994.[93]

A similar admission is made in a 2007 review of the literature by Parris[95], who *also* found 4 studies to be satisfactory for inclusion. These were: Bulger et al., 2004[11]; Moon et al., 1999[78]; Mackersie et al., 1991[36]; and Ullman et al., 1989.[89] Curiously, only

half of the "high methodological quality" studies overlap between the two most recent reviews.

One example of a study that Carrier and colleagues regarded as high quality and Parris did not is a 1994 investigation by Luchette et al.[83] This study did not address clinical outcomes (days in ICU, days in hospital, duration on mechanical ventilation, incidence of pneumonia) as much as variables thought to *affect* clinical outcomes (pain, pulmonary function). There is no mention of blinding (blinded to the nurses providing care, etc.). And patients were permitted into the study with associated injuries that were not explained or controlled for (and would likely affect patient-perceived pain level). It is important to consider the impact such limitations might have on the validity of Carrier et al.'s conclusions.

Regarding these conclusions, although zero original studies were published between the two reviews, Parris's interpretation of the data was slightly different from Carrier et al.'s: "On limited evidence from moderate quality studies, epidural analgesia/anaesthesia offers some benefits over intravenous analgesia but further studies are needed to strengthen this conclusion."

What seems consistent between the two reviews is not their interpretation of the findings, but their appraisal of the *quality* of available literature. According to Parris, "the limited quantity and quality of evidence illustrates the difficulties in studying this patient group and determining the most relevant outcomes." In terms of quantity, perhaps Parris didn't look very hard. In terms of quality, he makes a valid point. And he elaborates on that point: "All four studies looked at slightly different patient groups, different treatment

regimens and outcomes with consistently poor reporting of timing of placement of epidural catheters and administration of intravenous analgesics."

Although a new systematic review may be in order just to reconcile the conclusions of the previous attempts, it is also an ideal time to do so as new studies evaluating the safety and/or effectiveness of TEA have been published since 2009. According to our search, there are 10 studies that merit consideration, which were not considered in either of the aforementioned reviews: 4 published prior to 2009, 6 published since.

Prior to 2009: Wisner (1990)[82] compared epidural narcotics (87% lumbar, 13% thoracic) to a variety of analgesic modes, but most commonly intravenous/intramuscular narcotics among patients who had sustained thoracic trauma. Wu and colleagues (1999)[7] compared TEA to IV analgesia in patients with at least 3 fractured ribs. Bulger and colleagues (2000)[6] compared treatment outcomes of elderly Patients (≥ 65 y) with at least 1 fractured rib to younger patients (18-64 y) with at least 1 fractured rib; epidural catheters were compared to other treatment modalities (e.g., pleural block, IV/IM narcotics, oral narcotics, ketorolac, Tylenol). Kieninger et al. (2005)[96] compared epidural analgesia to IV narcotics in older patients with rib fractures.

Since 2009: Mohta and colleagues (2009)[29] compared TEA to thoracic paravertebral infusion in patients with at least 3 fractured ribs. Hashemzadeh and colleagues (2011)[61] compared TEA to intercostal block in patients with multiple fractured ribs. Kim and colleagues (2011)[97] reported the complications that arose in patients who underwent surgical reduction and fixation of fractured ribs, and were treated with TEA.

Hakim & Latif (2012)[28] evaluated TEA compared to lumbar epidural analgesia (both lidocaine) in patients admitted with blunt chest trauma. Yeh and colleagues (2012)[8] compared TEA to IV and oral narcotics in patients with at least 3 fractured ribs. Waqar and colleagues (2013)[9] compared TEA to IV opioids among patients with multiple fractured ribs.

Objectives of this review

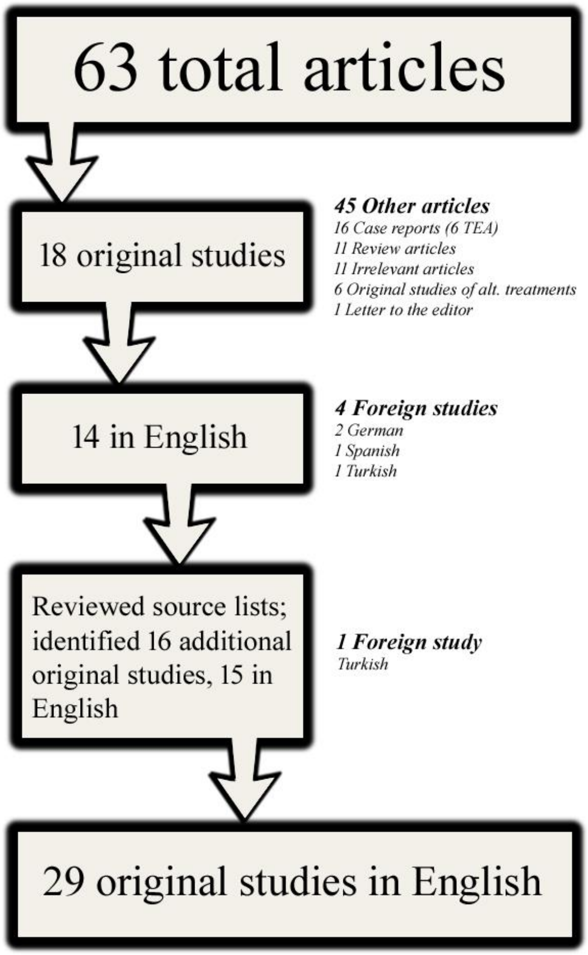
In this review, we complete a comprehensive search for articles related to the use of TEA in patients with rib fractures. In doing so, we attempt to identify the value of TEA as it relates to mortality, length of stay in the ICU and hospital, use of mechanical ventilation, improvement in subjective pain levels, effect on respiratory function, and incidence of pneumonia and other complications/adverse events (e.g., sepsis, acute respiratory distress syndrome, respiratory failure). Wherever possible, we make comparisons to other treatments.

METHODS

Search strategy

An electronic search was conducted using PubMed on March 29, 2014. Two search terms were used:

1) (thoracic) AND (catheter* OR epideral* OR "epidural analgesia" OR "Analgesia, Epidural"[MAJR]) AND pain AND (fracture*) AND (rib OR ribs)



2) (("thoracic catheter" OR "thoracic epidural" OR "thoracic catheters" OR "thoracic epidurals" OR "thoracic paravertebral catheter" OR "Analgesia, Epidural"[MAJR] OR "epidural analgesia") AND pain AND fracture* AND (rib OR ribs))

After running each search, the PubMed Advanced Search Builder tool was used to combine their results, eliminating duplicate studies.

Search results

This search yielded 63 total articles; 14 of these presented original research about the effectiveness of TEA in English.[7,8,11,25,29,39,41,61,82,83,91,93,96,98]

Additional articles

After completing the search, we reviewed the source lists of all relevant articles and found an additional 16 original trials that weren’t identified by our search term; 15 of these were in English.[6,9,10,28,30,36,65,66,78,84,85,89,94,97,99]

The study by Pierre and colleagues[94] was a poster presentation. The 1982 study by Dittmann et al.[65] was a duplicate of a German-language article published by the same authors in 1980.[155] The studies by Dittmann and colleagues from 1975[85] and 1978[84] quantify the same sample (the 1978 study is an expansion on the 1975 sample). These articles were included (the 1980 German article was replaced by the 1982 English version and Dittmann et al.'s 1975 and 1978 publications are treated as separate articles), bringing the total number of original studies evaluating TEA in patients with chest wall trauma to 33 (29 in English).

Extraction and Synthesis of Data

All 29 articles were read in full with data carefully extracted. Tables were generated, characterizing primary outcomes where available. The outcomes are: demographic information (sex, age), type of study (RCT, review, etc.), injury characteristics (number of ribs fractured, ISS, presence of flail chest and pulmonary contusion), type of treatment (TEA, IV, etc.), mortality, ICU length of stay, hospital length of stay, use and duration of mechanical ventilation, changes in subjective pain levels, changes in respiratory function, incidence of pneumonia and other complications/adverse events (sepsis, acute respiratory distress syndrome, respiratory failure).

Principle Summary Measures

Because there are inherent differences in the type and quality of the data published, and vast differences in the methods of their acquisition, we do not attempt to

meta-analyze the findings. At this stage in the research, such a summation would be little more than data alchemy, and worthy of distrust. Instead, we merely present the findings in tables, evaluate the quality of the relevant claims, and provide an overall appraisal of the state of the evidence.

RESULTS

Research supporting TEA

16 studies have reported epidural analgesia to be an effective treatment for patients with fractured ribs. Out of these, 8 do not include a comparison group, 4 compare TEA to IV opioid treatments, and the remaining 4 compare TEA to other regional techniques.

No comparison group

In 1984, Abouhatem et al.[25] investigated 19 patients (mean age of 53 yr) with multiple fractured ribs (mean of 5; 37% had a flail segment) who underwent TEA (bupivacaine). Gender and ISS are not reported. No inclusion or exclusion criteria are described. All but one patient experienced satisfactory pain relief (quantification not provided). Treatment lasted 2-17 days (mean of 8 days) and then patients were discharged from the ICU. Bradycardia occurred in 2 patients and hypotension occurred in 3 patients. No other data were reported. They concluded that TEA was an effective way to treat pain following multiple rib fractures.

In 1975[85] and in 1978[84], Dittmann and colleagues evaluated epidural analgesia. There was a comparison group, but that group was not treated with an alternative form of analgesia. Rather, they were given mechanical ventilation. Both articles came from the same database, but the 1978 study expanded on the sample from 1975.

In the 1975 study, Dittmann et al. assessed 48 patients with multiple fractured ribs who were admitted to the ICU at the university hospital of Basle, Switzerland between May 1972 and August 1974. 16 of those patients received epidural analgesia, but the authors only characterized 14 of them (100% male, mean age of 55.1 yr, mean num. of fractured ribs = 7.36). These patients received thoracic or high lumbar epidural analgesia of bupivacaine (.25% with adrenaline 1:200,000). The initial dose was 3 mL to 10 mL depending on age, bodyweight, and pain level of the patient. Catheters were left in position for 3 to 8 days. While under analgesia, inhalation therapy (tidal volumes of 15 mL/kg) was conducted. Patients also exhaled against resistance for 5 of every 60 minutes. There were 32 subjects assigned intubation and mechanical ventilation. Methods for mechanical ventilation are not described. The age, gender, and number of fractured ribs of these patients are not disclosed. ISS, flail segments, and pulmonary contusions are not reported for either group. The authors unnecessarily present findings by year. During the first year, 2 patients received epidural analgesia and were never described. During the second year, 14 patients received epidural analgesia and were characterized. 13 of these patients received adequate treatment per se; 1 patient was intubated (30 hours following initial injury). Pain control was purported to be successful in all patients ("All the patients after EA felt immediately better") but no data were provided to support this claim. Data were provided in pulmonary measures, where patients receiving epidural analgesia

exhibited improvements. Partial pressure of oxygen in the arterial blood (P_aO_2): pre-treatment = 63.0 mmHg; post-treatment = 74.7 mmHg. Vital capacity: pre-treatment = 10.6 ml/kg; post-treatment = 20.5 ml/kg. The one patient in this group who was intubated ("despite good analgesia") had poor vital capacity (fell under 13 mL/kg). The authors attribute this to his age (57), bodyweight (obese), and poor cooperation with the protocol. After 8 days of mechanical ventilation, he developed pneumonia; 21 days after the initial injury, he died. Mortality rate was thus 7.1%. During the first year of treatment, 17 patients received intubation and mechanical ventilation; 4 died (23.5%). During the second year, 15 patients were intubated and ventilated. These patients also received Droperidol and Diazepam for sedation and IV morphine for analgesia (it is unclear if patients from the first year received this treatment); 3 of these patients died (20%).

In 1978, Dittmann et al.[84] published further findings on the 1975 sample. At this time, 100 consecutive patients had been admitted at the University of Basle's Division of Intensive Care. They were assigned either epidural analgesia (n=49, mean age of 55.7 years with an average of 6.8 fractured ribs) or mechanical ventilation (n=51, mean age of 44.7 years (according to abstract) or 47.3 (according to page 195) with an average of 6.5 fractured ribs). Gender, ISS, and presence of flail segments and pulmonary contusions were not reported. The treatment methods are not well reported. The authors cite their 1975 paper and provide minimal additional detail. However, what is reported is incongruent with the 1975 study: epidural analgesia is bupivacaine .5% rather than .25%. The rest of the treatment is described vaguely as IPPB-inhalation and physiotherapy. Patients in the mechanical ventilation group presented with nearly 3 times as many "associated fractures and major injuries" (98 compared to 35). Among patients receiving

epidural analgesia, the average length of stay in the ICU was 4.5 days (range: 2 to 11 days). This was briefer than the duration stayed by patients who were treated with mechanical ventilation (9.8 days). However, 3 of the 49 patients receiving epidural analgesia had to be intubated and ventilated. All 3 died (6.1% overall mortality rate). The authors claim “none of the total EA group showed any evidence of pneumonia”, but they present a case study within the article that is a duplicate of the 1975 patient who died in the epidural analgesia group. And in the 1975 paper, it states he acquired pneumonia after 8 days of ventilation; in the 1978 paper, he doesn’t contract pneumonia. The researchers also chose 6 of the 49 epidural patients on whom to evaluate pulmonary measures. Selection criteria were never specified. 5 of these patients were male, they had a mean age of 58.6 years and an average of 8.5 fractured ribs (2.9 years older than the sample they came from; 1.7 more fractured ribs on average than the sample they came from). They had a P_aO_2 of 8.3 kPa before treatment and 8.5 kPa after treatment. They had a vital capacity of 23.6 mL/kg before the treatment and 28.5 ml/kg after the treatment. Functional residual capacity pre-treatment was 2473 mL and post-treatment was 2637 mL. Airway resistance before the treatment was 0.481 kPas/L and after the treatment was 0.378 kPas/L. Dynamic lung compliance was 1.08 mL/kPA before the treatment and 1.94 mL/kPA after the treatment. The implication (particularly by VC and Cdyn) are that the hypventilated portions of the lung may be better ventilated under epidural analgesia.

In 1982, Dittmann and colleagues once again compared epidural analgesia to mechanical ventilation.[65] This may have been another expansion on the 1970s sample. The epidural analgesia group included 112 patients (mean age of 57.5 yr, mean number of fractured ribs = 6.8, 1% had pulmonary contusions). The mechanical ventilation group

consisted of 155 patients (45.2 yr, num. of rib fractures = 6.6, 32% had pulmonary contusions). Despite being an average of 12.3 years younger and fracturing .2 fewer ribs, they had 32 times the incidence of pulmonary contusions (perhaps this was a documentation error). Gender, ISS, and presence of flail segments were not reported. Neither were the treatment methods (epidural catheterization, medication, dose, or ventilation methods). Patients were included in the study if they had multiple fractured ribs, were conscious and cooperative, had a vital capacity above 15 ml/kg (or reached that value "after a few hours of optimal conservative management"), and "if venous admixture proved the pulmonary lesion (by contusion, atelectasis or aspiration) to be of minor importance." No exclusionary criteria were described. The patients who received mechanical ventilation remained in the ICU for longer (13.1 days on page 91; 13.5 days on page 90) than patients who received epidural analgesia (6.1 days). Patients who received mechanical ventilation stayed in the hospital for longer (26.2 days) than patients who received epidural analgesia (16.8 days). Among patients receiving mechanical ventilation, 38 patients died (24.5%; 22 deaths because of pulmonary complications, 16 attributed to non-pulmonary causes). Among patients receiving epidural analgesia, there were 5 patient deaths (4.5%; 1 because of pulmonary complications, 4 attributed to non-pulmonary causes). Although level of significance is never mentioned with the reporting of any outcome, the magnitude of the differences is large and in favor of TEA (despite those patients being 12.3 years older).

In 1999, Doss and colleagues[41] investigated epidural analgesia (ropivacaine) on 57 patients (68% male, 21-62 yr; no mean provided) with multiple fractured ribs. They do not report how many fractured ribs the patients had, if flail segments were present, or the

ISS. Inclusion and exclusion criteria are not described. The authors report that all patients experienced “excellent pain relief” and none had respiratory depression. But they do not describe how data were collected or what those data were.

In 2002, Govindarajan and colleagues[39] investigated epidural buprenorphine on 27 patients (85.2% male, 48 ± 16 yr, a mean of 4 fractured ribs; range: 2-8, no SD provided). The authors don’t report the number of subjects with flail segments or the ISS. The average length of hospital stay was 5 days (range: 4-7 days, no SD provided), but findings are only reported for the first 3 days of treatment. During these 3 days, respiratory rate decreased and ventilatory function improved (compared to pre-analgesia data). From pre-analgesia to the third day of treatment: vital capacity went from 21.9 ± 3.19 ml/kg to 35.1 ± 2.56 ml/kg, resting respiratory rate went from 22.2 ± 2.08 breaths/min to 17.9 ± 1.49 breaths/min, resting tidal volume went from 2.86 ± .53 ml/kg to 5.77 ± .76 ml/kg, and resting minute volume went from 63.4 ± 3.88 ml/kg to 103.52 ± 3.72 ml/kg. Improvements were also found in magnitude of pain at rest and during coughing and deep breathing. At baseline, 89% of subjects reported severe pain at rest and 100% during coughing; on the third day of treatment, 78% of subjects reported no pain at rest and 41% during coughing. No patient required additional analgesics during the treatment. No patient developed hypotension, respiratory depression, or urinary retention. No patient experienced a catheter-related complication.

In 1980, Johnston & McCaughey[99] evaluated epidural morphine on 6 subjects (mean age of 49 yr) with multiple fractured ribs (1 patient had 3 fractured ribs, 1 patient had 4 fractured ribs. 3 patients had 6 fractured ribs, 1 patient had 7 fractured ribs). The

authors do not report gender, the presence of additional injury (e.g., flail segment), or ISS. No exclusionary criteria are noted. The effect of analgesia began within 2-3 min and lasted 6.67 h (range: 3-50 h). In all patients but one, doses were repeated for 7-10 days; the other subject required mechanical ventilation. To evaluate blood pressure, the two patients who were given bupivacaine were compared to two patients who received morphine. The average fall in blood pressure after bupivacaine administration was 15 mmHg (15 min after treatment). The average fall in blood pressure after morphine treatment was 0.2 mmHg. The only other result reported is that one patient (out of 6) required mechanical ventilation. That patient had other non-thoracic injuries as well.

In 1985, Worthley[30] evaluated the safety and effectiveness of patients admitted to the Royal Adelaide Hospital ICU (from 1975 to 1981) with chest wall trauma. Patients were excluded if they had sustained spinal trauma, were unconsciousness or uncooperative, or had a preexisting chronic neurological disease or a skin infection where epidural catheter would be inserted. 161 patients received TEA (76.4% male, 46.1 ± 16.8 yr, 16.1% had a flail segment, 9.9% had a pulmonary contusion). The mean number of fractured ribs and injury severity scores were not reported. TEA was bupivacaine (.5% with adrenaline 1/200,000). A 5 mL initial dose was used and was adjusted based on specific criteria such that doses would accommodate individual patient need. 147 of 161 patients were managed successfully using only TEA. Mechanical ventilation was used in 14 patients after the initiation of epidural catheters. 5 of these 14 patients had flail segments (36%) compared to 21 (14%) patients with flail segments in the 147 patients who were managed with epidural analgesia alone. 4 of the 14 patients who received mechanical ventilation (29%) had a pulmonary contusion compared to 12 of the 147

successful patients (8%). Two patients died (1.2%), both from respiratory failure. The side effects to epidural treatment included 2 cardiac arrests and one epidural infection.

Compared to IV treatments

Numerous studies have demonstrated superior pain relief and greater improvement in pulmonary tests when using epidural analgesia compared to IV opioids among patients with fractured ribs.[7,36,78] Epidural analgesia has also shown to be a favorable treatment among patients recovering from thoracic surgery.[68,156]

Pierre and colleagues presented a poster in 2005[94] that compared investigated the differences between lumbar epidural morphine and IV morphine in patients with multiple fractured ribs. 11 patients received epidural morphine (mean age of 53 yr, average, 4.5 fractured ribs, ISS = 19.8) and 11 patients received IV morphine (mean age of 53 yr, 3.8 fractured ribs, ISS = 17.6). Gender and percentage of patients with flail segments were not reported. The only inclusionary criterion mentioned is that the subjects were adults and they had multiple fractured ribs; no exclusionary criteria were mentioned. The duration spent on analgesic was similar (epidural: 3.5 days, patient-controlled analgesia: 3.7 days). Subjects in the epidural group spent significantly less time in the hospital (10.8 days vs. 15.9 days) and in the ICU (3.1 days vs. 6.6 days). The epidural group also experienced better pain reduction at 24 and 36 hours. No further information is provided.

In 1989, Ullman and colleagues[89] compared thoracic epidural morphine to IV morphine in patients with multiple fractured ribs. 15 patients received epidural morphine (73.3% male, 46.1 ± 4.6 yr, 7.3 ± 0.6 fractured ribs, ISS = 19.5 ± 2.0) and 13 patients

received IV morphine (84.6% male, 53.0 ± 6.0 yr, 6.6 ± 1.1 fractured ribs, ISS = 25.3 ± 2.9). The presence of flail segments was not noted. Patients receiving epidural analgesia spent shorter durations on ventilators (3.1 days vs. 18.2 days), spent less total time in the hospital (14.9 days vs. 47.7 days) and spent less time in the ICU (5.9 days vs 18.7 days). All of these are significant. At baseline, there was no difference between groups in tidal volume. However, the group receiving epidural analgesia exhibited better improvements in tidal volume (at 24 hours). That difference was significant. There were no differences between groups in vital capacity, either at baseline or following treatment. 5 patients in the IV group (38.5%) required trachestomy while it was only required by 1 patient in the epidural group (6.7%). This difference was significant. There were no complications related to the catheter placement. 2 patients in the epidural group experienced urinary retention but there was no nausea, vomiting, pruritus, or respiratory depression.

In 2013, Waqar and colleagues[9] compared TEA (bupivacaine) to IV opioids among patients with multiple fractured ribs. There were 47 patients in the epidural group (75% male, 54 ± 17 yr, 6.4 ± 2.1 fractured ribs, 19% had a flail segment, ISS = 23.6 ± 10.3) and 38 patients in the IV group (76% male, 45 ± 22 yr, 5.2 ± 2.5 fractured ribs, 13% had a flail segment, ISS = 21.0 ± 6.7). Subjects in the epidural group were significantly older and had significantly more fractured ribs. Despite this, pain relief was superior in the epidural group at all time points (data aren't reported). Patients in the epidural group had significantly shorter periods of time on analgesia (4.25 ± 1.2 days compared to 5.5 ± 3.2 days), significantly shorter stays in the hospital (19 ± 3.1 days compared to 21 ± 4.1 days), and the ICU (12 ± 2.4 days compared to 14 ± 3.5 days). There were no differences between groups in mortality or morbidity (cardiac, pulmonary,

or neurological complications). There were no complications related to epidural placement in any subject.

In 1990, Wisner[82] compared epidural narcotics (87% lumbar, 13% thoracic; methods not described) to a variety of analgesic modes, but most commonly intravenous and intramuscular (IV/IM) narcotics (methods not described) among patients who had sustained thoracic trauma. There were 52 patients in the epidural narcotic group (42.3% male, 71.0 ± 1.1 yr, ISS = 15.7 ± 1.0) and 167 patients in the IV/IM group (44.3% male, 69.4 ± 0.6 yr, ISS = 14.6 ± 0.8). Number of fractured ribs and the presence of a flail segment were not reported. At baseline, the IV/IM analgesia group was similar to the epidural group. The only significant differences were found in the Abbreviated Injury Scores. The degree of thoracic injury was higher (more severe) in patients treated with epidural analgesia. The degree of abdominal injury was higher (more severe) in patients treated with IV/IM analgesia. There was a significant difference in mortality rate: patients receiving epidural analgesia had a 4% rate compared to those receiving IV/IM analgesia who had a 16% rate. With all other covariates held constant, the risk of mortality was 38% lower among patients receiving epidural analgesia compared to patients receiving IV/IM treatments. There was an increased incidence of pneumonia in the IV/IM group compared to the epidural group. No major complications were associated with epidural use or placement. No cases of urinary retention or pruritus were found. When using logistic regression analyses to determine predictors of pulmonary complication, treatment type was significant (epidural analgesia predicted a decreased likelihood that pulmonary complications would develop when compared to IV/IM analgesia). Epidural analgesia was also associated with improved pain control (11 patients initially treated with an

alternate form of analgesia had to be switched to epidural analgesia; 6 of them were initially receiving IV/IM analgesia). There was a very strong trend (p=.052) that patients who received epidural analgesia had longer hospital stays, but data aren't reported. On average, patients were on mechanical ventilation for 4.4 days, but differences between groups are not presented.

Compared to other regional techniques

In 2005, Flagel and colleagues[10] compared the use of epidural analgesia to all alternative treatments (they did not specify which treatments these were). In evaluating the NTDB, they found 9% of patients (n = 64,750) to present with at least 1 fractured rib. Among these patients, 2% (n = 1,295) received epidural analgesia; the rest (63,455) received alternative treatments. No information is provided about what these forms are or how they were administered. Nor were the methods of epidural catheterization (including type and concentration of analgesia) described. Inclusionary and exclusionary criteria were not reported and numerous baseline variables were absent from the results. This includes age (overall and in each treatment group), gender (overall and in each treatment group), mean number of fractured ribs (overall and in each treatment group), and the incidence of flail segments and pulmonary contusions in individual treatment groups. Among all patients with rib fractures, epidural analgesia was used in 2% of cases. The more ribs fractured, the more common epidural analgesia was used (R_2 = 0.96). Use of this treatment jumped 50% in the presence of 6 or more fractured ribs (compared to treatments of patients with 5 or fewer). Despite greater number of rib fractures in the group receiving epidural analgesia, ISS was slightly lower, and odds of surviving were

much better (more than 96% survived, compared to a 10% overall mortality rate). Epidural analgesia had no effect on the incidence of pneumonia.

In 1973, Gibbons et al.[66] compared epidural analgesia (bupivacaine) to intercostal nerve block or parenteral narcotics (bupivacaine) in patients with fractured ribs and respiratory failure. If fractures were below the 5th rib, TEA was used (n=27). If fractures were on the 5th rib or above, subjects were assigned to the comparison group, in which either intercostal nerve block or parenteral narcotics was used (n=30). The patient characteristics (gender, age, number of fractured ribs, whether flail segments were present, and ISS) are not described. In the thoracic epidural group, hypotension developed in 12 patients. In 2 of these patients, the severity of the hypotension resulted in circulatory arrest. 6 patients required tracheobronchial suction and 6 patients ultimately required artificial ventilation. All patients recovered and all ultimately experienced satisfactory pain relief. In the Intercostal nerve block (or parenteral narcotic) group, 2 patients required tracheobronchial suction, 13 required artificial ventilation at some point in the recovery (compared to 6), and 2 patients died ("during resuscitation of aortic rupture"). No other data are reported.

In 2011, Hashemzadeh and colleagues[61] compared TEA (marcaine) to intercostal block (marcaine) among patients with multiple fractured ribs. 30 patients were randomized to the thoracic epidural group (95% male, 45.5 ± 15.4 yr) and 30 patients were randomized to the intercostal block group (90% male, 65.5 ± 7.2 yr). The authors collect but don't report number of fractured ribs and incidence of flail segments. They do report percentage of coexisting disease (10% of epidural subjects, 20% of intercostal

block subjects). They also report pain scores at rest and during coughing, but don't specify if those values are pre- or post-treatment or change scores. There were significant differences in pain scores both during rest and while coughing (p = .03 and .00 respectively) with thoracic epidural subjects reporting less pain. It is unknown if these are baseline, post-treatment, or change values. Subjects in the thoracic epidural group had shorter stays in the trauma unit (5.7 ± 2.0 days) than subjects in the intercostal group (7.7 ± 3.7 days; p = .04). Thoracic subjects also had shorter ICU stays (1.6 ± 1.0 days) than intercostal subjects (1.9 ± 1.4 days; p = .05). At baseline, respiratory rate, heart rate, oxygen saturation, and mean arterial pressure were not different. Minute volume (p= .03), tidal volume (p = .04), and vital capacity (p = .08) were lower in the intercostal subjects. Following treatment, these differences vanished (p = .67, .41, and .93 respectively). Before treatment, there was no difference in PaO_2 (thoracic epidural subjects had a non-significantly lower value; p = .20). Following treatment, thoracic epidural subjects had significantly higher values (p = .01). There was no difference in $PaCO_2$. The authors say there was no difference in the incidence of respiratory complications, but they do not report those rates or disclose what the complications were. The descriptions of findings in the discussion often cannot be reconciled with the reports found in the tables. It may be difficult to attribute superior outcomes to type of treatment when the intercostal group was 20 years older (p = .35) with twice the rate of coexisting disease (p = .19). Despite the lack of significance, the magnitude of the differences is considerable.

In 1994, Luchette and colleagues[83] compared thoracic epidural catheters (bupivacaine) to intrapleural catheters (bupivacaine) in patients with multiple fractured ribs. There were 9 subjects randomized to the thoracic epidural group (56 ± 18.3 yr, ISS

= 21.7 ± 5.5) and 10 randomized to the intrapleural catheter group (51 ± 10.9 yr, ISS = 19.4 ± 5.7). Gender, number of fractured ribs, and presence of flail segment were not reported. The researchers quantified three days of recovery. All data are displayed in graphs; exact values are not reported. At baseline, subjects in the epidural group had higher mean pain scores (visual analog score; not significant). During all 3 days of recovery, pain was significantly lower in the group receiving epidural analgesia (both at rest and during movement or coughing; < .05). Subjects in the epidural group also required less supplemental morphine at all time points ($p < .05$). Regarding pulmonary function tests, vital capacity, minute ventilation, and respiratory rate were not different between the two treatments. But tidal volume and negative inspiratory force improved significantly more in the epidural analgesia group (on day 3) than in the intrapleural group. Side effects/complications: mechanical ventilation was required in 78% of epidural subjects and 70% of intrapleural subjects. There was no bupivacaine toxicity, neurological deficit, dural perforation, catheter-related infections, or pneumothoraces. The most common complication was a "mild to moderate" (exact magnitude not reported) fall in blood pressure when thoracic epidurals were administered. Blood pressure was restored in 6 out of 9 patients with a lactated Ringer's solution; epinephrine was used in the other 3.

Research comparing different locations of epidural analgesia

In 2012, Hakim & Latif[28] investigated if TEA (lidocaine) is better than lumbar epidural analgesia (lidocaine) among patients who are admitted with blunt chest trauma. 27 patients received thoracic epidurals (63.0% male, 39.1 ± 13.5 yr, 3.7% had a flail

segment, VAS for pain: 67.3 ± 7.4) and 28 patients received lumbar epidurals (53.6% male, 41.3 ± 9.3 yr, 3.6% had a flail segment, VAS for pain: 62.9 ± 9.7). Number of fractured ribs was not reported. Duration of epidural analgesia: both groups had a mean of 3 days. Range in the lumbar group was 3-4 days; range in the thoracic group was 2-4 days ($p = .057$). Mean values are only presented as integers; no SDs are provided. Duration of ICU stay: both groups had a mean of 5 days. Range in the lumbar group was 5-7 days; range in the thoracic group was 4-9 days ($p = .227$). 17.9% of lumbar patients and 22.2% of thoracic patients received mechanical ventilation ($p = .686$). Mechanical ventilation lasted 5 days in the lumbar group and 6 days in the thoracic group ($p = .141$). 25% of lumbar patients and 22.2% thoracic patients developed pneumonia ($p = .808$). Both groups experienced initial reductions (first 24 hours) in pain scores, heart rate, respiratory rate, and mean arterial pressure ($p < .05$) relative to pre-randomization values. During this same time, SaO_2, PaO_2, PaO_2/FiO_2, $PaCO_2$, MIF, VT, and FEV_1% were elevated ($p < .05$). There were no significant differences between groups in pain scores, cardiopulmonary variables, total morphine use, or incidence of treatment-related side effects. The most common side effects were urinary retention (42.9% in lumbar, 40.7% in thoracic), pruritus (60% in lumbar, 55.6% in thoracic), and nausea/vomiting (25% in lumbar, 29.6% in thoracic).

Research not supporting TEA

Epidural analgesia is not always shown to be the most effective modality. Among patients admitted with rib fractures, the outcomes of TEA administration have been inconsistent.[7,82,96] Whereas 16 studies have reported positive outcomes with epidural

analgesia, 10 have reported either poorer or comparable outcomes for patients with fractured ribs. Out of these, 2 were not designed to evaluate the efficacy of TEA, 6 compared TEA to IV treatments, and 2 compared TEA to other regional techniques.

Methods not designed to evaluate epidural analgesia

In 2004, Balcı and colleagues[91] enrolled 64 patients who had flail injuries in a study that evaluated 3 different therapies: Group 1 (n=27, 74.1% male, 34.6 ± 8.4 yr, 100% had a flail segment, 14.8% bilateral flail, 48.1% had a pulmonary contusion, ISS = 21.0 ± 7.4) underwent open fixation of rib fractures, Group 2 (n=19, 78.9% male, 30.7 ± 8.4 yr, 100% had a flail segment, 11.1% bilateral flail, 42.1% had a pulmonary contusion, ISS = 18.2 ± 7.8) managed the injuries using intermittent positive pressure, and Group 3 (n=18, 72.2% male, 31.7 ± 11.1 yr, 100% had a flail segment, 11.1% bilateral flail, 44.4% had a pulmonary contusion, ISS = 18.6 ± 8.3) managed the injuries with synchronized intermittent mandatory ventilation. Among the patients who were not treated surgically (i.e., Groups 2 and 3), 13 patients received TEA (35.1%), 16 received intercostal nerve blockade (43.2%), and 8 received narcotic or nonnarcotic parenteral analgesia (21.6%). This study was not designed to look at TEA; it was just a side note in a protocol investigating surgical fixation. Epidural analgesia (0.10% bupivacaine and 10 mg·mL–1 fentanyl) was described as patient-controlled, but a dose of 4 $mL \cdot h^{-1}$ was used. No further information is provided about the methods of catheterization. The authors report that all patients receiving epidural analgesia or intercostal nerve blockades needed additional parenteral analgesia and repeated doses to address pain. They do not report pain outcomes or data concerning treatment repetition, but note that pain control was

inadequate and opioid drugs were the most commonly used option to increase the analgesic effect. Across the whole sample, mortality was 20.3%, the duration of mechanical ventilation ranged from 1.5 to 22 days, and the length of hospital stay ranged from 9 to 32 days. The authors concluded that surgical fixation was a successful treatment for patients with traumatic flail chest but thoracic epidural catheters were potentially problematic “not only because of the angle of the spinal processes and the smaller space but also because it was difficult to put patients with flail chest in the proper position to place the catheter, thus we do not advise its routine use.”

In 2000, Bulger and colleagues[6] compared outcomes of elderly Patients (≥ 65 y) with at least 1 fractured rib to younger patients (18-64 y) with at least 1 fractured rib. There were 277 elderly patients (57% male, 74 ± 6 yr, 3.6 ± 2.5 fractured ribs, 17% had a flail segment, ISS = 20.7 ± 12.7) and 187 younger patients (70% male, 39 ± 13 yr, 4.0 ± 2.9 fractured ribs, 11% had a flail segment, ISS = 21.4 ± 13.4). Elderly patients had more sternal fractures (6% vs. 2%) and fewer cases of pneumothorax (34% vs. 44%). No inclusionary or exclusionary criteria were specified. The mean duration spent in the ICU was 6.1 ± 10.0 days for elderly patients and 4.0 ± 9.4 days for young patients ($p < .05$). The mean hospital stay was 15.2 ± 16.5 days for elderly patients and 11.0 ± 13.1 days for young patients ($p < .01$). The mean ventilator duration was 4.3 ± 9.3 days for elderly patients and 3.1 ± 9.2 days for young patients ($p = .16$). Ventilatory support was required in 57% of the young group and 52% of the elderly group. Elderly patients experienced more pulmonary complications: pneumonia (31% vs. 17%), late pulmonary effusion (41% vs. 14%), and adult respiratory distress syndrome (9% vs. 5%). As the number of fractured ribs increased, so did the odds of contracting pneumonia and adult respiratory

distress syndrome (especially in the elderly group). 22% of the elderly patients died compared to 10% of the young patients ($p < .001$). As the number of fractured ribs increased in both groups, so did risk of mortality. Elderly patients and patients with more severe injuries were most likely to receive epidural catheters. Despite greater chest injury in the catheter group, mortality rates were lower (11% in epidural group, 25% in those not receiving epidurals). Other treatments included rib block, pleural block, PCA, IV/IM narcotics, oral narcotics, ketorolac, and Tylenol. Among patients who received epidural catheters, the duration of treatment was 6.3 days for elderly patients and 4.3 days for younger patients. Despite a lower mortality rate among patients receiving epidural analgesia, that treatment was associated with more pulmonary complications and longer stays in the ICU and hospital. A possible explanation for both of these outcomes is the increased injury severity of those receiving epidurals. Additionally, basic treatment logistics might explain some of the length of stay: once a catheter is applied, it is generally left in place for 4–5 days.

Compared to IV treatments

In 2004, Bulger and colleagues[11] compared epidural analgesia (bupivicaine, morphine, and fentanyl) to IV opioids (morphine, hydromorphone, and fentanyl) in patients with multiple fractured ribs. 22 patients received epidural analgesia (77% male, 49 ± 18 yr, 7.2 ± 3.2 fractured ribs, 38% had a flail segment, ISS = 26 ± 8) and 24 patients received IV opioids (76% male, 46 ± 16 yr, 6.8 ± 3.3 fractured ribs, 21% had a flail segment, ISS = 25 ± 8). Although the IV group experienced a higher risk of pneumonia and longer duration spent on mechanical ventilation, there were no

differences in length of hospital stay or mortality. Epidural catheter treatment lasted 4.4 days and complications occurred in 6 (27%) patients (mostly pruritus, which was experienced by 5 patients). The length of IV treatment is not reported, but 8 (33%) patients experienced complications (mostly vomiting and pruritus; 6 and 5 patients respectively). Degree of pain relief is not reported. Pain is only characterized at baseline (via ISS and AISS for head and chest). Pain relief is not reported relative to treatment arm. However, the authors do report that 3 epidural patients and 3 IV patients each failed to experience adequate pain relief and switched treatment groups. The unadjusted pneumonia rate in the epidural group was 18% while it was 38% in the IV group (p = .15). After adjusting for pulmonary injury, risk of pneumonia in IV patients increased 6-fold (OR, 6.0; 95% CI, 1.0-35; P = .05). Unadjusted, patients in the IV group spent 9.1 days on ventilation compared to epidural patients who spent 7.6 days. Unadjusted incident rate ratio: 1.19 (95% CI, 0.97-1.45; P = .09), indicating a 19% increase in ventilator duration for the IV opioid group. If data are stratified based on the presence of a pulmonary contusion, there is a 2-fold increase in ventilator days for the IV group (IRR, 2.0; 95% CI, 1.6-2.6; P < .001). No differences were found in length of hospital stay or mortality between the two groups. Although there was a trend for patients in the epidural group to have a higher rate of acute respiratory distress syndrome (p = .15), no significant differences.

In 2005, Kieninger and colleagues[96] compared epidural analgesia (methods not specified) to IV narcotics (methods not specified) in older patients (>55 yr) with fractured ribs. 53 patients were in the epidural group (34% male, 77.7 ± 10.2 yr, 58.5% had a cardiopulmonary comorbidity, ISS = 10.3 ± 3.6) and 134 patients were in the IV group

(40.3% male, 77.3 ± 10.5 yr, 16.4% had a cardio-pulmonary comorbidity, ISS = 8.3 ± 3.9). ISS was significantly different between groups ($p = .001$). AIS for chest was also significantly higher in the epidural group (2.86 vs. 2.16; $p < .0001$). Number of fractured ribs and the presence of flail segments were not noted. The authors found the length of hospital stay to be significantly longer for patients receiving epidurals (8.6 ± 4.6 days) compared to those receiving IV narcotics (5.6 ± 5.1 days) ($p = .007$). The rest of the findings focus on the incidence of cardiopulmonary complications (effusion, infiltrate, and/or pneumonia) and presence of comorbidities (history of myocardial infarction, arrhythmia, heart failure, chronic obstructive pulmonary disease, tobacco use). 122 total patients (65%) had cardio-pulmonary comorbidities. 31 (58%) of these patients were in the epidural group; 91 (68%) were in the IV group. The difference was not significant ($p=.226$). 96 patients developed a cardiopulmonary complication. This was more common in the epidural group, even when stratified by ISS and AISS. If patients had cardiopulmonary comorbidities, they fared worse with epidural treatment regardless of ISS and AIS. A total of 5 patients (2.6%) died. 3 of these patients (5.6%) were in the epidural group. 2 (1.5%) were in the IV group. The difference was not significant ($p = .324$).

In 1991, Mackersie and colleagues[36] compared epidural administration of fentanyl to an IV administration among patients with multiple fractured ribs. 15 patients were randomized to the epidural group (49.3 ± 19 yr, 4.2 ± 1.0 fractured ribs, ISS = 20 ± 7.6) and 17 patients were randomized to the IV group (47.8 ± 14 yr, 4.8 ± 1.7 fractured ribs, ISS = 16 ± 7.2). Gender and incidence of flail segments were not reported. Subjects receiving the epidural treatment experienced longer hospital stays (8.7 ± 4.2 days) than

subjects receiving IV treatment (7.1 ± 6.2 days). The duration of analgesia administration was longer in the epidural group (84 ± 37 hours) than in the IV group (82 ± 33 hours). The cost of epidural treatment ($21,000 ± $10,000) was more expensive than the cost of IV treatment ($15,000 ± $16,000). Subjects in the IV group used more total fentanyl (90 ± 34 μg/kg/hour) than subjects in the epidural group (78 ± 22 μg/kg/hour). These differences (volume of analgesia used, length of hospital stay, and the length and cost of treatment) did not reach significance. Both groups improved significantly in vital capacity. Only the epidural group improved significantly in maximum inspiratory pressure (17 ± 20 cm H_2O compared to 5.3 ± 19 cm H_2O in the IV group). There was no change in respiratory rate, tidal volume, or minute ventilation in either group. Arterial PaO_2 did not change in the epidural group (0.8 ± 19) but fell in the IV group (-19 ± 14). Arterial $PaCO_2$ did not change in the epidural group (1.8 ± 5.9) but was increased in the IV group (5.6 ± 4.2). The two groups were significantly different in arterial changes in PaO_2. Both groups experienced significant pain reductions at rest and during coughing and deep breathing. The epidural group experienced a trend (p=.08) toward greater pain reductions during coughing and deep breathing. Nausea scores trended upward in both groups (epidural: 7.5 ± 16, IV: 7.2 ± 34). Nausea/vomiting was present in 46% of epidural cases and 29% of IV cases. The IV group experienced no change in pruritus (visual analog scale; -1.1 ± 11), but the epidural group significantly increased (10.3 ± 19). There were no complications resulting from epidural placement. Neither group had any cases of pneumonia. No patient developed respiratory failure. No patient required bronchoscopy.

In 1999, Moon and colleagues[78] compared TEA (lidocaine) to IV opioids (morphine) among patients with multiple fractured ribs. There were 13 patients randomized to the epidural group (61.5% male, 37 yr, ISS = 26.6; SDs not reported) and 11 patients randomized to the IV group (54.5% male, 40 yr, ISS = 23.4; SDs not reported). Number of fractured ribs and percentages of patients with flail segments were not reported. During the first 24 hours, the epidural group experienced significantly better pain relief (while coughing; not at rest) than the systemic group. Differences vanished at day 2 and returned at day 3. Need for supplemental oxygen was not different between groups (data not reported). Neither was forced expiratory volume (data not reported). But maximal inspiratory force was: patients receiving the opioids systemically experienced a gradual decline (-15%) throughout the course of the study while the patients receiving TEA experienced a gradual improvement (+23%). By day 3, the difference between groups was significant. Similarly, tidal volume gradually declined in the systemic opioid group (reaching 56% of original value by day 3) and gradually increased in the thoracic epidural group (+45%) with the difference between groups reaching significance on the third day. Interleukins 1β and 2 as well as TNF-α didn't fluctuate throughout the course of the study.

In 1999, Wu and colleagues[7] compared TEA (bupivacaine and fentanyl) to IV analgesia (morphine) in patients with at least 3 fractured ribs. There were 25 patients in the epidural group (52% male, 56 ± 17 yr, 5.6 ± 2.1 fractured ribs, ISS = 21.6 ± 10.3) and 39 patients in the IV group (51% male, 45 ± 22 yr, 4.4 ± 1.5 fractured ribs, ISS = 21.9 ± 6.7). Presence of a flail segment was not reported. Patients in the epidural group were significantly older than those in the IV group ($p = .04$) and they had significantly more

fractured ribs ($p = .01$). Following treatment, there were no differences in length of stay in the hospital, length of stay in the ICU, or duration of analgesia administration. The closest finding to significance was duration in the ICU: 4.4 ± 4.1 days in the epidural group vs. 2.5 ± 3.5 days in the IV group ($p = .18$). There were also no differences between the groups in incidence of cardiac, pulmonary, or neurological complications. No differences in mortality. There were no side effects associated with epidural treatment. Patients in the epidural group did experience superior pain reduction at all time points (every 8 hours up to hour 80).

In 2012, Yeh and colleagues[8] compared TEA (bupivicaine and fentanyl) to IV and oral narcotics (no methods provided) in patients with at least 3 fractured ribs. There were 34 patients in the epidural group (73.9% male, 48.8 ± 18.4 yr, 5.0 ± 2.0 fractured ribs, ISS = 23.1 ± 9.3) and 153 in the non-epidural group (65.6% male, 69.6 ± 10.1 yr, 5.6 ± 2.3 fractured ribs, ISS = 21.5 ± 9.3). The presence of flail segments and/or pulmonary contusions were not reported. Age ($p < .001$) and gender ($p = .054$) were different. The patients who received epidurals had longer stays in the hospital (median of 7 vs. 5 days; $p < .001$) and ICU (median of 1 vs. 0 days; $p = .001$). However, they also had more severe injuries. They fractured more total ribs (7.1 vs. 5.0; $p < .001$), had a higher incidence of bilateral rib fractures (32.4% vs. 15.0%; $p = .026$), and showed a trend of having more common upper rib fractures (47.1% vs. 30.1%; $p = .070$) and required more chest tube placements (55.9% vs. 37.9%; $p = .082$). The only variable that significantly predicted complication (when adjusted for age, injury severity, etc.) was the requirement for chest tube placement (OR 2.791 [95% confidence interval 1.205–6.462], $p = .017$). Those with chest tubes placed had complications 29.7% of the time compared to 11.8% in those

without chest tubes (p = .029). Three variables predicted longer hospital stay: increasing age (coefficient 0.106 [95% confidence interval 0.040–0.172], p = 0.002), increasing injury severity (coefficient 0.236 [95% CI 0.097–0.076], p = 0.001), and requiring chest tube placement (coefficient 3.263 [95% CI 0.948–5.579], p = 0.006). Chest tube placement associated with a median of 6 days compared to 5.5 days (p = .037). No variables predicted longer stay in the ICU. Older patients (≥ 55, n=123) experience more complications than those who are <55 (n=64) (26.6% vs. 12.2%; p = .023) despite having lower rates of organ injury (7.8% vs. 25.2%; p = .003) and chest tube placement (29.7% vs. 47.2%; p = .028). There was a trend for older patients to stay longer in the hospital as well (p = .067). Yeh and colleagues concluded that TEA did not improve outcomes in pulmonary complications or length of stay in the ICU or hospital relative to IV and oral narcotics.

Compared to other regional techniques

In a 2009 pilot study by Mohta and colleagues[29], they compared TEA (bupivacaine) to thoracic paravertebral infusion (bupivacaine) in patients with at least 3 fractured ribs. They randomized 15 patients to the epidural group (80% male, 38.9 ± 14.9 yr, 4.9 ± 1.8 fractured ribs, 7% had a flail segment, ISS = 15.9 ± 7.1) and 15 patients to the paravertebral group (80% male, 40.4 ± 14.8 yr, 4.9 ± 1.4 fractured ribs, 27% had a flail segment, ISS = 13.6 ± 5.6). There was no difference in the duration of bupivacaine infusion between groups (thoracic epidural group = 129.1 hours, thoracic paravertebral group = 120.5 hours, p = .525) or the duration of hospital or ICU stays (10.1 and 6.3 days for thoracic epidural group; 11.7 and 6.8 days for thoracic paravertebral group). Both

groups experienced a significant reduction in pain (measured by visual analog scale) during rest and during coughing at every time point following administration of treatment but no intergroup differences were found (rest: p = .426; coughing: p = .721). Respiratory rate and peak expiratory flow rate significantly improved in both groups at all time points but no differences were found between groups (respiratory rate p = .092; peak expiratory flow rate p = .515). The ratio of arterial oxygen to inspired oxygen concentration showed little change but there was a difference between the two groups at 72 hours, with the thoracic epidural group having a better ratio (p = .018). There was no patient mortality. Pneumonia was developed by 1 patient in the thoracic epidural group and 2 patients in the thoracic paravertebral group. Fever was developed by 2 patients in the thoracic epidural group and 3 patients in the thoracic paravertebral group. Overall, pulmonary complications were not different between groups, but incidence of hypotension was higher with the thoracic epidural group (40%) than the paravertebral group (7%). A patient in the thoracic paravertebral group developed convulsions 68 hours after commencement of treatment (attributed to local anesthetic toxicity).

In 1994, Shinohara and colleagues[93] compared thoracic epidural block (lidocaine) and intrapleural block (lidocaine) in patients with multiple unilateral fractured ribs and hemopneumothorax. All subjects received a chest drain for hemopneumothorax (average duration: 5 ± 1.7 days). Both intrapleural and thoracic blocks were installed in all patients. On the first day, when a patient complained of pain, that patient received treatment through one of the two blocks (randomly chosen). On the second day, when a patient complained of pain, the other block was used. The intervention group is considered to be those who received intraleural block prior to thoracic block and the

comparison group consisted of those who received thoracic block prior to intrapleural block. There were 8 patients randomized to the thoracic epidural block group and 9 patients randomized to the intrapleural block group. Patient characteristics were only presented among the total sample (88.2% male, 50.3 ± 16.0 yr, 5.7 ± 1.4 fractured ribs). ISS and presence of flail segments were not reported. There were no significant differences in pain relief. 4 patients showed no hypesthesia with intrapleural block; 2 patients showed no hypesthesia with thoracic epidural block. Blood pressure fell significantly with thoracic epidural block, but not with intrapleural block (data presented in unclear graphs). Heart rate fell significantly 10 minutes after intrapleural block and 5 to 30 minutes after thoracic epidural block (data presented in unclear graphs). Respiratory rate fell significantly in both treatments (intrapleural: 20.6 to 17.7, thoracic epidural: 20.7 to 16.9) but the difference between treatments was not significant. Blood gas values changed significantly in both groups but the difference between groups was not significant (PaO_2 in thoracic epidural: 89.2 to 102.7, PaO_2 in intrapleural group: 94.2 to 103.9; $PaCO_2$ in thoracic epidural: 43.4 to 38.9, $PaCO_2$ in intrapleural group: 43.9 to 39.9). No subject required additional analgesia during treatment. There was no mortality, no toxic reactions from lidocaine administration (e.g., no cardiovascular toxicity, etc.), and no pneumonia. No other side effects were seen in either group.

Risks of TEA

Treating with epidural analgesia is not without risks. It's more technically complex than the administration of IV analgesia, which puts the patient at a higher risk of complications.[38] Although infrequent, these include inadvertent dural puncture[101,102] and

spinal cord injury (when done in the thoracic region)[38,47], epidural infection[30,56], hypotension[30,47], hematoma (following puncture of epidural vessels during catheter placement)[68], abscesses in the epidural space[109,110], nausea, vomiting[36,37], respiratory depression[56], pruritis and urinary retention in the presence of an opioid[38], and motor block compromising mobilization.[47]

In 2011, Kim and colleagues[97] reported on the complications that arose in 35 patients (65.7% male, 51.4 ± 12.8 yr, 1,7 ± .7 fractured ribs) who underwent surgical reduction and fixation of fractured ribs, and were treated with thoracic epidural anesthesia and analgesia. 83% of patients were undergoing their first surgery (fixing malunions of fractured ribs). The remaining 17% underwent a second surgery (owing to incompletely fixed ribs during prior surgery under general anesthetic). ISS and the presence of flail segments were not noted. General anesthesia was administered to 1 patient (out of 36). There were no adverse events (e.g., hypotension, arrhythmia, or respiratory failure by cardiopulmonary dysfunction). 3 patients experienced postoperative complications (a wound infection that was treated and 2 cases of extrapleural hematoma that resolved without treatment). No patient died. All patients resumed eating upon waking up and ambulation without limitation the day after surgery.

Individual outcomes associated with TEA

Mortality

4 studies found epidural analgesia to associate with a lower mortality rate compared to an alternative treatment: Bulger et al., 2000 (compared to all other non-

epidural patients)[6], Dittmann et al., 1982 (compared to mechanical ventilation; 24.5% of ventilated patients died compared to 4.5% of patients receiving epidurals; this is never described as different and no p-value is provided)[65], Flagel et al., 2005 (compared to all other treatments)[10], and Wisner, 1990 (compared to IV/IM narcotics).[82]

No study found epidural analgesia to associate with a higher mortality rate compared to an alternative treatment.

8 studies found no difference in mortality rate when using epidural analgesia compared to an alternative treatment: Bulger et al., 2004 (compared to patient-controlled IV morphine, hydromorphone, and fentanyl)[11], Dittmann et al., 1975 (compared to mechanical ventilation; 13.7% of ventilated patients died compared to 6.1% of patients receiving epidurals; this is never described as different and no p-value is provided)[85], Gibbons et al., 1973 (compared to intercostal nerve block or parenteral narcotics; 2 patients died, both in the comparison group; no p-value or other statistics are provided)[66], Kieninger et al., 2005 (compared to IV narcotics; patients in the epidural group had more severe injuries)[96], Mohta et al., 2009 (compared to thoracic paravertebral bupivacaine; no patient in either group died)[29], Shinohara et al., 1994 (compared to intrapleural lidocaine; no patient in either group died)[93], Waqar et al., 2013 (compared to IV opioids)[9], and Wu et al., 1999 (compared to patient-controlled IV morphine; no patient in either group died).[7]

Pain management

7 studies found epidural analgesia to associate with better pain management compared to an alternative treatment: Hashemzadeh et al., 2011 (compared to intercostal block with marcaine; the data are significant, but unclear)[61], Luchette et al., 1994 (compared to intrapleural bupivacaine)[83], Moon et al., 1999 (compared to patient-controlled IV morphine; only significant on days 1 and 3)[78], Pierre et al., 2005 (compared to patient-controlled IV morphine; actual data aren't provided)[94], Waqar et al., 2013 (compared to IV opioids; actual data aren't provided)[9], Wisner, 1990 (compared to IV/IM narcotics; based on number of patients who had to switch treatments)[82], and Wu et al., 1999 (compared to patient-controlled IV morphine).[7]

No study found epidural analgesia to be inferior at reducing pain compared to an alternative treatment.

3 studies found no difference in pain management when using epidural analgesia compared to an alternative treatment: Mackersie et al., 1991 (compared to IV administration of fentanyl; both groups experienced significant pain reductions; the epidural group experienced a trend, $p = .08$, toward greater reduction)[36], Mohta et al., 2009 (compared to thoracic paravertebral bupivacaine)[29], and Shinohara et al., 1994 (compared to intrapleural lidocaine).[93]

Duration of stay in the ICU

6 studies found epidural analgesia to associate with shorter stays in the ICU compared to an alternative treatment: Dittmann et al., 1978 (compared to mechanical ventilation)[84]; Dittmann et al., 1982 (compared to mechanical ventilation)[65];

Hashemzadeh et al., 2011 (compared to intercostal block with marcaine)[61]; Pierre et al., 2005 (compared to patient-controlled IV morphine)[94]; Ullman et al., 1989 (compared to IV morphine)[89]; Waqar et al., 2013 (compared to IV opioids).[9]

2 studies found epidural analgesia to associate with longer stays in the ICU compared to an alternative treatment: Bulger et al., 2000 (compared to all other non-epidural patients; patients in the epidural group were older and had more severe injuries)[6] and Yeh et al., 2012 (compared to patient-controlled oral and IV narcotics; patients in the epidural group had more severe injuries).[8]

4 studies found no difference in ICU duration when using epidural analgesia compared to an alternative treatment: Bulger et al., 2004 (compared to patient-controlled IV morphine, hydromorphone, and fentanyl; epidural patients had more chest tubes placed, p = .03, and were 1.8 times more likely to have a flail segment, though not significant; p = .20)[11], Mohta et al., 2009 (compared to thoracic paravertebral bupivacaine)[29], Moon et al., 1999 (compared to patient-controlled IV morphine; epidural analgesia associated with 1.9 days longer stay, but it didn't reach significance)[78], and Wu et al., 1999 (compared to patient-controlled IV morphine; epidural analgesia associated with 1.9 days longer stay, but it didn't reach significance).[7]

Duration of stay in the hospital

4 studies found epidural analgesia to associate with shorter stays in the hospital compared to an alternative treatment: Dittmann et al., 1982 (compared to mechanical ventilation)[65], Pierre et al., 2005 (compared to patient-controlled IV morphine)[94], Ullman

et al., 1989 (compared to IV morphine)[89], and Waqar et al., 2013 (compared to IV opioids).[9]

3 studies found epidural analgesia to associate with longer stays in the hospital compared to an alternative treatment: Bulger et al., 2000 (compared to all other non-epidural patients; patients in the epidural group were older and had more severe injuries)[6], Kieninger et al., 2005 (compared to IV narcotics; patients in the epidural group had more severe injuries)[96], Yeh et al., 2012 (compared to patient-controlled oral and IV narcotics; patients in the epidural group had more severe injuries).[8]

5 studies found no difference in hospital duration when using epidural analgesia compared to an alternative treatment: Bulger et al., 2004 (compared to patient-controlled IV morphine, hydromorphone, and fentanyl; epidural patients had more chest tubes placed, p = .03, and were 1.8 times more likely to have a flail segment, though not significant; p = .20)[11], Mackersie et al., 1991 (compared to IV administration of fentanyl)[36], Mohta et al., 2009 (compared to thoracic paravertebral bupivacaine)[29], Moon et al., 1999 (compared to patient-controlled IV morphine)[78], and Wu et al., 1999 (compared to patient-controlled IV morphine).[7]

Incidence of pneumonia

2 studies found epidural analgesia to associate with a lower incidence of pneumonia compared to an alternative treatment: Bulger et al., 2004 (compared to patient-controlled IV morphine, hydromorphone, and fentanyl)[11] and Wisner, 1990 (compared to IV/IM narcotics; 8% vs. 19%, but no p-value was reported).[82]

1 study found epidural analgesia to associate with a higher incidence of pneumonia compare to alternative treatments: Bulger et al., 2000 (compared to all other non-epidural patients; patients in the epidural group were older and had more severe injuries).[6]

6 studies found no difference in the incidence of pneumonia when using epidural analgesia compared to an alternative treatment: Flagel et al., 2005 (compared to all other treatments)[10], Mackersie et al., 1991 (compared to IV administration of fentanyl; neither group experienced any cases of pneumonia)[36], Mohta et al., 2009 (compared to thoracic paravertebral bupivacaine)[29], Shinohara et al., 1994 (compared to intraleural lidocaine; neither group experienced any cases of pneumonia)[93], Waqar et al., 2013 (compared to IV opioids; patients taking IV opioids had twice the incidence of pneumonia – 26% compared to 13% – but it wasn't significant; p = .87)[9], and Wu et al., 1999 (compared to patient-controlled IV morphine).[7]

Cardiopulmonary outcomes

6 studies have reported mixed findings when comparing the effects of epidural analgesia to an alternative treatment on cardiopulmonary outcomes: Hashemzadeh et al., 2011 (compared to intercostal block with marcaine; epidural subjects improved more in arterial oxygen tension; intercostal block patients improved more in minute volume, tidal volume, and vital capacity; no differences were found in respiratory rate, heart rate, oxygen saturation, or mean arterial pressure)[61], Luchette et al., 1994 (compared to intrapleural bupivacaine; patients receiving epidural analgesia improved more in tidal

volume and negative inspiratory force on day 3 of treatment; no differences were found in vital capacity, minute ventilation, or respiratory rate)[83], Mackersie et al., 1991 (compared to IV administration of fentanyl; patients receiving epidural analgesia improved more in maximum inspiratory pressure, arterial oxygen tension, and carbon dioxide tension; no differences were found in vital capacity, respiratory rate, tidal volume, or minute ventilation)[36], Moon et al., 1999 (compared to patient-controlled IV morphine; patients receiving epidural analgesia exhibited better outcomes in maximal inspiratory force and tidal volume; no differences were found in forced expiratory volume)[78], Shinohara et al., 1994 (compared to intrapleural lidocaine; blood pressure was adversely affected by epidural analgesia but not intrapleural block; no differences were found in respiratory rate or arterial oxygen tension)[93], and Ullman et al., 1989 (compared to IV morphine; patients receiving epidural analgesia exhibited better outcomes in tidal volume; no differences were found in vital capacity).[89]

DISCUSSION

Discrepancies in findings

The treatment for rib fracture pain has not been standardized; not just mode (e.g., oral, IV, epidural, etc.), but location (e.g., lumbar vs. thoracic epidural).[7] This might be a consequence of discrepant findings in the literature, in which some studies do not find enhanced outcomes with TEA use. One explanation for the reduced success in many of the studies comparing TEA to other treatments is that the data often come from retrospective reviews in which patients were not randomly assigned treatments.

There are 10 studies that randomize patients to a treatment group: Abouhatem et al., 1984[25]; Allen et al., 2009[98]; Bulger et al., 2004[11]; Hakim et al., 2012[28]; Hashemzadeh et al., 2011[61]; Luchette et al., 1994[83]; Mackersie et al., 1991[36]; Mohta et al., 2009[29]; Moon et al., 1999[78]; Shinohara et al., 1994.[93]

There are 18 non-randomized, retrospective trials: Balci et al., 2004[91]; Bulger et al., 2000[6]; Dittmann et al., 1975[85]; Dittmann et al., 1978[84]; Dittmann et al., 1982[65]; Doss et al., 1999[41]; Flagel et al., 2005[10]; Gibbons et al., 1973[66]; Govindarajan et al., 2002[39]; Johnston et al., 1980[99]; Kieninger et al., 2005[96]; Kim et al., 2011[97]; Ullman et al., 1989[89]; Waqar et al., 2013[9]; Wisner, 1990[82]; Worthley, 1985[30]; Wu et al., 1999[7]; Yeh et al., 2012.[8]

Pierre et al.'s 2005 poster presentation[94] never mentions whether the study was prospective or retrospective or assignment based on patient-specific criteria. Studies not in the English language have been omitted from these lists.

When treatment is not randomly assigned, the criteria for assignment is often based on injury severity (and sometimes age), with the more severe cases and older patients more commonly receiving epidural catheters.[6,7] For example, Flagel et al.[10] found use of epidural analgesia to increase by 50% among patients who fracture 6 or more ribs (compared to patients who fracture 5 or fewer). Despite this, in Flagel et al.'s sample, the ISS of patients treated with epidural catheters was slightly lower (18.71 ± 0.26) than that of patients who were not treated with epidurals (21.10 ± 0.06). In the 2012 study by Yeh et al.[8], the 34 patients who received TEA (73.9% male, 48.8 ± 18.4 yr, ISS = 23.1 ± 9.3) were older ($p < .001$) and had more severe injuries than those assigned

alternative treatments (65.6% male, 69.6 ± 10.1 yr, ISS = 21.5 ± 9.3). They fractured more total ribs (7.1 vs. 5.0; $p < .001$), had a higher incidence of bilateral rib fractures (32.4% vs. 15.0%; $p = .026$), and showed a trend of having more common upper rib fractures (47.1% vs. 30.1%; $p = .070$) and requiring more chest tube placements (55.9% vs. 37.9%; p=.082). Thus, when those with TEA require longer stays in the hospital (median of 7 vs. 5 days; $p < .001$) and ICU (median of 1 vs. 0 days; $p = .001$), it seems likely to be related more to injury severity than mode of treatment. Likewise, in the study by Waqar and colleagues (2013), patients who received TEA (75% male, 54 ± 17 yr, 6.4 ± 2.1 fractured ribs, 19% having a flail segment, ISS = 23.6 ± 10.3) were significantly older and had significantly more fractured ribs than patients in the IV group (76% male, 45 ± 22 yr, 5.2 ± 2.5 fractured ribs, 13% having a flail segment, ISS = 21.0 ± 6.7). It was despite this severity that patients receiving thoracic epidurals had significantly shorter periods of time on analgesia (4.25 ± 1.2 days compared to 5.5 ± 3.2 days), and significantly shorter stays in the hospital (19 ± 3.1 days compared to 21 ± 4.1 days), and the ICU (12 ± 2.4 days compared to 14 ± 3.5 days). Similarly, in the 1999 study by Wu and colleagues[7], patients assigned thoracic epidural treatment (52% male, 56 ± 17 yr, 5.6 ± 2.1 fractured ribs) were significantly older and had significantly more fractured ribs than the patients who were assigned IV treatment (51% male, 45 ± 22 yr, 4.4 ± 1.5 fractured ribs).

Additionally, the methods of catheterization are not always described, so one cannot know how differences in administration technique might impact outcomes.

There are 11 studies that describe the methods of catheterization thoroughly: Abouhatem et al., 1984[25]; Dittmann et al., 1975[85]; Govindarajan et al., 2002[39]; Hakim et al., 2012[28]; Luchette et al., 1994[83]; Mohta et al., 2009[29]; Moon et al., 1999[78]; Shinohara et al., 1994[93]; Ullman et al., 1989[89]; Worthley, 1985[30]; Wu et al., 1999.[7]

There are 16 studies in which the methods of catheterization are either absent or incompletely described: Allen et al., 2009[98]; Bulger et al., 2000[6]; Bulger et al., 2004[11]; Dittmann et al., 1982[65]; Doss et al., 1999[41]; Flagel et al., 2005[10]; Gibbons et al., 1973[66]; Hashemzadeh et al., 2011[61]; Johnston et al., 1980[99]; Kieninger et al., 2005[96]; Kim et al., 2011[97]; Mackersie et al., 1991[36]; Pierre et al., 2005[94]; Waqar et al., 2013[9]; Wisner et al., 1990[82]; Yeh et al., 2012.[8]

Dittmann et al.'s 1978 study[84] provides minimal detail concerning methods, but cite their 1975 paper[85] (of which the present study is merely an expansion of that study's dataset) for further methodological instruction. However, in the brief details they do provide (namely bupivacaine concentration), the methods between the two papers are incongruent. Balci et al.[91] do not discuss catheterization methods, but they only discuss methods of analgesia briefly as a tertiary outcome. Studies not in the English language have been omitted from these lists.

Lastly, confounding variables such as age are often, but not always accounted for (the effect of age is illustrated under the mortality heading on page 6). Among the studies evaluating TEA outcomes in English, 2 failed to report age[41,66] and other researchers, such as Hashemzadeh and colleagues[61], claim age to be insignificant despite large-scale differences (Hashemzadeh et al.'s groups had differences of 20 years; $p = .19$).

Summary of evidence

To date, 16 studies have shown TEA to be effective at improving treatment outcomes in patients with rib fractures; 8 of these involved a comparison group. Opposing these findings, 10 studies have reported either poorer outcomes or comparable outcomes associated with TEA use; 2 of these were not designed to evaluate the efficacy of TEA. Thus, out of all studies with methods sufficient to answer this question, 8 have supported the use of TEA against alternative treatments and 8 have failed to show a benefit of TEA.

Owing to the complexity of administration, TEA may put the patient at a slightly elevated risk of treatment-associated complications such as dural puncture, epidural infection, abscesses in the epidural space, and hematoma. Nausea, vomiting, and hypotension have also been seen.

Limitations

Much of the available literature either evaluates the NTDB or quantifies groups of patients from individual hospitals. Little of this work controls for influential variables such as injury severity; less of it randomizes the treatment options. In general, greater injury severity associates with more likely use of TEA. Groups are analyzed accordingly and described incompletely.

Conclusions

Based on limited evidence, TEA may associate with benefits in mortality rate among patients with multiple fractured ribs. As a first step, more hospitals should quantify their data registries, controlling for injury severity (particularly number of fractured ribs, presence of flail segment, and injury severity score), and evaluate the effectiveness and safety of TEA among patients with rib fractures.

Disclaimers

This study is associated with no source of funding. It is a collaboration between the University of Connecticut, Sum Integral in Chicago, and St. Vincent Hospital in Indianapolis.

Chapter 3: The efficacy of thoracic epidural analgesia in the treatment of rib fractures

ABSTRACT

300,000 patients with rib fractures are admitted to U.S. trauma centers each year. The mortality rate among these patients may be as high as 10%, but risk varies depending on the age of the patient and severity of the injury. Pain management is crucial to successful treatment outcomes. Thoracic epidural analgesia (TEA) is one type of pain management. The purpose of this investigation was to assess the impact of TEA on treatment outcomes among rib fracture patients, and determine whether more frequent use may be indicated. **Methods:** We retrospectively analyzed the registry of an ACS-verified Level II trauma center. All patients admitted with ≥ 1 rib fracture (n=1,008) were evaluated; 195 of them received TEA. The primary outcome was mortality. Secondary outcomes were incidence of complications, the use of mechanical ventilation, and the length of stay (LOS) in the hospital and intensive care unit (ICU). Additional data include patient demographics and the mechanism and severity of injuries. **Results:** The overall mortality rate was 6.1%; the incidence of pneumonia was 12.2%; mechanical ventilation was required in 23.3% of patients for an average duration of 9.1 days; the average LOS in the hospital was 7.5 nights; 51.2% of patients were admitted to the ICU with an average LOS of 6.7 nights. TEA was administered to 19.3% of all patients (~10 times the national average). The patients who received TEA had more severe injuries: 2.3 more fractured ribs ($p<0.001$), 4.7 times the incidence of flail segments ($p<0.001$), 1.6 times the incidence of

pneumothoraces ($p<0.001$), 1.4 times the incidence of pulmonary contusions ($p=0.016$), and 1.4 times the incidence of bilateral fractures ($p=0.042$). Despite the differences in injury severity, patients who did not receive TEA were 7 times more likely to die ($p<0.001$). After eliminating patients who were not candidates for TEA, the use of TEA continued to improve mortality outcomes. **Conclusion:** TEA appears to reduce the risk of mortality in patients with rib fractures but it remains uncommonly used in most hospital settings. Better care of this population might be facilitated by the implementation of a dedicated anesthesia/pain service that permits greater reliance on TEA.

INTRODUCTION

Rib fractures are the most common injury in blunt thoracic trauma.[1,2,49] Rib fractures are reported to be present in 7% to 10% of all patients admitted to U.S. trauma centers[2,10,113] but the true incidence might be even higher as some fractures likely go undetected at admission.[5,49] In total, it is estimated that nearly 300,000 patients with rib fractures are admitted to U.S. hospitals each year.[4] The most common cause of this injury is motor vehicle collisions while falls account for about 25% of the incidence.[6,26,27,57]

Depending on the age of the patient and the severity of the injury, there is a high risk of morbidity and mortality. Among people who fracture 3 or more ribs, these risks increase as a consequence of pain-induced changes in breathing mechanics.[11,35,36,38-40] Painful breathing can impair a patient’s ability to clear airway secretions by coughing, resulting in the retention of sputum.[11,37-39] In turn, this elevates the risk of atelectasis, pneumonia, and ultimately respiratory failure and the need for ventilatory support.[38,41] In

many cases, the pain a patient experiences following an injury is more harmful than the injury itself.[10,19,37] Thus, effective pain management is vital to the success of the treatment.[41,46,47]

There are numerous modes of pain control. Patients who present with 1 or 2 fractured ribs are usually treated with oral analgesic drugs (NSAIDs, acetaminophen, or hydrocodone)[47] and have a low risk of complications and mortality.[1,10] If pain relief is inadequate, other systemic modes of pain control may be administered, such as intravenous (IV) morphine or dilaudid.[47] In the presence of 3 or more fractured ribs, however, systemic drugs might not be sufficient. As the number of fractures increases, so does the likelihood that regional modes of analgesia will become the primary treatment.[10,47] Regional analgesia comes in a variety of forms, including intercostal nerve block, intrapleural nerve block, thoracic paravertebral block, and thoracic epidural analgesia (TEA).[37,47]

The purposes of this study were 1) to describe the characteristics of patients admitted to a Level II trauma center with one or more fractured ribs, 2) to investigate the effectiveness of TEA in reducing mortality, incidence of pulmonary complications, use of mechanical ventilation, and duration of stay in the hospital and ICU, and 3) to examine the relationships between patient age, the number of fractured ribs, the presence of bilateral fractures, injury severity score (ISS), the incidence of associated injuries (flail segment, pulmonary contusion, pneumothorax, and hemothorax), and mortality to provide perspective on the complexities of managing patients with fractured ribs.

Setting, Care Structure, and Review of Literature

St. Vincent Trauma Center

Ascension Health is a non-profit network of Catholic health facilities operating in the United States. In addition to being the largest Catholic health system in the U.S., it is also the largest non-profit health system. With more than 70 hospitals in 23 states and an annual operating revenue exceeding $17 billion, it is more than twice the size of its runner up.[157-159] St. Vincent Health is one of many members of Ascension Health, and currently operates 22 hospitals and health facilities in the state of Indiana.[160] The flagship hospital of this group is St. Vincent Hospital in Indianapolis.

Although St. Vincent Hospital was founded in 1881 (then known as the St. Vincent Infirmary), the trauma center was not complete until November 2010. Since then, it has been open 24 hours/day, every day of the year, with 16 beds and StatFlight and StatGround transportation support. It is currently a Level II trauma center, certified by the American College of Surgeons (ACS), treating patients in an urban-suburban setting.

History of rib fracture care at St Vincent's – The patients

The first patient admitted to the St. Vincent Trauma Center (on November 5, 2010) was a 44-year-old male who sustained 7 unilateral rib fractures with a flail segment in a fall. He had an injury severity score (ISS) of 17 and presented with a pulmonary contusion and pneumothorax. He received TEA, spent 4 nights in the intensive care unit

(ICU), and 7 in the hospital. He was never intubated and experienced no pulmonary complications.

Since the successful discharge of that patient, St. Vincent Trauma Center has treated about 250 patients with rib fractures each year; a total of 1,008 since opening. The range of injury severity in these patients is broad. While many arrive with a single rib fractured, one patient, a 27-year-old male, fractured all 24 ribs in an automotive accident. He died before treatment could be administered.

The administration of TEA at St. Vincent Trauma Center

A unique feature of St. Vincent's treatment model is Anesthesia Pain Service (APS). APS is a care team that includes dedicated anesthesiologists and nurses who are trained in pain management. Although the anesthesiologists are only available to place epidurals during the daytime hours, once installed, the nurses provide 24/7 patient coverage, monitoring pain levels and adjusting medication doses as necessary. If complications arise during the nighttime hours, the anesthesiologists are available for consultation by telephone.

Although this model increases the likelihood of TEA administration, not all patients are candidates. The decision to request an APS consultation is complex. Characteristics that increase the likelihood are: a greater number of rib fractures, the presence of flail chest, bilateral fractures, and a subjective pain level that interferes with respiratory excursions and the patients' ability to cough and clear secretions.

Among patients with less severe injuries, the initial treatment is typically IV narcotics or a combination of IV and oral narcotics. If that does not provide sufficient relief, an APS consultation will be requested. The time of day that a patient is admitted will also affect epidural placement, as APS is only in house during the day (and on the weekends, they may only be available in the mornings). Thus, if a patient is admitted in the morning, and is likely to benefit from an epidural, then TEA may be the first line of treatment. If the same patient were to be admitted in the evening, an alternative pain medication is often attempted first and pain levels are reevaluated the following morning. At that time, if pain control is inadequate, an APS consultation will be scheduled.

Mortality and morbidity associated with rib fracture

The mortality rate among patients with rib fractures is approximately 10%[2,3,5,10] although some smaller studies have reported more favorable odds of survival. In 2003, a Turkish hospital published a 2-year mortality rate of 5.7%.[58] However, 31% of the patients in this sample were children and adolescents, age 5–17, and none of them died. Conversely, the mortality rate among adults was 8.2%. More recently, a "multidisciplinary clinical pathway" has been used as a highly aggressive approach to reduce mortality. Among patients age 45 years or older who sustain 4 or more fractured ribs, the default treatment involves physical therapy, respiratory therapy, nutrition services, and multiple modes of pain management (oral, IV, and TEA). In one study, this combination of treatments reduced mortality from 13% to 4%.[59] This approach is both extensive and expensive. While it might be worth the cost, follow-up studies have yet to validate efficacy or assess the individual contribution of each therapeutic component.

Pulmonary complications (e.g., pneumonia, aspiration pneumonia, empyema, pulmonary embolism, pneumothorax, and respiratory distress syndrome) can be expected to arise in nearly half of all patients who fracture at least 1 rib.[10] With each additional rib fractured, these risks increase.[6,10] Pneumonia is a commonly reported complication but incidence varies broadly depending on the patients' age and injury characteristics.[10,46] Bulger et al.[6] found pneumonia in 17% of younger patients and 31% of elderly patients.

Previous reports suggest about 60% of rib fracture patients require mechanical ventilation for a mean duration of 13 days; the severity of injury predicts both need for ventilation and the duration of use.[10] On average, rib fracture patients spend 7 to 16 nights in the hospital and about 44% are admitted to the ICU, where they remain for 4 to 8 nights; a greater number of fractures corresponds to a longer length of stay (LOS).[2,5,10]

Research on the effectiveness of TEA

I found 16 studies reporting epidural analgesia to be effective at treating patients with rib fractures.[9,10,25,30,39,41,61,65,66,82-85,89,94,99] Five studies did not include a comparison group[25,30,39,41,99], 3 compared epidural analgesia to mechanical ventilation[65,84,85], 4 compared epidural analgesia to IV treatments[9,82,89,94], and the remaining 4 compared epidural analgesia to other regional techniques.[10,61,66,83]

Conversely, 10 studies did not find epidural analgesia to be a superior treatment for patients with rib fractures. [6-8,11,29,36,78,91,93,96] Two of these were not designed to

evaluate the efficacy of epidural analgesia[6,91], 6 compared epidural analgesia to IV treatments[7,8,11,36,78,96], and 2 compared epidural analgesia to other regional techniques.[29,93]

Among all 26 studies, 4 reported that epidural analgesia reduced mortality compared to an alternative treatment[6,10,65,82], no study found epidural analgesia to increase the risk of mortality, and 8 studies reported no difference between epidural analgesia and an alternative treatment.[7,9,11,29,66,85,93,96] The incidence of pneumonia was reported to be lower in patients treated with epidural analgesia in 2 studies[11,82] and higher in 1.[6] Six studies reported no difference in rates of pneumonia between patients receiving epidural analgesia and those receiving an alternative treatment.[7,9,10,29,36,93] Six studies reported that epidural analgesia shortened the duration of care in an ICU when compared to an alternative treatment[9,61,65,84,89,94], 2 reported longer stays for patients receiving epidural analgesia[6,8], and 4 studies reported no differences.[7,11,29,78] Four studies found epidural analgesia to shorten the length of hospitalization compared to an alternative treatment[9,65,89,94], 3 studies found longer stays for patients receiving epidural analgesia[6,8,96], and 5 studies found no differences.[7,11,29,36,78]

METHODS

The current study is a retrospective analysis of a trauma registry from an ACS-verified Level II trauma center. It was approved by the hospital's institutional review board (IRB) and by the IRB of a collaborating university.

We examined all patients who were admitted with 1 or more rib fractures,

comparing the treatment outcomes of those who received TEA with those who did not receive TEA.

Data acquisition and management

All data were exported from the hospital's trauma registry. The documented ICD9 codes were compared with written descriptions of each patient's injuries to determine which patients sustained rib fractures, how many ribs were fractured, whether the injuries were unilateral or bilateral, and the presence of associated injuries such as flail segments and pulmonary contusions. These data were compiled with demographic records, vital signs and cardiorespiratory markers, methods of treatment, and treatment outcomes into a single database. Where data only existed in written reports (e.g., mechanism of injury, which medications were used), entries were assigned nominal values. Where the timing of treatment was important (e.g., anticoagulation, intubation), data were extracted by comparing time stamps on the procedure codes.

Outcomes

The primary outcome was patient mortality. Secondary outcomes were incidence of pulmonary complications, the use of mechanical ventilation, and the duration of stay in the hospital and ICU. Additional data reported include patient demographics and the mechanism and severity of injuries sustained.

Data are reported across the whole sample and across matched samples.

Matching samples

Decision tree for TEA administration

Patient is admitted to trauma center
Presents with at least 2 fractured ribs
Rib fractures are bilateral
Presence of flail chest
No contraindications to epidural (e.g., anticoagulated or already intubated)
Clinical assessment: pain level, interference with respiratory excursion, ability to cough/clear secretions
Possible failure of other methods of pain control
Patient agrees to epidural catheter use
APS consultation
APS agrees placement is indicated and would be beneficial
Epidural catheter is placed

To assess effectiveness, we eliminated patients who were not candidates for TEA. In doing so, we attempted to compare outcomes of patients who received TEA to those who could have been treated with TEA but were not.

We combed the patient records to identify 3 groups: 1) patients who received TEA, 2) patients who were not candidates for TEA, and 3) patients who were candidates for TEA but received alternative treatments. We then compared groups 1 and 3.

Criteria for TEA administration

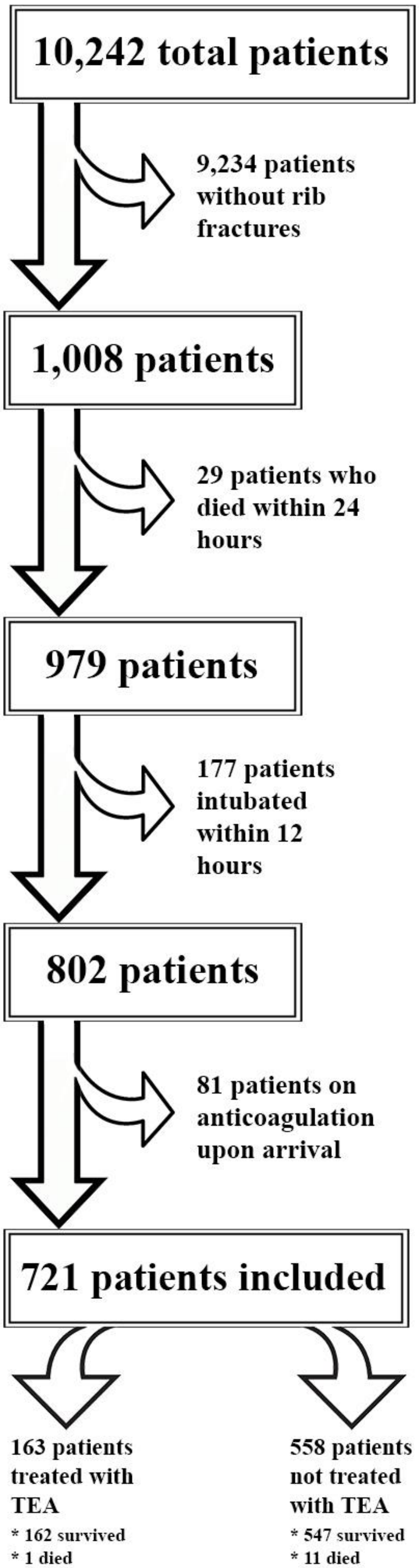
Contraindications for the use of TEA include anticoagulation prior to treatment and intubation upon arrival.

Anticoagulation medications such as Coumadin and Plavix increase the risk of atrial fibrillation and the likelihood of bleeding into the epidural space, thus elevating the patients' risk of spinal cord compression and paralysis. However, delivery of anticoagulation commonly follows TEA to reduce the risk of clotting, elevated by long hours spent lying in bed.

Early intubation and ventilatory support are often administered in more severely injured patients, but those patients are not usually treated with TEA. Instead, their pain can be managed with high doses of narcotics. However, some patients who are intubated for a short time do receive epidurals immediately after extubation to optimize pain control and their ability to cough and breathe deeply.

Finally, some patients succumbed to their injuries before treatment with TEA could be considered. To better match the characteristics of patients who received TEA with those who did not, these patients were also excluded from comparison.

To summarize, when matching important characteristics of the patients treated with TEA to those who were candidates for TEA but treated with other forms of pain management, we eliminated the patient record if: 1) the patient died within 24 hours of arrival, 2) the patient was intubated upon arrival or within 12 hours of admission, or 3) the patient was on anticoagulation medication prior to treatment.



During the 4-year study period, a total of 10,242 patients were admitted to St. Vincent Trauma Center; 1,008 of these patients had rib fractures. After eliminating patients who met exclusionary criteria for the use of TEA, 721 patients with rib fractures remained in the database.

Data analyses

Dichotomous data (e.g., mortality, presence of complications, use of mechanical ventilation) were analyzed with binary logistic regression. Discrete data (e.g., number of days in the ICU and hospital, days on mechanical ventilation, ISS) were analyzed with linear regression. Group means (TEA vs. non-TEA and survival vs. mortality) were compared with independent samples t-tests; wherever Levene's test for equality of variances was significant, equal variances were not assumed. Categorical variables were compared with chi-square tests. All analyses were first conducted on the total samples. Patients who met the exclusionary

criteria were then eliminated and all analyses were repeated.

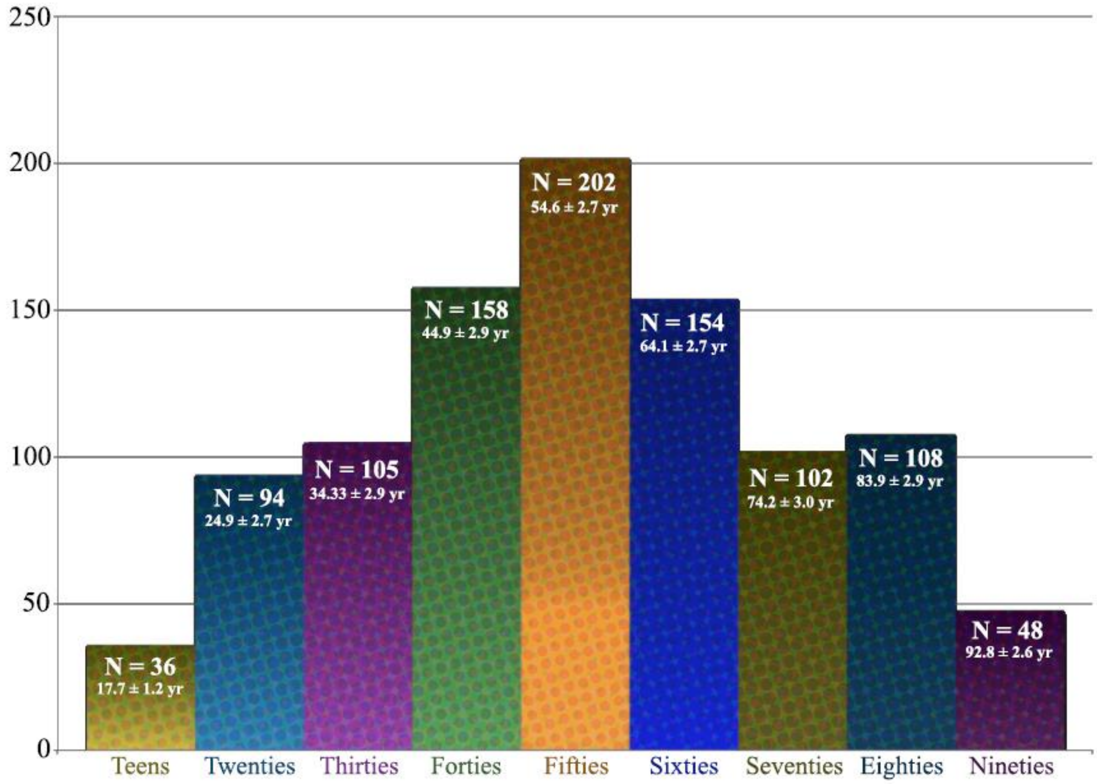
All statistical tests were conducted using SPSS version 22 (IBM SPSS Statistics, IBM Corporation, Chicago, IL).

RESULTS

Patient characteristics across the total sample (n=1,008)

Two-thirds of the patients were male, 92% were white, and their ages ranged across the lifespan, from 15 to 98 years. On average, patients were middle aged (55.3 ± 20.3 yrs), but the distribution was broad (Figure 3.1).

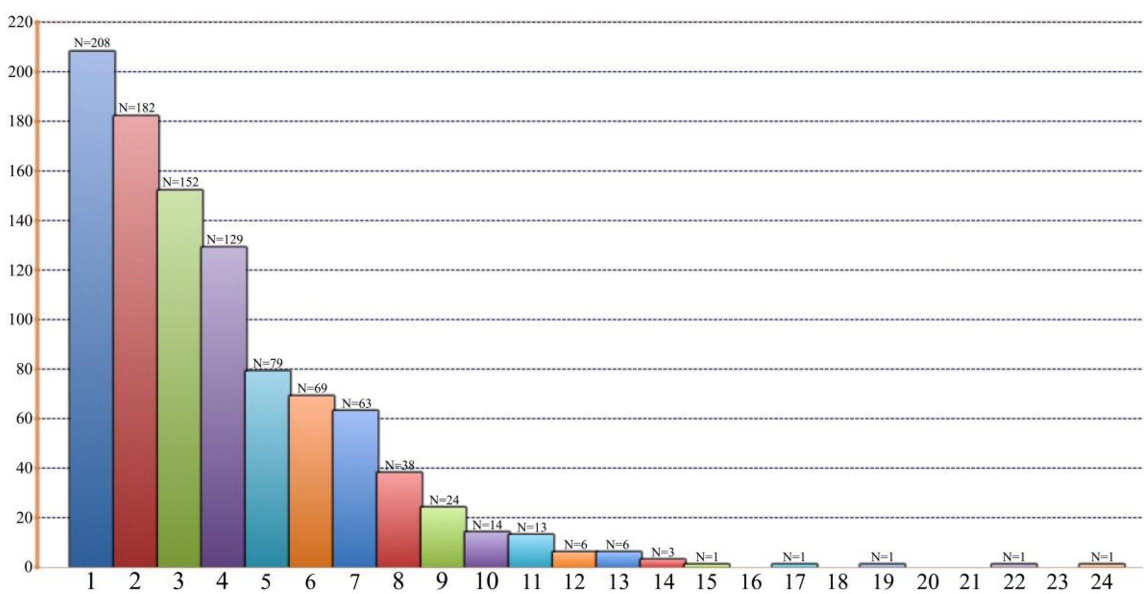
Figure 3.1: Patient ages by decade



The most common causes of injury were automotive accidents (37.6%), falls (32.9%), and motorcycle accidents (13.7%). The remaining 15.8% of patients were injured during a variety of activities – in order of most to least frequent: bicycle accidents, ATV accidents, firearm/bullet injuries, assault, struck by an object (e.g., baseball, jack stand), pedestrian struck by a car, animal-related injuries (e.g., fall, bite, kick, gore, trample), other motor vehicle accidents (e.g., golf carts, snowmobiles), heavy machinery accidents (e.g., mining, earth-drilling), and pedestrian struck by a train. There were no significant relationships between mode of injury and use of TEA (p=0.717) or survival (p=0.204).

On average, across all modes of injury, patients fractured about 4 ribs, but the range was broad, from a single rib to all 24 (mode=1; median=3). The frequency of rib fracture counts is displayed in Figure 3.2.

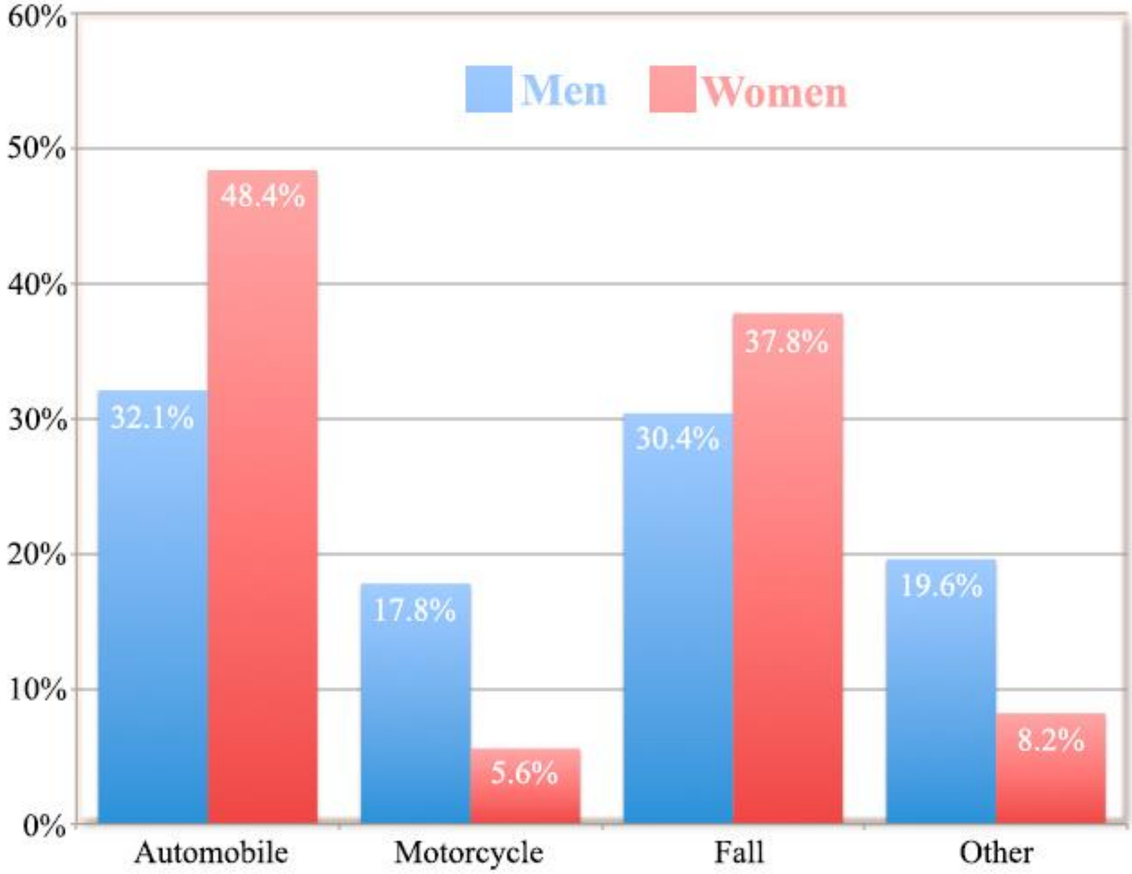
Figure 3.2: Frequency of rib fracture counts



Men and women differed in both age and number of ribs fractured. On average, men were younger (52.4 ± 18.5 vs. 60.9 ± 22.3 yrs; $p<0.001$) and fractured more ribs (4.0 ± 3.1 vs. 3.7 ± 2.5; $p=0.049$). Men also had a higher ISS (16.7 ± 10.3 vs. 15.1 ± 10.7; $p=0.018$) and a higher incidence of flail segments (7.5% vs. 4.1%; $p=0.036$). Despite being younger, men were more likely to experience pneumonia (14.0% vs. 8.8%; $p=0.018$), require mechanical ventilation (26.3% vs. 17.5%; $p=0.002$), and be intubated within 12 hours of admission (22.3% vs. 15.5%; $p=0.011$) owing to the extent of their injuries. More men were also admitted to the ICU (54.4% vs. 44.9%; $p=0.004$), although there was no difference in LOS between men and women who were admitted (6.9 ± 8.5 vs. 6.2 ± 7.5 days; $p=0.328$).

It's possible that the differences in the severity of injury are at least partly related to differences in the mode of injury between men and women ($p<0.001$), as depicted in Figure 3.3.

Figure 3.3: Mode of injury among men versus women.

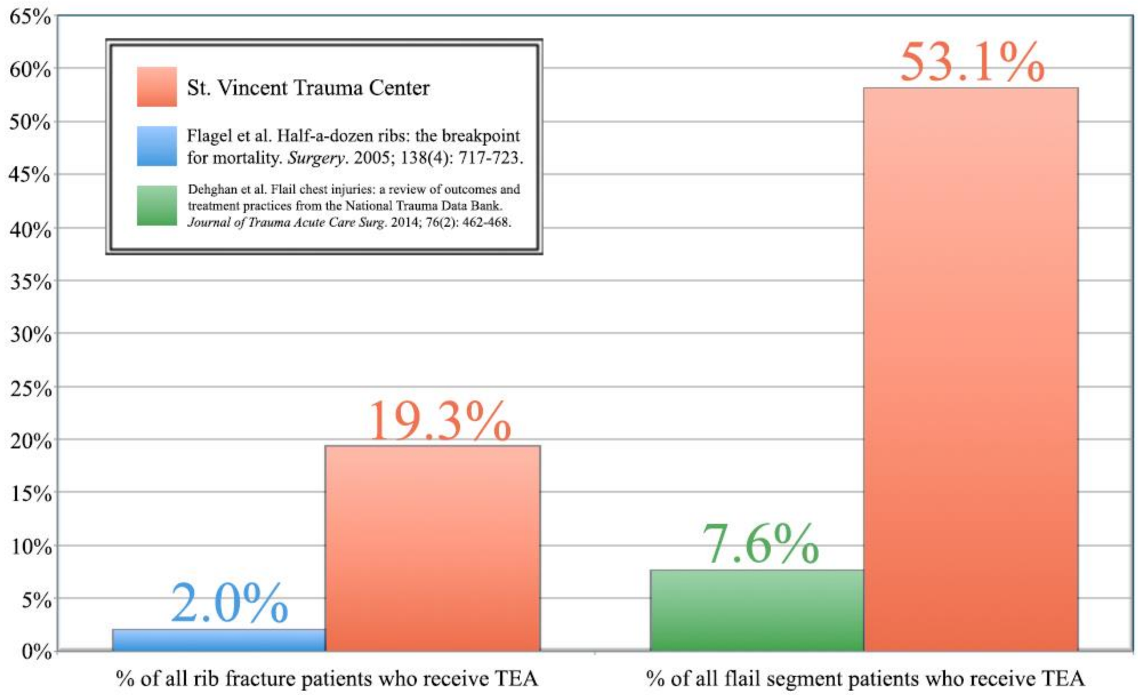


The greater severity of injuries suffered by men may have resulted in a higher mortality rate (6.9% vs. 4.4%; p=0.116) although a larger sample is needed to confirm this observation. There were no differences between men in women in the proportion treated with TEA (19.5% vs. 19.1%; p=0.871).

Overall, TEA was administered much more frequently at St Vincent compared to other hospitals. Based upon reports from the National Trauma Data Bank (NTDB), patients who presented with rib fractures at St. Vincent were almost 10 times more likely to receive TEA[10] and patients with flail segments were 7 times more likely to receive TEA.[26] Figure 3.4 compares St. Vincent's use of TEA to published NTDB reports among

all patients who sustained rib fractures and among patients who presented with flail segments.

Figure 3.4: Use of TEA among patients with rib fractures and those with flail segments



At St. Vincent Trauma Center, nearly 20% of all patients admitted with rib fractures received TEA and more than half of all patients with flail segments received TEA.

There were numerous differences in injury severity between those who received TEA and those who did not (Table 3.1).

Table 3.1: Demographics and injury characteristics

	Non-TEA	**TEA**	**Total Sample**	**Significance**
N	813	195	1008	
Sex	66.1% male	66.6% male	66.2% male	p = 0.871
Age (years)	54.9 ± 20.7	56.9 ± 18.4	55.3 ± 20.3	p = 0.197
# Ribs Fractured	3.5 ± 2.8	5.8 ± 2.7	3.9 ± 2.9	**p < 0.001**
Injury Severity Score	16.1 ± 10.9	16.5 ± 8.2	16.1 ± 10.4	p = 0.492

% Flail Segment	3.7%	17.4%	6.4%	**p < 0.001**
% Bilateral Fracture	13.3%	18.5%	14.7%	**p = 0.042**
% Pulmonary Contusion	18.5%	26.2%	20.0%	**p = 0.016**
% Pneumothorax	18.6%	30.3%	20.9%	**p < 0.001**
% Hemothorax	5.5%	5.6%	5.6%	p = 0.957
% Hemopneumothorax	5.2%	7.2%	5.6%	p = 0.272
Pulse (scene)	91.8 ± 23.6	92.5 ± 18.6	91.9 ± 22.8	p = 0.763
Pulse (hospital)	89.4 ± 22.9	90.3 ± 19.8	89.5 ± 22.3	p = 0.602
Respiratory rate (scene)	17.6 ± 6.0	19.6 ± 6.5	18.0 ± 6.2	**p = 0.008**
Respiratory rate (hospital)	18.0 ± 6.0	19.1 ± 4.9	18.2 ± 5.8	**p = 0.018**
SBP (scene)	132.1 ± 34.5	132.9 ± 28.5	132.2 ± 33.4	p = 0.825
SBP (hospital)	129.8 ± 31.9	136.5 ± 25.6	131.1 ± 30.9	**p = 0.007**
DBP (scene)	80.2 ± 17.3	80.9 ± 16.6	80.4 ± 17.1	p = 0.749
DBP (hospital)	80.3 ± 17.1	82.1 ± 16.3	80.6 ± 17.0	p = 0.169
Glasgow Coma Score (scene)	12.7 ± 4.2	14.3 ± 2.3	13.0 ± 4.0	**p < 0.001**
Glasgow Coma Score (hospital)	12.8 ± 4.5	14.4 ± 2.3	13.1 ± 4.2	**p < 0.001**

Patients receiving TEA presented with 2.3 more fractured ribs, had 4.7 times the incidence of flail segments, 1.6 times the incidence of pneumothorax, 1.4 times the incidence of pulmonary contusions, and 1.4 times the incidence of bilateral fractures.

At the scene of the accident, TEA and non-TEA patients were similar in pulse, systolic blood pressure (SBP) and diastolic blood pressure (DBP), but patients receiving TEA presented with a higher respiratory rate and Glascow Coma Score (GCS). Upon arrival at the hospital, pulse and DBP remained similar, but SBP was higher in patients treated with TEA. Respiratory rate and GCS also remained higher in TEA patients. These differences however are small and unlikely of clinical importance.

Treatment outcomes across the total sample (n=1,008)

Despite similar complication rates between groups, patients who did not receive TEA were 7 times more likely to die than patients who were treated with TEA (Table 3.2).

Table 3.2: Mortality, complications, and treatment outcomes

	Non-TEA	TEA	Total Sample	Significance
Mortality	7.2%	1.0%	6.1%	**p = 0.001**
Pneumonia	11.4%	15.4%	12.2%	p = 0.132
Sepsis	0.9%	0.5%	0.8%	p = 0.623
Respiratory Distress	2.1%	1.5%	2.0%	p = 0.619
Respiratory Failure	1.8%	3.1%	2.1%	p = 0.279
LOS in the Hospital (days)	7.2 ± 8.7	8.7 ± 5.8	7.5 ± 8.2	**p = 0.006**
% Admitted to ICU	48.2%	63.6%	51.2%	**p < 0.001**
LOS in the ICU (days)	7.0 ± 8.6	5.8 ± 6.7	6.7 ± 8.2	p = 0.110
% Needing Ventilation	24.4%	18.5%	23.3%	p = 0.075
Ventilation duration (days)	9.0 ± 9.0	9.6 ± 8.1	9.1 ± 8.8	p = 0.689

There were no differences between patients who received TEA and those who did not in complication rates. There was a trend that patients who did not receive TEA were 32% more likely to need mechanical ventilation, possibly owing to failure of the treatment. Conversely, the patients receiving TEA were 32% more likely to be admitted to the ICU, possibly owing to the increased severity of their injuries. Despite more frequent admissions to the ICU, among those admitted, there was no significant difference in LOS between patients who received TEA (5.8 days) and those who did not (7.0 days). Patients receiving TEA did spend an additional 1.5 days in the hospital, however.

Relationships with mortality across the total sample (n=1,008)

Differences in demographics, injury characteristics, and treatment outcomes between the patients who survived and the patients who died are characterized in Tables 3.3 and 3.4.

Table 3.3: Demographics, injury characteristics, and treatment outcomes of survivors and non-survivors

	Survivors	Non-Survivors	Total Sample	Significance
N	947	61	1008	
Sex	65.6% male	75.4% male	66.2% male	p = 0.116

Age (years)	55.0 ± 20.1	59.4 ± 22.3	55.3 ± 20.3	p = 0.102
# Ribs Fractured	3.8 ± 2.8	6.0 ± 4.4	3.9 ± 2.9	**p < 0.001**
Injury Severity Score	15.3 ± 9.5	28.6 ± 15.8	16.1 ± 10.4	**p < 0.001**
% Flail Segment	5.9%	13.1%	6.4%	**p = 0.026**
% Bilateral Fracture	13.3%	29.5%	14.7%	**p = 0.001**
% Pulmonary Contusion	19.0%	34.4%	20.0%	**p = 0.004**
% Pneumothorax	21.0%	18.0%	20.9%	p = 0.576
% Hemothorax	4.4%	23.0%	5.6%	**p < 0.001**
% Hemopneumothorax	5.5%	6.6%	5.6%	p = 0.726
Pulse (scene)	92.0 ± 20.9	91.3 ± 38.4	91.9 ± 22.8	p = 0.910
Pulse (hospital)	90.0 ± 20.6	81.5 ± 40.4	89.5 ± 22.3	p = 0.120
Respiratory rate (scene)	18.3 ± 5.3	14.3 ± 11.9	18.0 ± 6.2	**p = 0.052**
Respiratory rate (hospital)	18.5 ± 5.4	13.7 ± 9.5	18.2 ± 5.8	**p = 0.001**
SBP (scene)	134.3 ± 29.0	106.8 ±61.8	132.2 ± 33.4	**p = 0.010**
SBP (hospital)	133.3 ± 27.8	96.2 ± 50.5	131.1 ± 30.9	**p < 0.001**
DBP (scene)	80.0 ± 16.9	87.3 ± 19.9	80.4 ± 17.1	p = 0.081
DBP (hospital)	81.3 ± 16.5	67.7 ± 20.0	80.6 ± 17.0	**p < 0.001**
Glasgow Coma Score (scene)	13.6 ± 3.3	7.3 ± 5.6	13.0 ± 4.0	**p < 0.001**
Glasgow Coma Score (hospital)	13.6 ± 3.6	6.0 ± 4.9	13.1 ± 4.2	**p < 0.001**
Pneumonia	12.1%	13.1%	12.2%	p = 0.825
Sepsis	0.7%	1.6%	0.8%	p = 0.443
Respiratory Distress	1.9%	3.3%	2.0%	p = 0.454
Respiratory Failure	1.6%	9.8%	2.1%	**p < 0.001**
LOS in the Hospital (days)	7.7 ± 8.3	4.4 ± 6.3	7.5 ± 8.2	**p = 0.003**
% Admitted to ICU	50.3%	65.6%	51.2%	**p = 0.020**
LOS in the ICU (days)	6.8 ± 8.4	5.1 ± 5.6	6.7 ± 8.2	p = 0.079
% Needing Ventilation	20.4%	67.2%	23.3%	**p < 0.001**
Ventilation duration (days)	10.1 ± 9.1	4.1 ± 4.9	9.1 ± 8.8	**p < 0.001**

On average, patients who died fractured 2.2 more ribs, were 2.2 times more likely to experience bilateral fractures, and 2.2 times more likely to present with a flail segment. They also had a greater incidence of both pulmonary contusions (34.4% vs. 19.0%) and hemothorax (23.0% vs. 4.4%), their ISS was 13.3 points higher, and they had less stable vital signs at the scene of the accident and at the hospital.

Patients who died had a higher risk of respiratory failure (9.8% vs. 1.8%) but otherwise did not exhibit a greater risk of complications. Survivors were less likely to require mechanical ventilation (20.4% vs. 67.2%) but if ventilated, the duration was 6.0 days longer. The survivors also stayed 3.3 additional days in the hospital, and if admitted to the ICU, showed a trend of staying an additional 1.7 days.

Table 3.4: Demographics, injury characteristics, and treatment outcomes of survivors and non-survivors who did and did not receive TEA

	TEA Mort.	**TEA** Survived	**No TEA** Mort.	**No TEA** Survived
N	2	193	59	754
Sex	100% male	66.3% male	74.6% male	65.4% male
Age (years)	83.0 ± 4.2	56.7 ± 18.3	58.6 ± 22.3	54.6 ± 20.5
# Ribs Fractured	7.0 ± 0	5.8 ± 2.7	6.0 ± 4.5	3.3 ± 2.5
Injury Severity Score	13.5 ± 5.0	16.6 ± 8.2	29.1 ± 15.8	15.0 ± 9.8
% Flail Segment	0%	17.6%	13.6%	2.9%
% Bilateral Fracture	0%	18.7%	30.5%	11.9%
% Pulmonary Contusion	0%	26.4%	35.6%	17.1%
% Pneumothorax	0%	30.6%	18.6%	18.6%
% Hemothorax	0%	5.7%	23.7%	4.1%
% Hemopneumothorax	0%	7.3%	6.8%	5.0%
Pulse (scene)	No data	92.5 ± 18.9	91.2 ± 38.4	91.8 ± 21.4
Pulse (hospital)	65.0 ± 1.4	90.6 ± 19.8	82.1 ± 41.0	89.9 ± 20.8
Respiratory rate (scene)	No data	19.6 ± 6.5	14.3 ± 11.9	17.9 ± 4.9
Respiratory rate (hospital)	22.5 ± 9.2	19.1 ± 4.9	13.4 ± 9.4	18.4 ± 5.6
SBP (scene)	No data	132.9 ± 28.5	106.8 ± 61.8	134.7 ± 29.1
SBP (hospital)	134.0 ± 1.4	136.5 ± 25.8	94.8 ± 50.8	132.5 ± 28.2
DBP (scene)	No data	80.9 ± 16.6	87.3 ± 19.9	79.7 ± 17.0
DBP (hospital)	68.5 ± 5.0	82.3 ± 16.3	67.7 ± 20.5	81.0 ± 16.6
Glasgow Coma Score (scene)	No data	14.3 ± 2.3	7.3 ± 5.6	13.4 ± 3.5
Glasgow Coma Score (hospital)	9.0 ± 0.0	14.4 ± 2.2	6.0 ± 5.0	13.3 ± 3.9
% Pneumonia	100%	14.5%	10.1%	11.5%
% Sepsis	50%	0%	0%	0.9%
% Respiratory Distress	50%	1.0%	1.7%	2.1%
% Respiratory Failure	50%	2.6%	8.5%	1.3%
LOS in Hospital (days)	12.5 ± 16.3	8.6 ± 5.7	4.1 ± 5.9	7.5 ± 8.9
% Admitted to ICU	100%	63.2%	64.4%	46.9%
LOS in ICU (days)	12.0 ± 15.6	5.7 ± 6.5	4.7 ± 4.9	7.2 ± 8.9
% Needing Ventilation	50%	18.1%	67.8%	21.0%
Vent duration (days)	15 ± 0.0	9.5 ± 8.1	3.9 ± 4.7	10.3 ± 9.3

Patients who received TEA and survived (n=193) were the same age (p=0.508) and fractured the same number of ribs (p=0.749) as the patients who did not receive TEA and died (n=59). However, the ISS of survivors who received TEA was 12.5 points lower than the ISS of those who did not receive TEA and died (p<0.001). Although there was no difference in the incidence of flail segments (p=0.464), there was a trend for survivors who received TEA to present with fewer bilateral fractures (p=0.070). Survivors who received TEA also exhibited a trend for more frequent pneumothorax (p=0.073) while the patients who did not receive TEA and died had a greater incidence of hemothorax

(p<0.001).

At the scene of the accident, the respiratory rate of survivors who received TEA was higher (p<0.001) and this difference was preserved upon arrival at the hospital (p<0.001). There were no differences in pulse at the site of the injury (p=0.850) or upon arrival at the hospital (p=0.145). SBP of survivors who received TEA was higher at the scene of the accident (p=0.016) and this difference was exacerbated upon arrival at the hospital (p<0.001). Although there was no difference in DBP at the scene of the accident (p=0.150), upon arrival at the hospital, survivors who received TEA had much higher values than patients who did not receive TEA and died (p<0.001). The GCS of survivors who received TEA was also higher at the scene of the accident (p<0.001) and this difference was exacerbated upon arrival at the hospital (p<0.001).

Patients who did not receive TEA and died experienced more acute respiratory failure (p=0.043) than survivors who received TEA. There were no other significant differences in complication rates. The patients who did not receive TEA and died were 3.7 times more likely to require mechanical ventilation (p<0.001) than the survivors who received TEA, although if ventilated, the survivors receiving TEA remained on it for an additional 5.6 days (p=0.001). There were no differences in the percentage of patients who were admitted to the ICU (p=0.868) or ICU LOS (p=0.404), but survivors who received TEA stayed in the hospital 4.5 days longer (p<0.001) than patients who did not receive TEA and died.

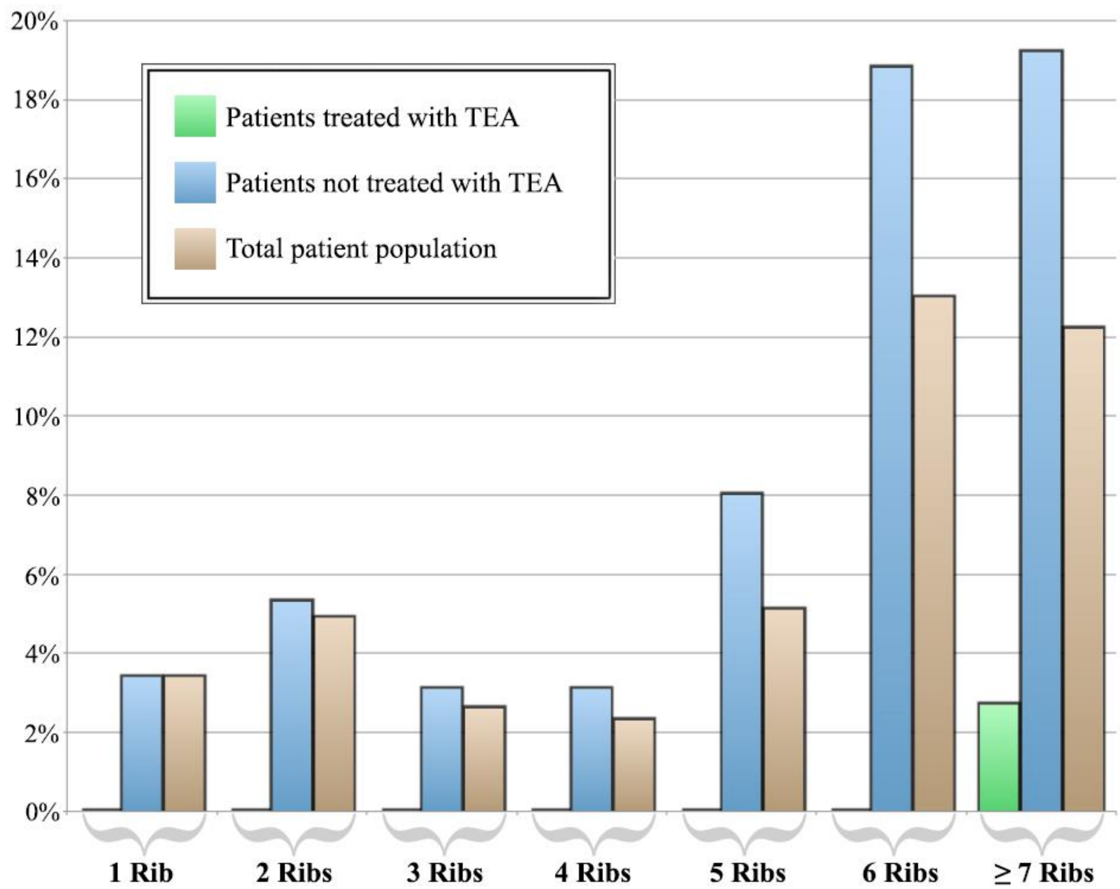
Predictors of mortality across the total sample (n=1,008)

Unilateral vs. bilateral rib fractures: If a patient sustained bilateral fractures, the odds of mortality were 2.9:1 (95% CI of odds ratio: 1.6–5.1; p=0.001).

Presence of a flail segment: If a patient presented with a flail segment, the odds of mortality were 2.4:1 (95% CI of odds ratio: 1.088–5.291; p=0.026).

Number of ribs fractured: For each additional rib fractured, the odds of mortality were 20% greater (95% CI of odds ratio: 1.1–1.3; p<0.001). Much of this relationship was driven by an inflexion point at 6 fractured ribs. If a patient fractured 5 or fewer ribs, the risk of mortality was 3.6%; if a patient fractured 6 or more ribs, the risk of mortality was 12.4% (p<0.001). This inflexion point is illustrated in Figure 3.5.

Figure 3.5: Mortality rate based on number of ribs fractured



Among patients who did not receive TEA, at 4 fractured ribs, the mortality rate was 3.1%, at 5 fractures, it was 8.0%, and at 6 fractures, it was 18.8%. Among patients who received TEA, no patient who fractured fewer than 7 ribs died and among patients who fractured 7 or more ribs, the mortality rate was 2.7%. By comparison, the mortality rate of patients who fractured a single rib and did not receive TEA was 3.4%.

The number of fractured ribs remained a significant predictor of mortality in the presence of additional variables in the equation; however, bilateral injury status and the presence of a flail segment did not maintain significance in the presence of additional predictors.

Incidence of pulmonary contusion: If a patient presented with a pulmonary contusion, the odds of mortality were 2.2 times greater (95% CI of odds ratio: 1.286–3.882; $p=0.004$).

When the number of ribs fractured and the presence of a pulmonary contusion were both included in the model, having a pulmonary contusion increased odds of mortality by about 74% (95% CI of odds ratio: .957–3.168; $p=0.069$) and each additional rib fractured increased the odds of mortality by about 18% (95% CI of odds ratio: 1.098–1.270; $p<0.001$).

Incidence of pneumothorax and/or hemothorax: Having a pneumothorax did not predict risk of mortality, but having a hemothorax did. However, with hemothorax in the model, pulmonary contusion is no longer a significant predictor of mortality. With hemothorax and number of fractured ribs in the model, both are significant ($p<0.001$), the

model accurately predicts 94.3% of deaths, and it accounts for 9.4% of the variance in mortality. In this model, if a patient presented with a hemothorax, the odds of mortality were 3.8 times greater (95% CI of odds ratio: 1.805–8.160).

Injury severity score: By itself, ISS accounts for 17.2% of the variance in mortality ($p<0.001$). Each additional point of injury severity (scores range from 1 to 75) increased the odds of mortality by 8% (95% CI of odds ratio: 1.062–1.105). With all 3 variables in the equation (number of fractured ribs, hemothorax, and ISS), the model accounts for about 22% of the variance in mortality. In this model, ISS is significant ($p<0.001$), hemothorax is significant ($p=0.005$), and the number of fractured ribs is trending ($p=0.066$).

Vital signs: Pulse, respiratory rate, SBP, and DBP have varying levels of predictive power, generally sharing inverse relationships with mortality (as pulse, respiratory rate, and blood pressure decrease, the odds of mortality increase). Unfortunately, none of these variables met assumptions of normally distributed data. The variances are much larger than the means, the skewness and kurtosis are concerning, box-and-whiskers plots show numerous data points far outside of the interquartile range, and the Kolmogorov-Smirnov test of normality (used for larger samples) is highly significant. In short, there is no pulse, no respiratory rate, and no blood pressure in a deceased patient; the correlations with survival were driven by these zeroes.

Glascow Coma Scale: The GCS has three components (eye, verbal, and motor) that give a composite score rating a patient's degree of consciousness. Scores range from 3 (comatose) to 15 (normally conscious and functional). Similar to vital signs, when the

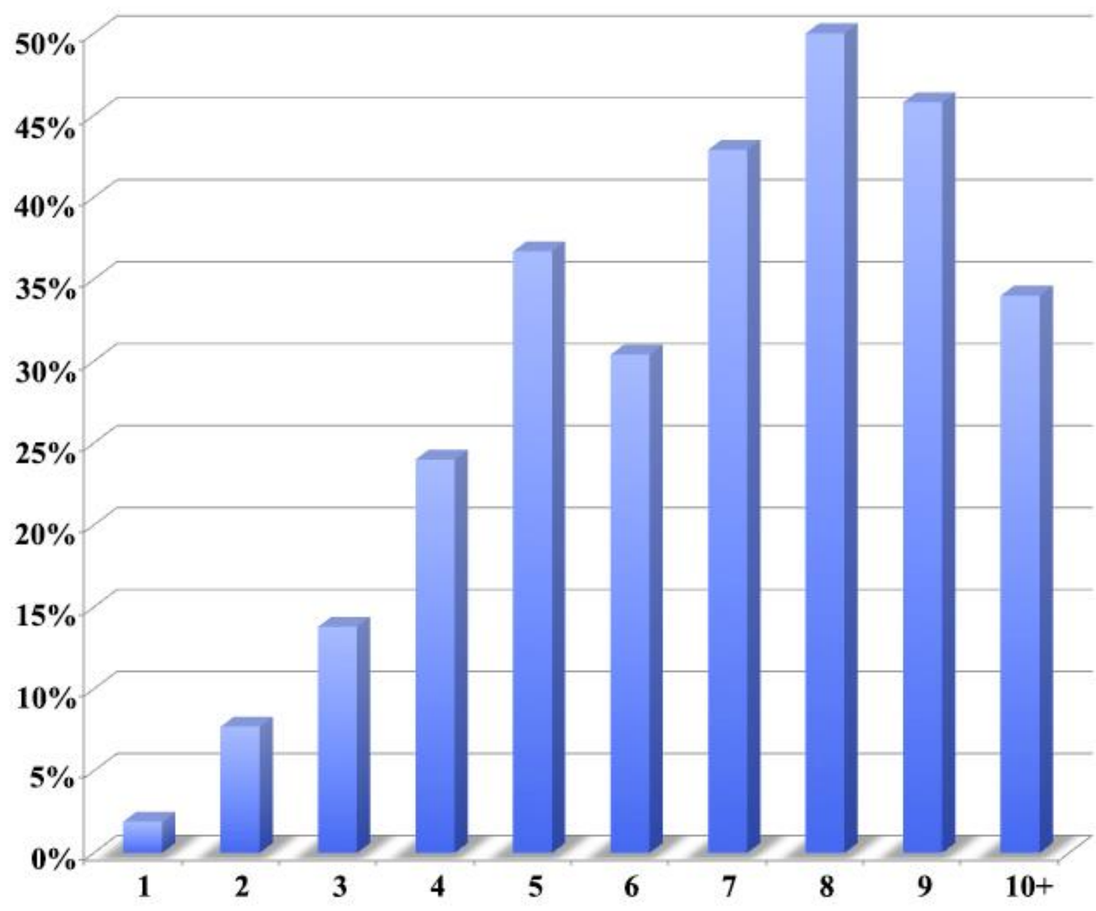
GCS was used to predict mortality, the strength of the relationship was in the outliers.

The use of mechanical ventilation: If mechanical ventilation (dichotomous variable: y/n) is included in the model with ISS, number of fractured ribs, and incidence of hemothorax, each individual predictor is significant ($p<0.05$), the overall model is significant ($p<0.001$), and it accounts for 26.6% of the variance in mortality. In this model, if a patient received mechanical ventilation as a component of treatment, the odds of mortality were 4.2 times greater (95% CI of odds ratio: 2.150–8.300).

Evaluating the number of days spent on mechanical ventilation is useful on its own, but not as a part of the predictive equation, as it reduces the sample to 230 cases while sharing predictive power with other variables. However, it is worth noting that, when evaluating ISS and duration of mechanical ventilation together, each additional day on mechanical ventilation reduced the odds of survival by 14% ($p<0.001$). Moreover, the two variables shared little predictive power, so this finding was not strictly a product of injury severity.

Use of TEA: By itself, TEA explains about 4% of the variance in mortality ($p=0.005$). The administration of TEA reduced the odds of mortality by about 87% (95% CI of odds ratio: 0.032–0.547). This relationship may have been stronger, but the more ribs a patient fractured (and thus the greater odds of mortality), the greater the likelihood of TEA administration (Figure 3.6).

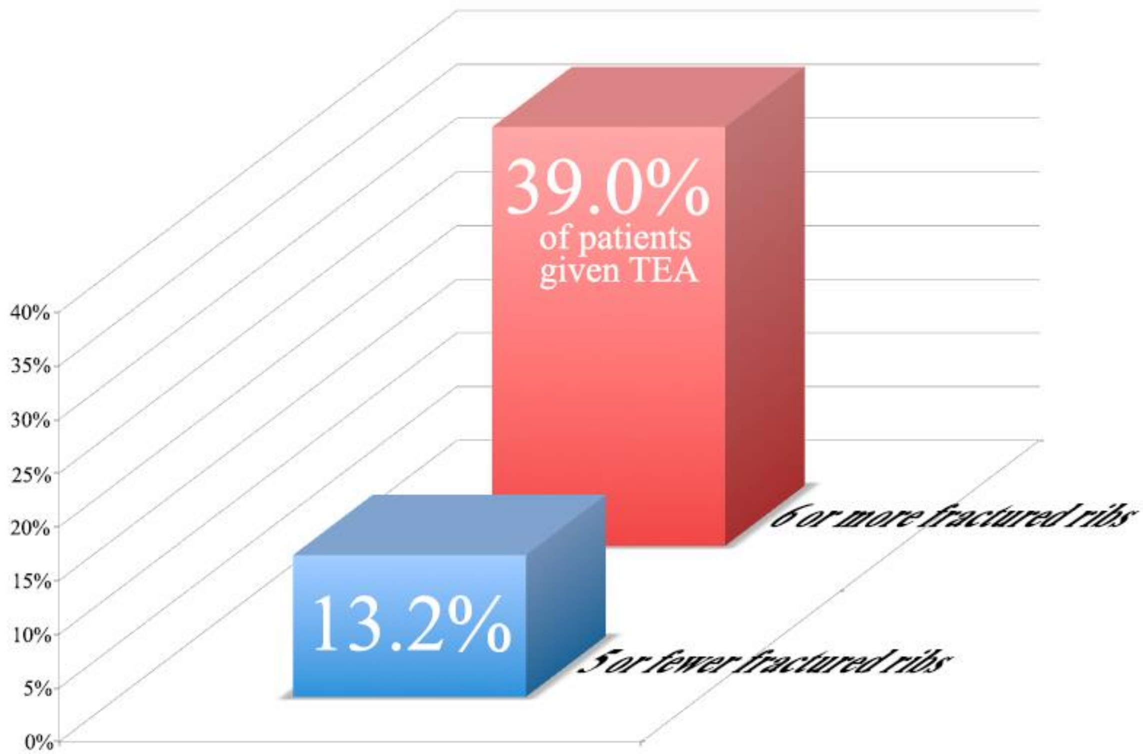
Figure 3.6: Use of TEA based on number of ribs fractured



Among patients who presented with a single rib fracture, 1.9% of them received TEA; among patients who fractured 8 ribs, 50.0% received TEA. Many patients who fractured 9 or more ribs still received TEA, but an increasing number were not candidates, owing to conditions such as early intubation.

Although there wasn't as clear of an inflexion point with the number of fractured ribs and the use of TEA, there is a clear difference in administration of TEA above and below the inflexion point for mortality (Figure 3.7).

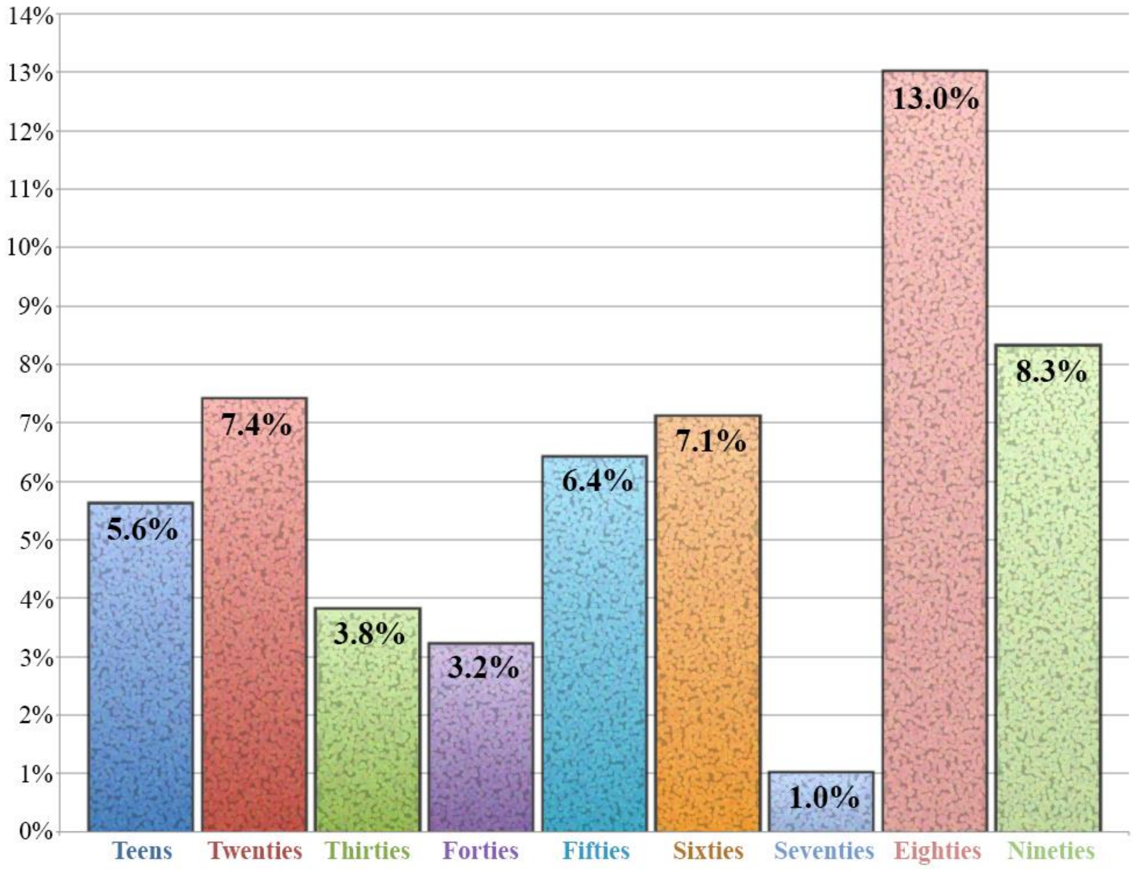
Figure 3.7: Use of TEA above and below the inflexion point of rib fractures and mortality



Among patients who fracture 6 or more ribs (12.4% mortality rate), 39.0% received TEA; among patients who fractured 5 or fewer ribs (3.6% mortality rate), 13.2% received TEA ($p<0.001$).

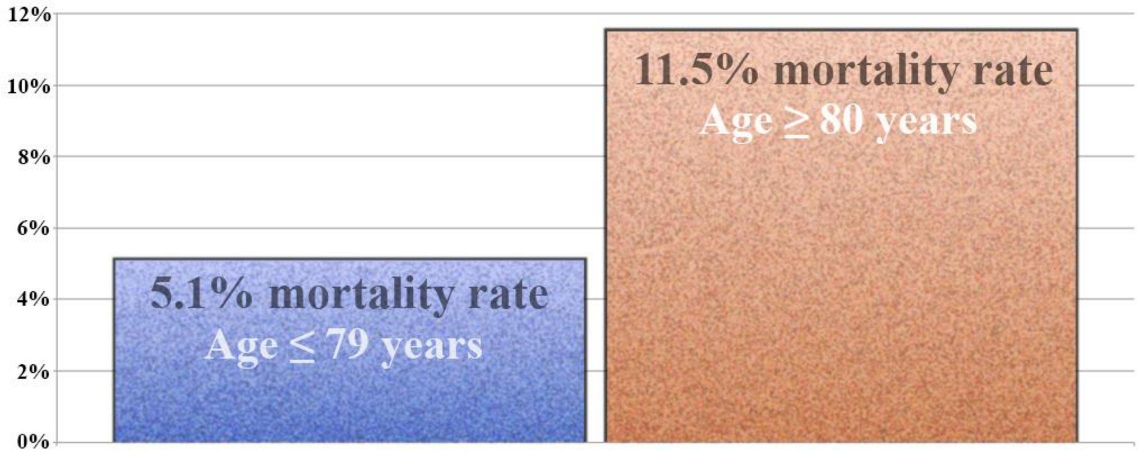
Age: When tested by itself, age is not a significant predictor of mortality as a continuous variable ($p=0.101$) or as a categorical variable, categorized by decade ($p=0.122$). The mortality rate across age groups is displayed in Figure 3.8.

Figure 3.8: Mortality rates among individual age groups



There was an inflexion point at 80 years whereby patients above that age had more than twice the risk of mortality compared to patients age 79 and below (p=0.002). This inflexion point is illustrated in Figure 3.9.

Figure 3.9: Mortality rates above and below inflexion point of age



When tested by itself, if a patient was age 80 or older, the odds of mortality were 2.5 times greater (95% CI of odds ratio: 1.374–4.374; p=0.002).

Binary logistic regression: Prediction equation for mortality across the total sample (n=1,008)

Variables in the equation: Use of TEA, number of fractured ribs, ISS, presence of hemothorax, use of mechanical ventilation, and inflexion point of age.

986 subjects (97.8%) had sufficient data to be included in this analysis. All variables maintain significance when tested individually (Table 3.6).

Table 3.6: Analysis of variables when tested individually (not in the equation)

Variable	Score	Degrees of Freedom	Significance
Use of TEA	9.918	1	p=0.002
Number of fractured ribs	30.981	1	p<0.001
Injury Severity Score	99.251	1	p<0.001
Presence of hemothorax	23.057	1	p<0.001
Use of mechanical ventilation	74.240	1	p<0.001
Inflexion point of age	12.121	1	p<0.001
Overall Statistics	**168.530**	**6**	**p<0.001**

This model elicits a Nagelkerke R^2 value (a surrogate R^2 for binary logistic regressions) of 0.375, indicating that about 38% of the variance in mortality can be explained by this collection of predictors. The overall model is significant (Table 3.7) and all predictors are significant when tested in the model (Table 3.8).

Table 3.7: Variables in the equation

	β	**S.E.**	**Wald**	**D.F.**	**Sig.**	**Odds Ratio**
Constant	-2.791	0.136	418.361	1	p<0.001	0.061

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

Table 3.8: Variables in the equation

Variable	**β**	**S.E.**	**Wald**	**D.F.**	**Sig.**	**Odds Ratio**
Use of TEA	-2.257	0.766	8.675	1	p=0.003	0.105
Number of fractured ribs	0.116	0.044	7.024	1	p=0.008	1.123
Injury Severity Score	0.056	0.013	16.981	1	p<0.001	1.057
Presence of hemothorax	1.343	0.438	9.422	1	p=0.002	3.831
Use of mechanical ventilation	1.892	0.396	22.806	1	p<0.001	6.630
Inflexion point of age	2.195	0.408	28.979	1	p<0.001	8.976
Constant	-5.843	0.482	146.899	1	p<0.001	0.003

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

In this model, use of TEA reduced the odds of mortality by almost 90% (95% CI of odds ratio: 0.023–0.470), each additional fractured rib increased the odds of mortality by 12% (95% CI of odds ratio: 1.031–1.224), each additional point of severity in the ISS increased the odds of mortality by 6% (95% CI of odds ratio: 1.030–1.085), the presence of a hemothorax increased the odds of mortality by 383% (95% CI of odds ratio: 1.625–9.032), needing mechanical ventilation increased the odds of mortality by 663% (95% CI of odds ratio: 3.050–14.411), and being ≥80 years of age increased the odds of mortality by 898% (95% CI of odds ratio: 4.037–19.957).

If age (continuous variable) is used in the place of its inflexion point

(dichotomous variable), it is not significant when tested on its own, but is significant in the full model (p=0.001). The overall model is weaker (Nagelkerke R^2 is reduced from 0.375 to 0.297), but for each additional year of age, the odds of mortality increased by 2.6% (95% CI of odds ratio: 1.010–1.043).

The presence of a flail segment is generally considered to be an important predictor of mortality, but it was not significant in our patient population. A probable explanation is its association with TEA. At St. Vincent, patients with flail segments were much more likely to receive TEA. Among patients who did not receive TEA, 3.7% presented with flail segments; among patients who received TEA, 17.4% had flail segments (p<0.001). In short, having a flail segment associated with increased use of TEA and increased use of TEA associated with better odds of survival.

Matched samples: Characteristics of eliminated patients

Patients were eliminated if they died within 24 hours of arrival, if they were intubated within 12 hours of admission, or if they were on anticoagulation medication prior to treatment.

29 patients died within 24 hours of arrival. One of them – an 80-year-old male who broke 7 ribs in a fall – received TEA, but died shortly after the epidural was placed. The other 28 did not receive TEA. The demographic data and injury characteristics these patients are displayed in Table 3.9.

Table 3.9: Demographics and injury characteristics of patients who died within 24 hours

	Died within 24h	**Survived 24h**	**Significance**
N	29	979	
Sex	79.3% male	65.8% male	p = 0.129

Age (years)	50.6 ± 23.0	55.4 ± 20.2	p = 0.270
# Ribs Fractured	6.8 ± 5.1	3.9 ± 2.8	**p = 0.007**
Injury Severity Score	31.1 ± 15.8	15.7 ± 9.9	**p < 0.001**
% Flail Segment	24.1%	5.8%	**p < 0.001**
% Bilateral Fracture	48.1%	13.7%	**p < 0.001**
% Pulmonary Contusion	44.8%	19.2%	**p = 0.001**
% Pneumothorax	20.7%	20.9%	p = 0.982
% Hemothorax	34.5%	4.7%	**p < 0.001**
% Hemopneumothorax	10.3%	5.4%	p = 0.254

202 patients (20.0%) were intubated within 12 hours of admission. The majority of these patients were not candidates for TEA; only 23 (11.4%) were administered TEA either before or after intubation. Moreover, patients who were intubated within 12 hours of admission were much more likely to die (22.3%) than patients who were not intubated within the first 12 hours (2.0%; $p < 0.001$). The demographic data and injury characteristics of these patients are displayed in Table 3.10.

Table 3.10: Demographics and injury characteristics of patients intubated within 12 hours

	Intubated within 12h	**Not intubated during first 12h**	**Significance**
N	202	806	
Sex	73.8% male	64.3% male	**p = 0.011**
Age (years)	48.7 ± 18.3	56.9 ± 20.4	**p < 0.001**
# Ribs Fractured	5.0 ± 4.1	3.7 ± 2.5	**p < 0.001**
Injury Severity Score	20.7 ± 13.5	13.4 ± 7.4	**p < 0.001**
% Mortality	22.3%	2.0%	**p < 0.001**
% Flail Segment	11.9%	5.0%	**p < 0.001**
% Bilateral Fracture	28.9%	11.0%	**p < 0.001**
% Pulmonary Contusion	40.6%	14.8%	**p < 0.001**
% Pneumothorax	26.7%	19.4%	**p = 0.021**
% Hemothorax	11.9%	4.0%	**p < 0.001**
% Hemopneumothorax	12.8%	3.7%	**p < 0.001**

91 patients (9.0%) were on anticoagulation upon arrival at the hospital. On average, these patients were 20 years older ($p<0.001$), had an ISS nearly 4 points lower ($p<0.001$), and lower incidences of pulmonary contusions ($p=0.002$) and pneumothorax ($p=0.001$). Despite contraindications, 10 of these patients (11.0%) still received TEA; to

be consistent, these patients were removed from the database as well. The demographic data and injury characteristics are displayed in Table 3.11.

Table 3.11: Demographics and injury characteristics of patients on anticoagulation upon arrival

	Anticoagulation on arrival	**No anticoagulation on arrival**	**Significance**
N	91	917	
Sex	61.5% male	66.6% male	p = 0.327
Age (years)	73.2 ± 13.3	53.5 ± 20.0	**p < 0.001**
# Ribs Fractured	3.9 ± 3.1	3.9 ± 2.9	p = 0.915
Injury Severity Score	12.7 ± 7.3	16.5 ± 10.7	**p < 0.001**
% Mortality	2.2%	6.4%	p = 0.106
% Flail Segment	8.8%	6.1%	p = 0.318
% Bilateral Fracture	15.6%	14.6%	p = 0.799
% Pulmonary Contusion	7.7%	21.2%	**p = 0.002**
% Pneumothorax	7.7%	22.2%	**p = 0.001**
% Hemothorax	6.6%	5.5%	p = 0.652
% Hemopneumothorax	6.6%	5.5%	p = 0.652

Patient characteristics across matched samples (n=721)

287 patients met criteria for exclusion. After eliminating them from analyses, the difference in injury severity between patients who received TEA and those who did not receive TEA was enlarged (Table 3.12).

Table 3.12: Demographics and injury characteristics (matched samples)

	Non-TEA	**TEA**	**Total Sample**	**Significance**
N	558	163	721	
Sex	64.7% male	65.0% male	64.8% male	p = 0.937
Age (years)	54.5 ± 20.6	56.9 ± 8.6	55.0 ± 20.2	p = 0.188
# Ribs Fractured	3.1 ± 2.1	5.5 ± 2.4	3.6 ± 2.4	**p < 0.001**
Injury Severity Score	13.0 ± 7.2	15.7 ± 7.5	13.6 ± 7.4	**p < 0.001**
% Flail Segment	2.0%	12.9%	4.4%	**p < 0.001**
% Bilateral Fracture	9.0%	16.4%	10.6%	**p = 0.008**
% Pulmonary Contusion	12.9%	23.9%	15.4%	**p = 0.001**
% Pneumothorax	19.0%	27.6%	20.9%	**p = 0.018**
% Hemothorax	3.1%	5.5%	3.6%	p = 0.137
% Hemopneumothorax	2.3%	6.7%	3.3%	**p = 0.006**
Pulse (scene)	88.8 ± 19.3	90.5 ± 18.0	89.2 ± 19.0	p = 0.471
Pulse (hospital)	88.6 ± 19.5	89.8 ± 19.3	88.9 ± 19.5	p = 0.482
Respiratory rate (scene)	18.2 ± 3.9	19.5 ± 4.6	18.5 ± 4.1	**p = 0.019**
Respiratory rate (hospital)	18.7 ± 4.8	19.0 ± 3.9	18.8 ± 4.6	p = 0.420
SBP (scene)	137.2 ± 25.6	132.8 ± 29.3	136.2 ± 26.5	p = 0.192

SBP (hospital)	135.1 ± 25.6	137.1 ± 25.5	135.6 ± 25.5	p = 0.387
DBP (scene)	80.7 ± 15.0	80.5 ± 15.4	80.7 ± 15.1	p = 0.921
DBP (hospital)	81.6 ± 15.4	82.3 ± 15.9	81.7 ± 15.5	p = 0.609
Glasgow Coma Score (scene)	14.5 ± 1.8	14.5 ± 1.5	14.5 ± 1.7	p = 0.728
Glasgow Coma Score (hospital)	14.7 ± 1.5	14.7 ± 1.0	14.7 ± 1.4	p = 0.432

Compared to patients who did not receive TEA, those who were treated with TEA fractured 2.4 more ribs, were 1.8 times more likely to present with bilateral fractures, had 6.5 times the incidence of flail segments, 1.9 times the incidence of pulmonary contusions, and 1.5 times the incidence of pneumothorax. The ISS of patients who received TEA was 2.7 points higher.

Treatment outcomes across matched samples (n=721)

After eliminating patients who met exclusionary criteria, the overall mortality rate fell from 6.1% to 1.7%. Despite TEA patients having more severe injuries, there was no difference in mortality between treatment groups (Table 13).

Table 3.13: Mortality, complications, and treatment outcomes (matched samples)

	Non-TEA	**TEA**	**Total Sample**	**Significance**
Mortality	2.0%	0.6%	1.7%	p = 0.233
Pneumonia	5.4%	11.0%	6.7%	**p = 0.011**
Sepsis	0.5%	0.6%	0.6%	p = 0.909
Respiratory Distress	0.5%	1.8%	0.8%	p = 0.107
Respiratory Failure	0.9%	2.5%	1.2%	p = 0.115
LOS in the Hospital (days)	5.0 ± 5.0	7.9 ± 5.1	5.6 ± 5.2	**p < 0.001**
% Admitted to ICU	37.1%	58.2%	41.9%	**p < 0.001**
LOS in the ICU (days)	3.5 ± 3.8	4.9 ± 5.9	4.0 ± 4.6	**p = 0.047**
% Needing Ventilation	5.6%	9.8%	6.6%	p = 0.056
Ventilation duration (days)	6.8 ± 5.1	11.5 ± 7.4	8.4 ± 6.3	**p = 0.013**

The patients receiving TEA had 1.8 times the risk of pneumonia, but they did not experience increased risk of other complications. There was a trend for more TEA patients to require ventilation. Among those who received ventilation, patients given

TEA were intubated for an additional 4.7 days. They also spent an additional 2.9 days in the hospital and were 1.6 times more likely to be admitted to the ICU, likely owing to the increased severity of their injuries. Among patients admitted to the ICU, the LOS of those receiving TEA was 1.4 days longer.

Relationships with mortality across matched samples (n=721)

Differences in demographics, injury characteristics, and treatment outcomes between the patients who survived and the patients who died are characterized in Tables 3.15 and 3.16.

Table 3.15: Demographics, injury characteristics, and treatment outcomes of survivors and non-survivors (matched samples)

	Survivors	**Mortalities**	**Total Sample**	**Significance**
N	709	12	721	
Sex	64.7% male	66.7% male	64.8% male	p = 0.890
Age (years)	54.7 ± 20.1	72.1 ± 22.0	55.0 ± 20.2	**p = 0.003**
# Ribs Fractured	3.6 ± 2.4	4.4 ± 2.5	3.6 ± 2.4	p = 0.254
Injury Severity Score	13.6 ± 7.3	14.3 ± 6.5	13.6 ± 7.4	p = 0.719
% Flail Segment	4.5%	0%	4.4%	p = 0.451
% Bilateral Fracture	10.8%	0%	10.6%	p = 0.248
% Pulmonary Contusion	15.7%	0%	15.4%	p = 0.136
% Pneumothorax	21.0%	16.7%	20.9%	p = 0.712
% Hemothorax	3.4%	16.7%	3.6%	**p = 0.015**
% Hemopneumothorax	3.4%	0%	3.3%	p = 0.517
Pulse (scene)	89.0 ± 18.8	97.5 ± 29.4	89.2 ± 19.0	p = 0.281
Pulse (hospital)	88.8 ± 19.4	94.1 ± 24.8	88.9 ± 19.5	p = 0.369
Respiratory rate (scene)	18.5 ± 4.1	18.7 ± 3.9	18.5 ± 4.1	p = 0.941
Respiratory rate (hospital)	18.8 ± 4.6	18.5 ± 3.1	18.8 ± 4.6	p = 0.856
SBP (scene)	136.2 ± 26.5	134.2 ± 33.6	136.2 ± 26.5	p = 0.850
SBP (hospital)	135.6 ± 25.5	133.2 ± 27.9	135.6 ± 25.5	p = 0.755
DBP (scene)	80.7 ± 15.0	80.4 ± 20.0	80.7 ± 15.1	p = 0.968
DBP (hospital)	81.9 ± 15.5	72.3 ± 13.6	81.7 ± 15.5	**p = 0.042**
Glasgow Coma Score (scene)	14.5 ± 1.6	12.8 ± 4.8	14.5 ± 1.7	p = 0.438
Glasgow Coma Score (hospital)	14.8 ± 1.2	11.2 ± 5.3	14.7 ± 1.4	**p = 0.051**
Pneumonia	6.2%	33.3%	6.7%	**p < 0.001**
Sepsis	0.4%	8.3%	0.6%	**p < 0.001**
Respiratory Distress	0.7%	8.3%	0.8%	**p = 0.004**
Respiratory Failure	0.8%	25%	1.2%	**p < 0.001**
LOS in the Hospital (days)	5.6 ± 5.1	9.3 ± 8.3	5.6 ± 5.2	p = 0.144
% Admitted to ICU	91.7%	41.0%	41.9%	**p < 0.001**
LOS in the ICU (days)	3.8 ± 4.5	8.4 ± 6.7	4.0 ± 4.6	**p = 0.048**

% Needing Ventilation	5.5%	66.7%	6.6%	**p < 0.001**
Ventilation duration (days)	8.4 ± 6.6	8.5 ± 5.1	8.4 ± 6.3	p = 0.955

On average, the patients who died were 17.4 years older than those who survived. Injury severity was similar between groups. The only differences were a higher incidence of hemothorax among patients who died and a higher GCS upon arrival at the hospital (not on scene) among patients who survived.

Despite similar injury severity, the patients who died were 5.4 times more likely to acquire pneumonia, 20.8 times more likely to become septic, 11.9 times more likely to develop respiratory distress syndrome, and 31.3 times more likely to experience acute respiratory failure compared to the patients who survived. The patients who died were also 12.1 times more likely to receive mechanical ventilation. The duration of ventilation was similar between groups. Lastly, the patients who died were 2.2 times more likely to be admitted to the ICU and among those admitted, the patients who ultimately died stayed an additional 4.6 days.

Table 3.16: Demographics, injury characteristics, and treatment outcomes of survivors and non-survivors who did and did not receive TEA (matched samples)

	TEA Mort.	**TEA** Survived	**No TEA** Mort.	**No TEA** Survived
N	1	162	11	547
Sex	Male	64.8% male	63.6% male	64.7% male
Age (years)	86	56.7 ± 18.5	70.8 ± 22.6	54.2 ± 20.5
# Ribs Fractured	7	5.5 ± 2.4	4.2 ± 2.5	3.1 ± 2.1
Injury Severity Score	17	15.7 ± 7.5	14.1 ± 6.7	12.9 ± 7.2
% Flail Segment	No	13.0%	0%	2.0%
% Bilateral Fracture	No	16.5%	0%	9.1%
% Pulmonary Contusion	No	24.1%	0%	13.2%
% Pneumothorax	No	27.8%	18.2%	19.0%
% Hemothorax	No	5.5%	18.2%	2.7%
% Hemopneumothorax	No	6.8%	0%	2.4%
Pulse (scene)	No data	90.5 ± 18.0	97.5 ± 29.4	88.6 ± 19.1
Pulse (hospital)	66	90.0 ± 12.3	96.1 ± 24.2	88.4 ± 19.4
Respiratory rate (scene)	No data	19.5 ± 4.6	18.7 ± 3.9	18.2 ± 3.9
Respiratory rate (hospital)	16	19.1 ± 3.9	18.8 ± 3.1	18.7 ± 4.8
SBP (scene)	No data	132.8 ± 29.3	134.2 ± 33.6	137.3 ± 25.5

SBP (hospital)	135	137.1 ± 25.6	133.0 ± 29.4	135.2 ± 25.5
DBP (scene)	No data	80.5 ± 15.4	80.4 ± 20.0	80.7 ± 14.9
DBP (hospital)	72	82.4 ± 16.0	72.3 ± 14.3	81.7 ± 15.4
Glasgow Coma Score (scene)	No data	14.5 ± 1.5	12.8 ± 4.8	14.5 ± 1.6
Glasgow Coma Score (hospital)	9	14.8 ± 0.9	11.4 ± 5.6	14.7 ± 1.3
% Pneumonia	Yes	10.5%	27.3%	4.9%
% Sepsis	Yes	0%	0%	0.5%
% Respiratory Distress	Yes	1.2%	0%	0.5%
% Respiratory Failure	Yes	1.9%	18.2%	0.5%
LOS in Hospital (days)	24	7.8 ± 5.0	8.0 ± 7.2	4.9 ± 4.9
% Admitted to ICU	Yes	58.0%	90.9%	36.0%
LOS in ICU (days)	23	4.7 ± 5.7	6.9 ± 4.9	3.4 ± 3.7
% Needing Ventilation	Yes	9.3%	63.6%	4.4%
Vent duration (days)	15	11.3 ± 7.6	7.6 ± 4.7	6.5 ± 5.3

Among patients who did not receive TEA, the survivors were 16.6 years younger than those who died (p=0.008). Furthermore, the patients who died had a higher incidence of hemothoraces (p=0.003) and exhibited trends for more fractured ribs (p=0.077), a lower DBP at the hospital (p=0.056), and a lower GCS at the hospital (p=0.091). Patients who died were more likely to develop pneumonia (p=0.001) and acute respiratory failure (p<0.001), and ultimately require mechanical ventilation (p<0.001). Patients who died were 14.5 times more likely to be admitted to the ICU (p<0.001) and their average LOS was an additional 3.5 days (p=0.004).

Among patients who were treated with TEA, only one patient died: an 86-year-old man who fractured 7 ribs in a fall, was mechanically ventilated for 15 days and stayed in the ICU for 23 days. The remaining 162 patients survived.

When comparing survivors who received TEA to patients who did not receive TEA and died, survivors who received TEA were 14.1 years younger (p=0.017). There were trends for survivors who received TEA to have more fractured ribs (p=0.079), more pulmonary contusions (p=0.064), and a higher DBP at the hospital (p=0.054). Despite

trends for increased severity, survivors who received TEA had fewer instances of acute respiratory failure (p=0.002) and were less likely to need mechanical ventilation (p<0.001). If ventilated, they remained intubated for an additional 3.7 days, though owing to a small sample of patients (n=22), this difference was not significant (p=0.251). Survivors who received TEA were also admitted to the ICU less frequently (p=0.031) and, if admitted, were discharged 2.2 days sooner, although this, too, was statistically insignificant (p=0.233) and would need a larger sample to confirm. There were no other differences between groups.

Predictors of mortality across matched samples (n=721)

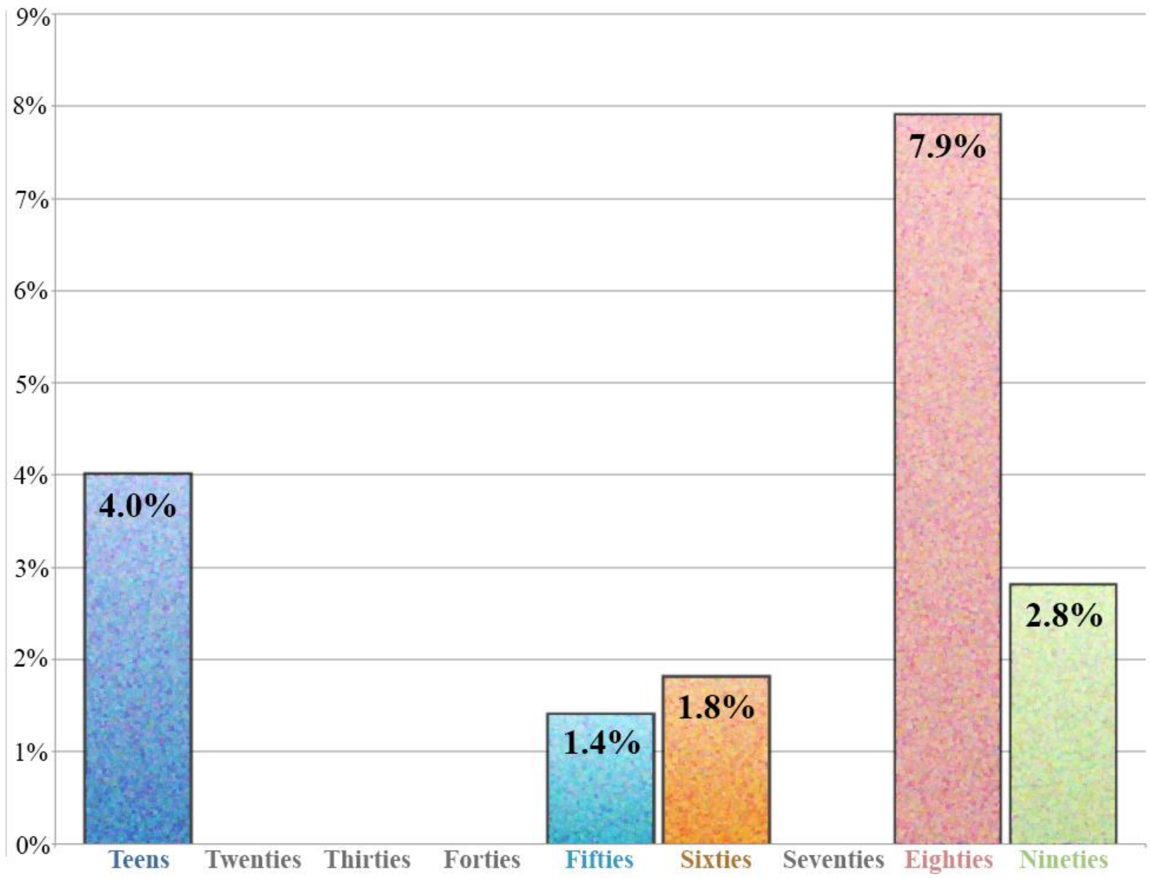
Variables that predict mortality when tested independently are the use of mechanical ventilation (p<0.001), the presence of a hemothorax (p=0.011), and age (p=0.003). When tested with other variables, the use of TEA is a trending predictor (p=0.071).

Use of mechanical ventilation: If a patient received mechanical ventilation as a component of treatment, the odds of mortality were 34.2 times greater (95% CI of odds ratio: 9.855–118.366; p<0.001). The duration a patient spent on ventilation was not a significant predictor (p=0.954).

Presence of a hemothorax: If a patient had a hemothorax, the odds of mortality were 5.7 times greater (95% CI of odds ratio: 1.805–8.160; p=0.030). The presence of a hemothorax lost its predictive power when paired with other explanatory variables.

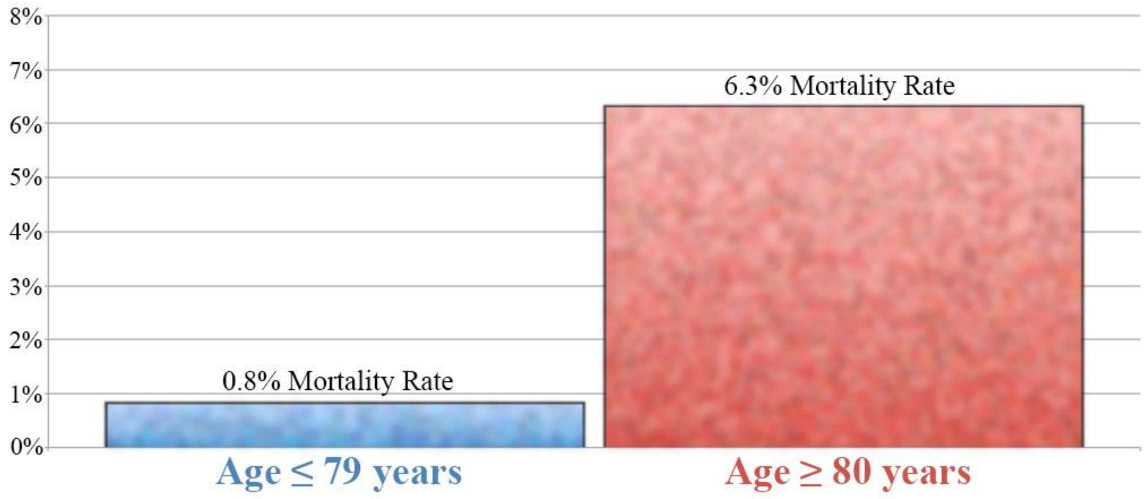
Age: When tested by itself, age predicts mortality as a continuous variable (p=0.005) or as a categorical variable, categorized by decade of life (p=0.009). For each additional year of age, the risk of mortality increased by 4.7% (95% CI of odds ratio: 1.014–1.081). The mortality rates across age groups are displayed in Figure 3.10.

Figure 3.10: Mortality rates among individual age group (matched samples)



The inflexion point at 80 years was even more exaggerated after samples were matched (Figure 3.11).

Figure 3.11: Mortality rates above and below inflexion point of age (matched samples)



Patients above the age of 80 were approximately 8 times more likely to die than patients below the age of 80 (95% CI of odds ratio: 2.509–25.849; p<0.001).

Among matched samples, the only patient who received TEA and died was 86 years old. If patients above the age of 80 (n=112) were to be eliminated from the database, mortality would become an all-or-none phenomenon in which every patient who received TEA survived while 1.1% of patients who did not receive TEA died.

<u>*Use of TEA*</u>*:* On its own, the use of TEA did not significantly predict mortality (p=0.230), but when tested with other variables, it became a trending predictor. For example, with age, use of mechanical ventilation, and the administration of TEA in the model, the use of TEA reduced the odds of mortality by about 87% (p=0.071).

Binary logistic regression: Prediction equation for mortality across matched samples (n=721)

<u>*Variables included in the prediction equation*</u>*:* Age, the use of TEA, and the use of mechanical ventilation.

Table 3.17: Analysis of variables when tested individually (not in the equation)

Variable	Score	Degrees of Freedom	Significance
Age	8.843	1	p=0.003
Use of TEA	1.441	1	p=0.230
Use of mechanical ventilation	71.993	1	p<0.001
Overall Statistics	**82.808**	**3**	**p<0.001**

717 subjects (99.4%) had sufficient data to be included in this analysis. The model elicits a Nagelkerke R^2 value of 0.390, indicating that about 39% of the variance in mortality can be explained by this collection of predictors.

Table 3.18: Variables in the equation

	β	S.E.	Wald	D.F.	Sig.	Odds Ratio
Constant	-4.073	0.291	195.768	1	p<0.001	0.017

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

Table 3.19: Variables in the equation

Variable	β	S.E.	Wald	D.F.	Sig.	Odds Ratio
Age	0.063	0.022	8.500	1	p=0.004	1.065
Use of TEA	-2.031	1.123	3.270	1	p=0.071	0.131
Use of mechanical ventilation	4.052	0.723	31.450	1	p<0.001	57.531
Constant	-9.130	1.752	27.145	1	p<0.001	0.000

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

In this model, each additional year of age increased the odds of mortality by about 7% (95% CI of odds ratio: 0.021–1.112; p=0.004), the use of TEA reduced the odds of mortality by about 87% (95% CI of odds ratio: 0.015–1.186; p=0.071), and patients who needed mechanical ventilation were about 58 times more likely to die (95% CI of odds ratio: 13.958–237.126; p<0.001).

If age is analyzed by its inflexion point, the use of TEA no longer exhibits a trend in prediction (p=0.101). Removing TEA, and only including the predictors that were significant both by themselves and in the model, the ideal equation to predict mortality among matched samples includes only age and the use of mechanical ventilation. If age is a continuous variable, this model explains about 35% of the variance in mortality, each additional year of age increases the risk of mortality by about 6% (95% CI of odds ratio: 1.018–1.106; p=0.005), and the patients who required mechanical ventilation were about 41 times more likely to die (95% CI of odds ratio: 10.919–154.667; p<0.001). If age is analyzed by its inflexion point, this model explains about 39% of the variance in mortality, patients who were above the inflexion point of age were about 14 times more likely to die (95% CI of odds ratio: 3.395–56.166; p<0.001), and the patients who required mechanical ventilation were about 52 times more likely to die (95% CI of odds ratio: 12.553–213.117; p<0.001). This model is displayed in Tables 3.20 and 3.21.

Table 3.20: Variables in the equation

	β	**S.E.**	**Wald**	**D.F.**	**Sig.**	**Odds Ratio**
Constant	-4.073	0.291	195.768	1	p<0.001	0.017

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

Table 21: Variables in the equation

Variable	**β**	**S.E.**	**Wald**	**D.F.**	**Sig.**	**Odds Ratio**
Age (inflexion point)	2.625	0.716	13.451	1	p<0.001	13.809
Use of mechanical ventilation	3.946	0.722	29.834	1	p<0.001	51.724
Constant	-6.189	0.714	75.201	1	p<0.001	0.002

β = coefficient for the constant; S.E. = standard error around the coefficient for the constant; Wald = Wald chi-square test; D.F. = degrees of freedom for the Wald chi-square test; Sig. = significance.

DISCUSSION

Rib fracture injuries normally account for 7–10% of all trauma center admissions.[2,113] At St. Vincent's trauma center, during the 4-year study period, 9.8% of all admissions were patients with rib fractures. These patients were typical of other patient populations admitted to trauma centers with rib fractures. Two-thirds were male, they had an average age of 55 years, presented with an average of 4 fractured ribs, and the rates of associated injuries (e.g., flail chest, pulmonary contusion) were comparable to the rates reported in other studies.

Among all patients admitted to trauma centers with ≥ 1 fractured rib, a mortality rate of about 10% can be expected[2,3,5,10] and the risk of pneumonia ranges between 17 and 31%.[6] About 60% of rib fracture patients will likely require mechanical ventilation for a mean duration of 13 days; the severity of injury predicts both the need for ventilation and the duration of its use.[10] The typical LOS in the hospital is 7 to 16 nights and among patients admitted to the ICU (generally > 40%) they can be expected to stay for 4 to 8 nights, with a greater number of fractures predicting longer stays.[2,5,10]

In our patients, the overall mortality rate was 6.1% and the incidence of pneumonia was 12.2%. Mechanical ventilation was required in 23.3% of patients for an average duration of 9.1 days. They spent 7.5 nights in the hospital, 51.2% were admitted to the ICU, and those patients remained there for 6.7 nights.

Given our normal patient profile, the relatively low rates of mortality and pulmonary complications may be partly explained by the mode of treatment. A unique feature of our treatment model is the APS care team. This team involves dedicated anesthesiologists with expertise and interest in acute pain techniques and nurses who are

trained in pain management. The anesthesiologists are assigned to the trauma patients for a week at a time and their duties are limited to those patients. They do not work in the operating room during the week they are covering, they round all 7 days, assume all pain management responsibilities for their patients, and they're available for nurses to page them 24 hours a day with questions about pain control, adjustments of dosage, and side effects. This service facilitates much higher reliance on TEA to manage rib fracture pain.

In published reports evaluating the NTDB, about 2% of all rib fracture patients and nearly 8% of patients with flail segments received TEA.[10,26] At St. Vincent, nearly 20% of all rib fracture patients and more than 50% of patients with flail segments received TEA. Moreover, as the severity of injury increased, so did the likelihood that TEA would be administered. For example, among patients who fractured a single rib, 1.9% received TEA; among patients who fractured 8 ribs, 50.0% received TEA. Many patients who fractured 9 or more ribs still received TEA (38.0%), but an increasing number were not candidates.

Although evaluations of the total population showed TEA was used in more severely injured patients, and it elicited remarkable improvements in treatment outcomes, most notably reducing mortality by a factor of 7, many patients with the most severe injuries were not eligible to receive TEA. Thus, to better understand the effect TEA had on mortality, morbidity, use of mechanical ventilation, and LOS in the hospital and ICU, we attempted to match patient samples. Patients who died within 24 hours or were intubated within 12 hours of admission may have missed the opportunity to receive TEA. Patients who were on anticoagulation medication upon arrival were contraindicated for

its use. After eliminating 287 patients who met these 3 criteria, we reevaluated our treatment outcomes.

The overall mortality rate fell from 6.1% to 1.7%. The variables that predicted mortality before matching the samples were age, the number of fractured ribs, the presence of a hemothorax, the use of ventilation, and the administration of TEA. Patients who received TEA had lower odds of mortality, whereas increasing age, fracturing more ribs, having a higher ISS, sustaining a hemothorax, and receiving mechanical ventilation all associated with greater odds of mortality. After matching samples, the predictors of mortality were narrowed to age (above or below the inflexion point of 80 years) and use of mechanical ventilation. Being ≥ 80 years of age increased the odds of mortality by a factor of 14 while use of mechanical ventilation increased the odds of mortality by a factor of 52.

After matching samples, there were 3 important differences between the patients who died and those who survived. On average, patients who died were 17.4 years older, they were 4.9 times more likely to present with a hemothorax, and they scored 3.6 points lower on the GCS upon arrival at the hospital. Despite otherwise comparable injury severity (e.g., number of fractured ribs, incidence of bilateral fractures, presence of flail segments and pulmonary contusions), the patients who died were 5.4 times more likely to contract pneumonia, 11.9 times more likely to develop respiratory distress syndrome, and 31.3 times more likely to experience acute respiratory failure. The patients who died were also 12.1 times more likely to require mechanical ventilation, 2.2 times more likely to be

admitted to the ICU, and, among those admitted, the patients who died stayed 4.6 additional days.

In attempt to avoid ventilation and minimize the risk of mortality and pulmonary complications, TEA was a mainstay in treating the patients with more severe injuries. Compared to the eligible candidates who did not receive TEA, those who were treated with TEA fractured 2.4 more ribs, were 1.8 times more likely to present with bilateral fractures, scored 2.7 points higher on the ISS, had 6.5 times the incidence of flail segments, 1.9 times the incidence of pulmonary contusions, and 1.5 times the incidence of pneumothoraces. In short, patients who received TEA had much more severe injuries. Despite this, there was no difference in mortality between patients who received TEA (0.6%) and those who did not (2.0%). Notably, the only patient who received TEA and died was an 86-year-old man who fractured 7 ribs in a fall. He was above the inflexion points for both age and the number of ribs fractured. The remaining 162 patients who received TEA survived. In contrast, the patients who did not receive TEA and died were about 15 years younger and fractured about 3 fewer ribs.

Comparisons can be drawn between the survivors who received TEA and the patients who did not receive TEA and died. The survivors who received TEA were 14.1 years younger, but displayed a trend of more fractured ribs and nearly a quarter of them had pulmonary contusions (compared to none among patients who did not receive TEA and died). There were also no bilateral injuries or cases of flail segments among the patients who did not receive TEA and died (compared to 13.0% and 16.5% respectively

among patients who received TEA and survived). Despite these being all-or-none phenomena, the sample size was not sufficient to elicit significance with these injuries.

In response to the treatments, despite trends for increased injury severity, survivors who received TEA had fewer instances of acute respiratory failure and were less likely to require mechanical ventilation.

At the very minimum, the use of TEA appears to have blunted the rise in mortality associated with increased injury severity. However, it did not seem to influence other treatment outcomes. There was a trend that patients who were treated with TEA had nearly twice the risk of acquiring pneumonia compared to patients who did not receive TEA. Among patients who were ventilated, those receiving TEA were intubated for nearly 5 more days. They stayed about 3 additional days in the hospital, were 57% more likely to be admitted to the ICU, and stayed in the ICU for an additional 1.4 days.

Limitations

In the present study, after matching samples, a single patient who received TEA died and there were 11 mortalities among patients not receiving TEA. Given these small samples, we may have missed important relationships and drawn meaningful conclusions where there were none. While our findings are an important step in outlining best practices for the treatment of patients with rib fractures, larger samples will be needed to confirm our observations.

Conclusions

Based on limited evidence, TEA appears to improve treatment outcomes for patients with rib fractures, most notably attenuating the rise in mortality that typically accompanies more severe injuries. Much of our success seems to be attributable to the presence of a dedicated anesthesiologist and the consequent ease with which TEA is administered and adjusted. This APS model for rib fracture care may be considered as a roadmap for other programs to implement. As a first step, more hospitals should quantify their data registries, controlling for injury severity, and evaluate the effectiveness, and safety of TEA among patients with rib fractures.

Disclaimers

This study is associated with no source of funding. It is a collaboration between the St. Vincent Hospital in Indianapolis, the University of Connecticut, and Sum Integral.

Chapter 4: The cost-effectiveness of thoracic epidural analgesia in rib fracture care

ABSTRACT

Rib fractures are the most common injury in blunt thoracic trauma; they are present in nearly 300,000 patients admitted to U.S. trauma centers each year. Patients who only fracture 1 or 2 ribs are typically treated with oral analgesic drugs and are discharged with few complications. The cost of those treatments generally reflects the brevity of the care. When a patient fractures 3 or more ribs, there is an increased risk of complication and mortality. To achieve successful outcomes, the extent of treatment is broadened and the duration prolonged. Hospital costs and patient expenses accumulate accordingly. While health, function, and survival have been widely explored, cost effectiveness has not. When a patient is admitted with rib fractures, there is a host of treatment options; thoracic epidural analgesia (TEA) is one of them. The purpose of this investigation was to assess the cost effectiveness of TEA as a treatment for patients with rib fractures. **Methods:** We analyzed the registry of a Level II trauma center. All patients who fractured at least 1 rib (n=1,008) were evaluated; 195 of them received TEA. The primary outcomes were hospital costs and patient billing. We also report patient demographics, the mechanism and severity of injuries, and the predictors of expense (e.g., duration of treatment). **Results:** The variables that predicted patient charges were age, injury severity, length of stay in the hospital and intensive care unit (ICU), the use of TEA, and the incidence of respiratory distress syndrome. The average patient bill was about \$55k and the use of TEA could be expected to reduce it by more than \$12k

($p<0.001$). The variables that predicted hospital expense were age, injury severity, length of stay in the hospital and ICU, and the use of TEA. The average cost per patient was about $6,700 and the use of TEA could be expected to reduce it by more than $2,500 ($p<0.001$). **Conclusion:** TEA significantly reduced both hospital costs and patient charges. From an administrative and insurance perspective, more frequent reliance on TEA may be indicated.

INTRODUCTION

Each year, about 10-15% of all patients admitted to U.S. trauma centers have sustained blunt thoracic trauma.[161] Chest wall injuries are common with most involving rib fractures.[1,2,49] Nearly 300,000 patients are admitted to U.S. trauma centers each year with rib fractures[4] (about 7% to 10% of all trauma patients).[2,10,113] The true incidence may be even higher as some fractures may go undetected at admission.[5,49] Many of these patients – especially older patients and those with more severe injuries – undergo extensive treatment.[59]

Patients who present with 1 or 2 fractured ribs are typically treated with oral analgesic drugs (e.g., NSAIDs)[47], scarcely die, and experience few complications.[1,10] If pain relief is not sufficient, other systemic analgesics (e.g., intravenous morphine) may be attempted.[47] Patients who present with 3 or more rib fractures have an elevated risk of complication.[1] Much of this risk is a consequence of pain-induced changes in ventilatory mechanics.[35,36] Patients who experience pain with coughing and deep breathing tend to avoid those behaviors, which limits the clearance of airway secretions. Retention of those

secretions increases the risk of pulmonary complications (e.g., pneumonia). These complications precipitate respiratory failure; respiratory failure often necessitates ventilatory support; and ventilatory support elevates the risk of mortality.[10,11,19,35-41] In short, pain can initiate a deleterious cascade that ends in poorer treatment outcomes. In turn, poorer treatment outcomes result in higher treatment costs.[162-164] Effective pain management is thus vital to a treatment's therapeutic success and its cost-effectiveness.[41,46,47] Thoracic epidural analgesia (TEA) is one mode of pain control. While TEA has been shown to reduce morbidity[11,82] and mortality[6,10,65,82] among patients with multiple rib fractures, we were unable to find any studies that reported its effect on treatment cost.

The purpose of this study is to evaluate the cost-effectiveness of TEA and determine which variables predict medical expenses in rib fracture patients. To our knowledge, this is the first publication of its kind.

Expected treatment outcomes and relationships with treatment cost

Among patients with ≥ 1 rib fracture, a mortality rate of about 10% can be expected[2,5,10] and pulmonary complications can arise in nearly half.[10] With each additional fracture, these risks increase.[6,10] Rates of pneumonia vary depending on the patients' age and injury severity, but an incidence of 17–31% can be expected.[6,10,46] Mechanical ventilation is required in about 60% of rib fracture patients and these patients remain ventilated for an average of 13 days; increased injury severity predicts the need for ventilation and the duration of its use.[10] Among all rib fracture patients, an average hospital stay of 7–16 nights can be expected, about 44% will be admitted to the intensive

care unit (ICU), and will likely remain there for 4–8 nights; the severity of injury predicts the length of stay (LOS).[2,5,10]

Some hospitals have achieved better outcomes in these domains by implementing more aggressive approaches, such as the “multidisciplinary clinical pathway”. Here, among older patients with more severe injuries, the default treatment includes physical therapy, respiratory therapy, nutrition services, and several modes of pain control. In one study, use of these services reduced the rate of mortality from 13% to 4% and the rates of complications similarly.[59] However, the cost of this treatment – both to the hospital and to the patient – was not reported. Few authors disclose the cost of medical care for patients with rib fractures. An analysis in 1993 found fewer than 2% of anesthesia publications included cost analyses.[165] Although others may exist, we were only able to identify 5 relevant studies:

In 1991, Mackersie and colleagues[36] reported on 32 patients admitted to a U.S. hospital with rib fractures: 17 were treated with IV opioids and 15 were treated with TEA. The total hospital charges among patients who received TEA was $21k ± $10k whereas the total charges among patients who received IV opioids was $15k ± $16k. Other than listing these figures, the only mention of financial outcomes in the paper was a clarification that “Although hospital charges and LOS were slightly higher for the epidural group, the ISS was also increased, resulting in a similar charge/ISS/day.”

In 2002, Tanaka and colleagues[164] reported on 37 patients who were admitted to a Japanese hospital with flail chest; 18 underwent surgical fixation and 19 were managed conservatively (internal pneumatic stabilization). Medical costs were obtained through

public health insurance records and yen were converted to dollars. These records showed total cost of the surgical group was \$13,455 ± \$5,840 while the conservative group cost \$23,423 ± \$1,380 ($p<0.05$). Most of this was related to duration of mechanical ventilation and LOS in the ICU, in which conservative treatments lasted 7.5 days longer ($p<0.05$) and 10.3 days longer ($p<0.05$) respectively.

In 2012, Bhatnagar and colleagues[162] evaluated Medicare reimbursement records of American patients with flail chest. Although very little detail was documented in the methods, they found surgical fixation to be more cost effective than non-operative care. While the operations themselves added to treatment costs, they reduced the rates of complications and shortened durations of ventilator use and hospital stay (by unreported amounts). The authors reported financial data relative to quality of life (measured by "an arbitrary quality of life improvement factor"). The incremental cost per quality of life unit was \$17,162 for the surgical option and \$22,537 for the non-surgical option.

In 2012, Menditto and colleagues[166] evaluated 240 patients admitted to an Italian hospital's emergency department with blunt thoracic trauma. These patients were analyzed in two separate groups: those treated in 2006 and those treated in 2007. There were 110 patients in the first group and 130 in the second. They fractured an average of 2.1 and 2.7 ribs respectively. Treatment costs were gathered from the hospital's finance department and were reported in euros. Cost-effectiveness was calculated by dividing the mean cost per patient by the success rate (the success rate was defined as the number of patients who were not readmitted to the emergency department divided by the total number of patients who were treated in the emergency department). The median cost per

patient was € 430 for the first group and € 588 for the second. The cost-effectiveness was € 487 for the first group and € 616 for the second.

In 2013, Marasco and colleagues[163] reported on 46 patients who were admitted to an Australian hospital with traumatic flail injuries; 23 were randomized to operative fixation and 23 were randomized to non-operative management. On average, patients in the non-operative group remained in the ICU for 5 extra days, which cost an additional $21,243 per patient. This difference was offset by the costs of the surgical procedure, which averaged $6,800 per patient. The estimated savings of having the operation were $14,443 per patient.

In other studies, topics such as "cost-effectiveness" were mentioned in the abstract, but no financial records were reported in the paper.[167]

Effect of TEA on treatment outcomes and implications on treatment cost

We found 16 studies reporting TEA to be an effective mode of treatment for patients with rib fracture injuries[9,10,25,30,39,41,61,65,66,82-85,89,94,99] and 10 studies that failed to find superior outcomes with TEA.[6-8,11,29,36,78,91,93,96] None of these studies reported any data related to treatment cost.

METHODS

We retrospectively analyzed the registry of an ACS-verified Level II trauma center. All patients who were admitted with rib fractures between November 2010 and

December 2014 were included in our analyses. We evaluated the cost-effectiveness of treatments, comparing those who received TEA to those who did not receive TEA.

This study was approved by the hospital's institutional review board (IRB) and by the IRB of a collaborating university.

Data acquisition and management

All data were exported from the trauma registry of St. Vincent Hospital in Indianapolis, Indiana. We compared ICD9 codes of each patient with the written reports of their injuries to determine the presence, number, and location of rib fractures as well as the incidence of associated injuries (e.g., flail segments). The characteristics of injury were compiled with demographic records, modes of treatment, and treatment outcomes. Where data only existed as written reports (e.g., mechanism of injury), we quantified those variables numerically. Wherever the timing of treatment was important (e.g., timing of intubation), we compared the time stamps of the relevant procedure codes with the time of admission.

Outcomes

The primary outcome was treatment cost, both to the patient and to the hospital. In investigating the predictors of cost, we analyzed interrelationships between patient demographics, injury severity, and the mode of treatment, particularly the administration of TEA. We also assessed the effects of mortality, pulmonary complications, mechanical ventilation, and LOS in the hospital and ICU on patient expenses and hospital costs.

Matching patient samples

Despite the seeming effectiveness of TEA when tested across the whole population, many patients were not candidates for its use. We identified 3 exclusionary criteria:

1) Patients who died within 24 hours of arrival. Patients who do not survive 24 hours often have the most severe injuries and many are unlikely to respond to any treatment. Moreover, depending on the day and time of admission, some of these patients do not survive long enough to be seen by an anesthesiologist; thus they miss the opportunity to have an epidural placed.

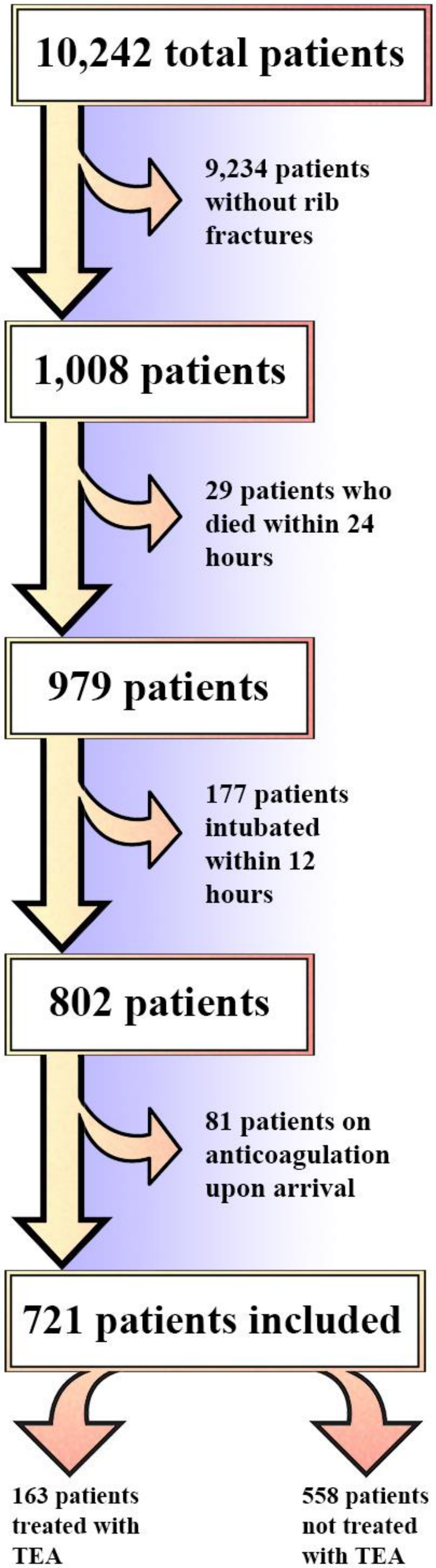
2) Patients who were intubated upon arrival or within 12 hours of admission. Many of the most severely injured patients develop respiratory failure quickly and are intubated before being seen by an anesthesiologist. A major goal of administering TEA is to avoid the need for intubation. Once intubated, patients generally have pain managed with higher doses of narcotics, are deeply sedated, and are no longer candidates for epidurals.

3) Patients who were on an anticoagulants prior to treatment. Anticoagulation medications elevate a patient’s risk of bleeding into the epidural space; this can cause spinal cord compression and paralysis. Thus TEA is typically contraindicated in these patients.

In our attempt to match patients who received TEA with those who did not receive TEA, every patient who met any of the above criteria was eliminated from analyses.

Data analyses

Discrete data (e.g., total cost of treatment) were analyzed with linear regressions. Predictor variables were eliminated if they had tolerance values ≤0.10 or variance inflation factors ≥10. If any data were missing, cases were excluded pairwise. Normal probability plots were assessed to ensure minimal deviance from line of best fit. Scatter plots were used to ensure well-distributed means and identify outliers. Group means (e.g., TEA vs. non-TEA) were compared with independent samples t-tests. Categorical data (e.g., inflexion points) were compared with chi-square tests. Analyses were conducted on the total population as well as matched samples. All statistical tests were conducted using SPSS version 22 (IBM SPSS Statistics, IBM Corporation, Chicago, IL).

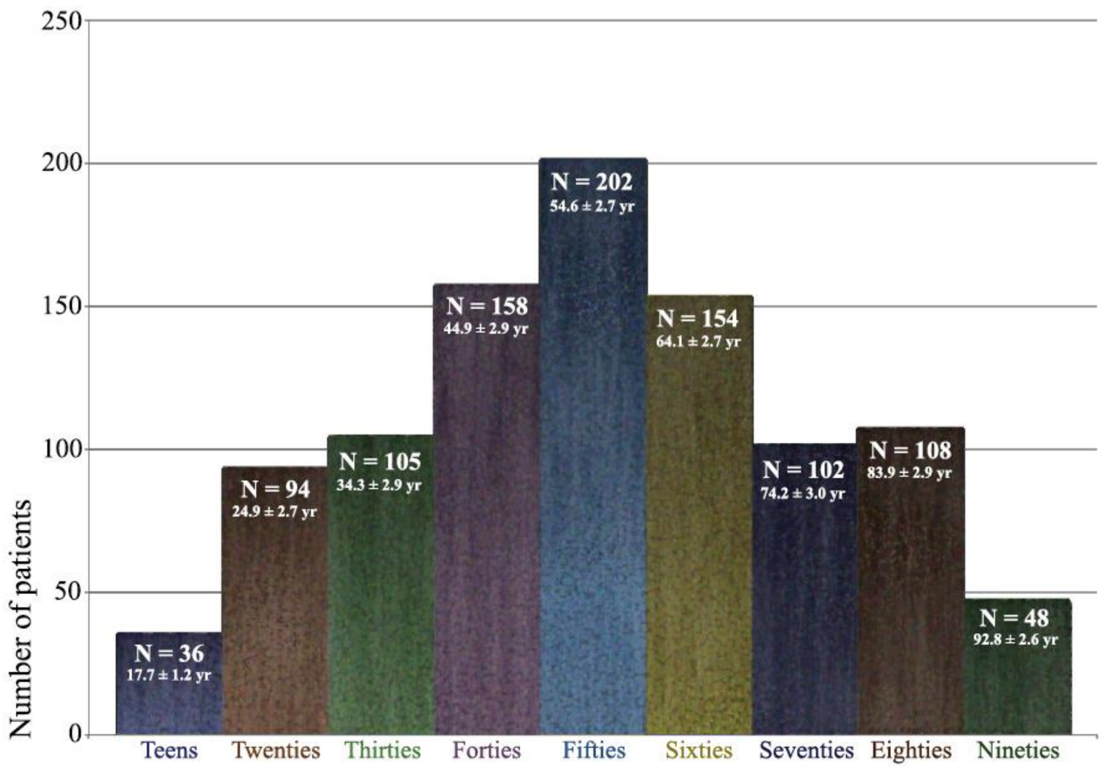


RESULTS

Population

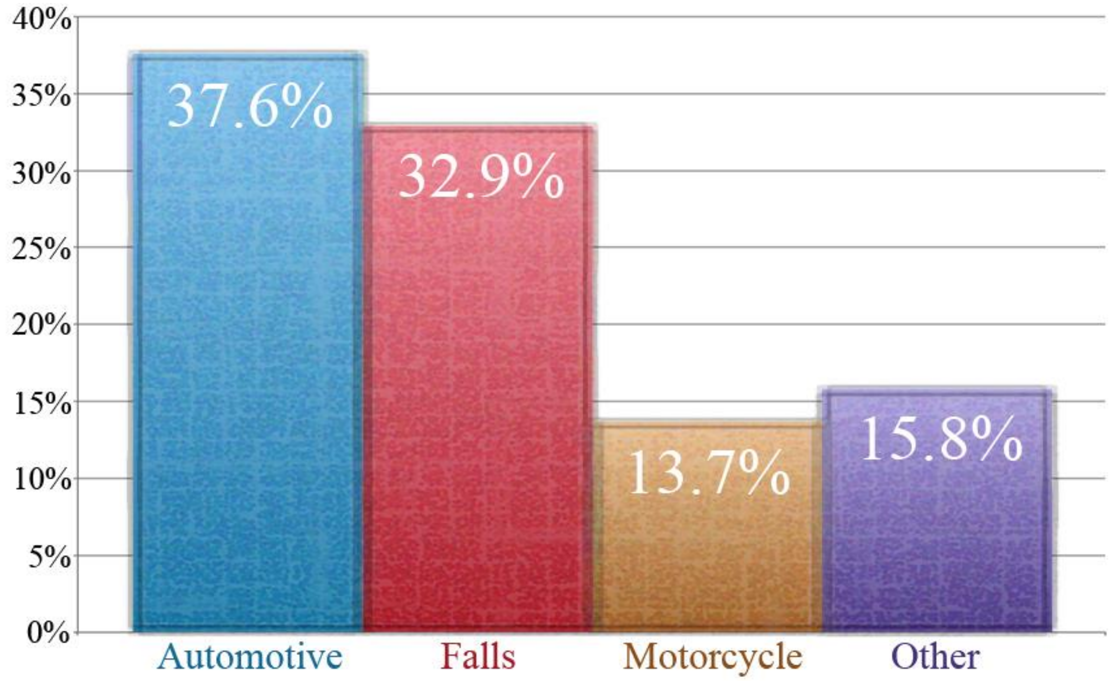
On average, patients were 55 years old, but age ranged across the lifespan, from 15 to 98 years (Figure 4.1).

Figure 4.1: Patient ages by decade (total sample)



Two-thirds of our patients were male, 92% were white, and the most common mode of injury was automotive accidents (Figure 4.2).

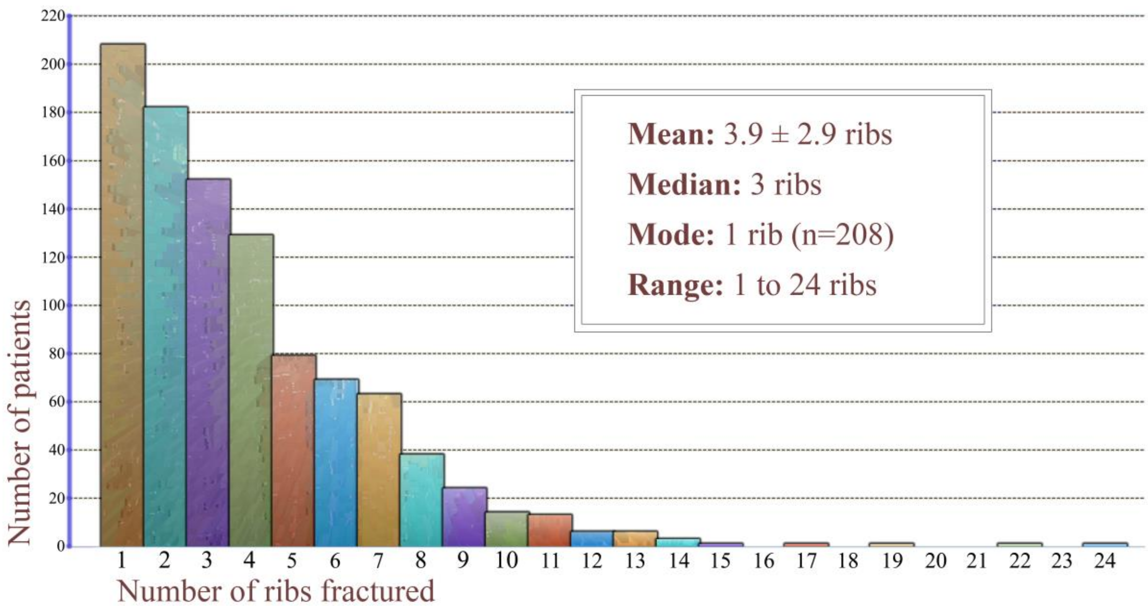
Figure 4.2: Mechanism of injury (total sample)



"Other" is a mode of injury encompassing a variety of activities. In order of most to least common: bicycle accidents, ATV accidents, firearm/bullet injuries, assault, struck by an object, pedestrian struck by a car, animal-related injuries, other motor vehicle accidents (e.g., golf carts, snowmobiles), heavy machinery accidents, and pedestrian struck by a train.

Across all mechanisms of injury, our patients presented with an average of 4 fractured ribs (Figure 4.3).

Figure 4.3: Frequency of rib fracture counts (total sample)



Patients who fractured more ribs were more likely to receive TEA. Patient demographics, injury characteristics, and treatment outcomes are displayed in Table 4.1.

Table 4.1: Patient demographics, injury characteristics, and treatment outcomes (total sample)

	Non-TEA	**TEA**	**Total Sample**	**Significance**
N	813	195	1008	
Sex	66.1% male	66.6% male	66.2% male	p = 0.871
Age (years)	54.9 ± 20.7	56.9 ± 18.4	55.3 ± 20.3	p = 0.197
# Ribs Fractured	3.5 ± 2.8	5.8 ± 2.7	3.9 ± 2.9	**p < 0.001**
Injury Severity Score	16.1 ± 10.9	16.5 ± 8.2	16.1 ± 10.4	p = 0.492
% Flail Segment	3.7%	17.4%	6.4%	**p < 0.001**
% Bilateral Fracture	13.3%	18.5%	14.7%	**p = 0.042**
% Pulmonary Contusion	18.5%	26.2%	20.0%	**p = 0.016**
% Pneumothorax	18.6%	30.3%	20.9%	**p < 0.001**
% Hemothorax	5.5%	5.6%	5.6%	p = 0.957
Glasgow Coma Score (scene)	12.7 ± 4.2	14.3 ± 2.3	13.0 ± 4.0	**p < 0.001**
Glasgow Coma Score (hospital)	12.8 ± 4.5	14.4 ± 2.3	13.1 ± 4.2	**p < 0.001**
Mortality	7.2%	1.0%	6.1%	**p = 0.001**
Pneumonia	11.4%	15.4%	12.2%	p = 0.132
Sepsis	0.9%	0.5%	0.8%	p = 0.623
Respiratory Distress	2.1%	1.5%	2.0%	p = 0.619
Respiratory Failure	1.8%	3.1%	2.1%	p = 0.279
LOS in the Hospital (days)	7.2 ± 8.7	8.7 ± 5.8	7.5 ± 8.2	**p = 0.006**
% Admitted to ICU	48.2%	63.6%	51.2%	**p < 0.001**
LOS in the ICU (days)	7.0 ± 8.6	5.8 ± 6.7	6.7 ± 8.2	p = 0.110
% Needing Ventilation	24.4%	18.5%	23.3%	p = 0.075
Ventilation duration (days)	9.0 ± 9.0	9.6 ± 8.1	9.1 ± 8.8	p = 0.689

There were several differences in injury severity but no differences in complication rates between patients who received TEA and those who did not. Patients who received TEA had one-seventh the risk of mortality but they stayed an extra day and a half in the hospital and were more commonly admitted to the ICU.

Among all patients admitted with rib fractures, the average bill for treatment was about $85k. The range was broad: from $2,448 to $985,979. The amount a patient was charged was proportionate to the length of stay (LOS) in the hospital; on average, patients were billed $11,727 per day.

Because patients treated with TEA stayed an additional day and a half, their bills were expected to be $17,590 higher. However, their average charges ($82,725) were comparable to patients who did not receive TEA ($85,425; p=0.707). This can be explained by the per-night charge of patients receiving TEA being about $3,500 less (p<0.001). In turn, part of this discrepancy can be explained by the fees associated with mortality. The average per-night charge to patients who die is 2.5 times greater than the amount survivors are charged (p<0.001). All financial data are displayed in Table 4.2.

Table 4.2: Financial data among TEA, non-TEA, survivors, and mortalities (total sample)

	Survivors	**Mortalities**	**Non-TEA**	**TEA**	**Total Sample**
N					
Total Charge to Patient	$85,599.69	$74,086.54	$85,425.09	$82,725.18	$84,902.27
Standard Deviation	$112,556.40	$72,125.19	$116,522.84	$81,205.83	$110,537.58
Direct Cost to Hospital	$11,121.78	$9,053.78	$11,169.15	$10,277.63	$10,996.51
Standard Deviation	$17,678.06	$10,747.69	$18,438.53	$11,721.28	$17,340.63
Charge:Cost Ratio	10.2:1	11.0:1	10.6:1	8.9:1	10.3:1
Standard Deviation	4.3:1	5.6:1	4.8:1	2.0:1	4.5:1
Per Night Charge	$10,824.00	$27,107.99	$12,428.13	$8,860.55	$11,726.84
Standard Deviation	$6,265.87	$18,308.10	$8,968.10	$3,668.20	$8,321.50

Although the patients who died were charged about 2.5 times more per night, survival added about $11,500 to the total charges; this is mostly a consequence of hospital LOS lasting 3.3 days longer in patients who survived.

The actual cost of care was about $11k per patient, but ranged from $143 to $148,594. Furthermore, although the direct cost to the hospital was similar between patients who did and did not receive TEA, the charge-to-cost ratio was lower in patients receiving TEA (p<0.001), resulting in a lower profit margin among patients treated with TEA.

Group differences between patients who received TEA and survived, patients who received TEA and died, patients who did not receive TEA and survived, and patients who did not receive TEA and died are displayed in Table 4.3.

Table 4.3: Financial data among TEA survivors, TEA mortalities, non-TEA survivors, and non-TEA mortalities (total sample)

	TEA Mortality	**TEA** Survivors	**noTEA** Mortality	**noTEA** Survivors
N	2	193	59	754
Age (years)	83.0 ± 4.2	56.7 ± 18.3	58.6 ± 22.3	54.6 ± 20.5
# Ribs Fractured	7.0 ± 0	5.8 ± 2.7	6.0 ± 4.5	3.3 ± 2.5
Injury Severity Score	13.5 ± 5.0	16.6 ± 8.2	29.1 ± 15.8	15.0 ± 9.8
LOS in Hospital (days)	12.5 ± 16.3	8.6 ± 5.7	4.1 ± 5.9	7.5 ± 8.9
% Admitted to ICU	100%	63.2%	64.4%	46.9%
LOS in ICU (days)	12.0 ± 15.6	5.7 ± 6.5	4.7 ± 4.9	7.2 ± 8.9
% Needing Ventilation	50%	18.1%	67.8%	21.0%
Vent duration (days)	15 ± 0.0	9.5 ± 8.1	3.9 ± 4.7	10.3 ± 9.3
Total Charge to Patient	$117,936.16	$82,360.30	$72,600.11	$86,429.97
SD	$144,507.69	$80,878.10	$70,376.35	$119,360.46
Direct Cost to Hospital	$16,516.83	$10,212.98	$8,800.79	$11,354.72
SD	$20,492.81	$11,671.45	$10,500.94	$18,912.26
Charge:Cost Ratio	7.4:1	8.9:1	11.2:1	10.6:1
SD	0.5:1	2.0:1	5.9:1	4.7:1
Per Night Charge	$12,462.70	$8,823.22	$27,660.64	$11,343.02
SD	$4,654.31	$3,653.28	$18,414.70	$6,685.89

Patients who received TEA and survived had higher injury severity scores (ISS)

than patients who did not receive TEA and died (p<0.001). Age and number of fractured ribs were similar. Patients who were not treated with TEA and died were 3.7 times more likely to need mechanical ventilation (p<0.001) than the survivors who were treated with TEA (p<0.001). However, if ventilated, survivors who were treated with TEA remained on ventilation for an additional 5.6 days (p=0.001). Survivors who received TEA also stayed in the hospital for an additional 4.5 days (p<0.001) than those who did not receive TEA and died.

If the average nightly charge of $11,726.84 were multiplied by the 4.5 additional days, the excess fees accumulated by the survivors who received TEA would be $52,770.78. However, the average bill for these survivors only exceeded that of the patients who did not receive TEA and died by $9,760.19. The difference was not significant (p=0.404). This is partly explained by discrepancies in nightly charges: survivors who received TEA were charged $18,837.42 less per day LOS than the patients who did not receive TEA and died (p<0.001). Much of this is accounted for by the charge-to-cost ratio. Patients who did not receive TEA and died had a charge-to-cost ratio that was about 26% higher than patients who received TEA and survived (p<0.001). Although it cost the hospital about $1,400 more to deliver care to the TEA patients who survived, the difference was not significant (p=0.406), the hospital billed those patients nearly $10,000 more (also insignificant: p=0.404), and the patients lived to pay the bills. The hospital collected 38% of the bill from TEA survivors and 32% from patients who did not receive TEA and died.

Variables that predict the price and cost of treatment across the total sample

Variables that predict total charges to the patient:

When tested individually, the variables that predict charges to the patient are: age (r = -0.145; p<0.001), number of fractured ribs (r = 0.202; p<0.001), presence of bilateral fractures (r = 0.231; p<0.001), presence of a flail segment (r = 0.105; p=0.001), presence of a pulmonary contusion (r = 0.230; p<0.001), presence of a pneumothorax (r = 0.121; p<0.001), presence of a hemothorax (r = 0.067; p=0.034), ISS (r = 0.532; p<0.001), use of mechanical ventilation (r = 0.604; p<0.001), duration of ventilation (r = 0.782; p<0.001), hospital LOS (r = 0.907; p<0.001), ICU LOS (r = 0.843; p<0.001), incidence of pneumonia (r = 0.463; p<0.001), incidence of respiratory distress syndrome (r = 0.261; p<0.001), acute respiratory failure (r = 0.203; p<0.001), and sepsis (r = 0.167; p<0.001).

Sex (p=0.329) and use of TEA (p=0.760) were not significant predictors on their own, but emerged as significant when tested in a prediction equation. At the same time, many other variables lost their significance, owing to shared explanatory power. For example, the number of fractured ribs was closely correlated with the presence of bilateral fractures (r = 0.427; p<0.001), the presence of a flail segment (r = 0.369; p<0.001), and ISS (r = 0.379; p<0.001). In turn, ISS was closely correlated with the presence of bilateral fractures (r = 0.239; p<0.001), hospital LOS (r = 0.442; p<0.001), and the use of mechanical ventilation (r= 0.507; p<0.001). When tested in the full equation, the only variables that maintained significance were:

$R^2 = 0.867$

Error: 40,444.237

F = 719.862

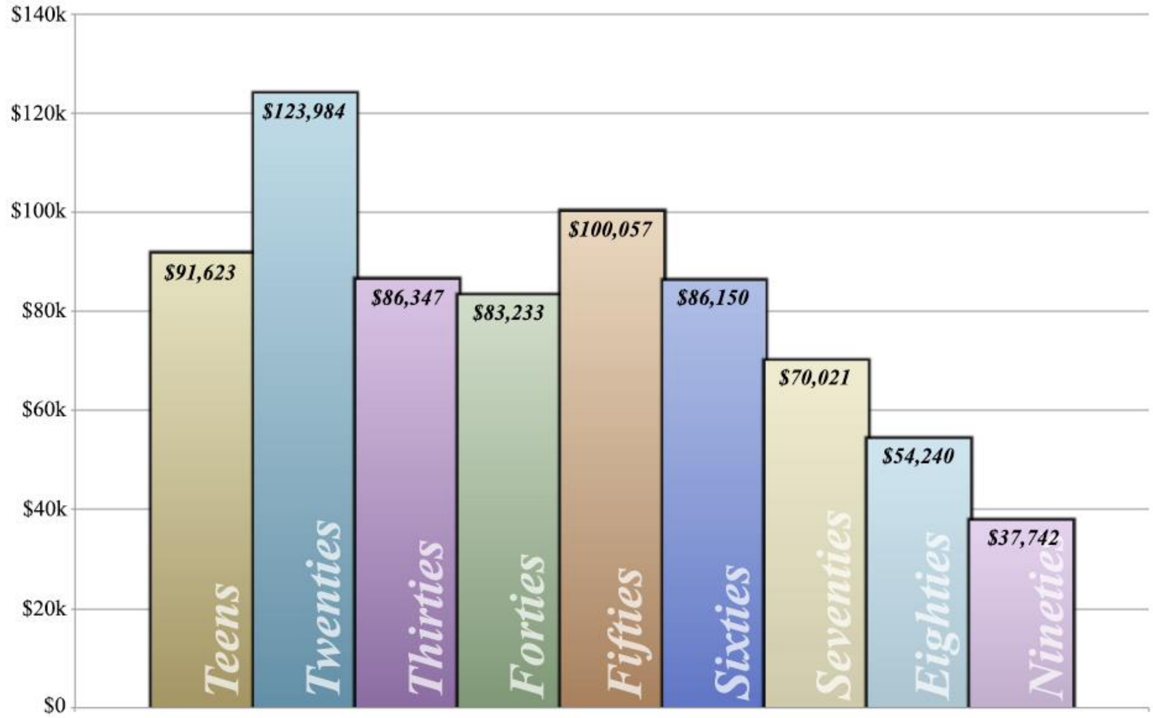
p < 0.001

DF (regression): 9
DF (residual): 991
DF (total): 1,000

Age: β = -319.27 (standardized: -0.059); p<0.001
Sex: β = 5,135.87 (standardized: 0.022); p=0.065
ISS: β = 1,162.66 (standardized: 0.110); p<0.001
Hospital LOS: β = 9,277.65 (standardized: 0.692); p<0.001
ICU LOS: β = 3,240.35 (standardized: 0.198); p<0.001
Use of ventilation: β = 13,271.76 (standardized: 0.051); p=0.002
Use of TEA: β = -15,358.74 (standardized: -0.055); p<0.001
Acute respiratory failure: β = 16,773.66 (standardized: 0.022); p=0.069
Pneumonia: β = -21,143.51 (standardized: -0.063); p<0.001

All tolerance values were >0.20 and variance inflation factors <5. In this model, if all other variables were held constant, each additional year of age predicts a $319 reduction in patient charges. Some of this relationship can be attributed to the decreasing medical expenses among patients above the age of 70. In turn, some of that relationship was related to increasing mortality, as there was an inflexion point at age 80. Among patients ≥ 80 years, the mortality rate was 11.5%; among patients ≤ 79 years, the mortality rate was 5.1% (p=0.002). Age also reflected injury severity. Patients who were < 70 years had an ISS that was 4.7 points higher than patients who were ≥ 70 years (p<0.001). Patient billing as it relates to age is illustrated in Figure 4.4.

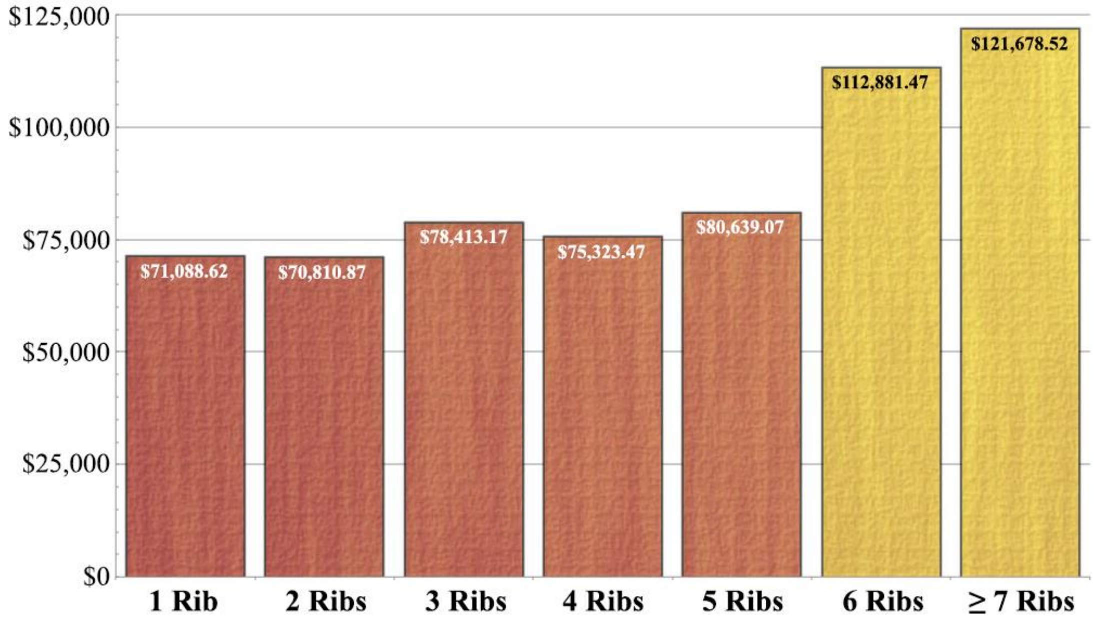
Figure 4.4: Average patient fees based on decade of age (total sample)



There was a trend for men to be billed more than women. Sex was related to both age and injury severity. On average, men were younger than women (52.4 ± 18.5 vs. 60.9 ± 22.3 yrs; p<0.001), fractured more ribs (4.0 ± 3.1 vs. 3.7 ± 2.5; p=0.049), had a higher ISS (16.7 ± 10.3 vs. 15.1 ± 10.7; p=0.018), a higher incidence of flail segments (7.5% vs. 4.1%; p=0.036), were more likely to require mechanical ventilation (26.3% vs. 17.5%; p=0.002), and were more likely to acquire pneumonia (14.0% vs. 8.8%; p=0.018).

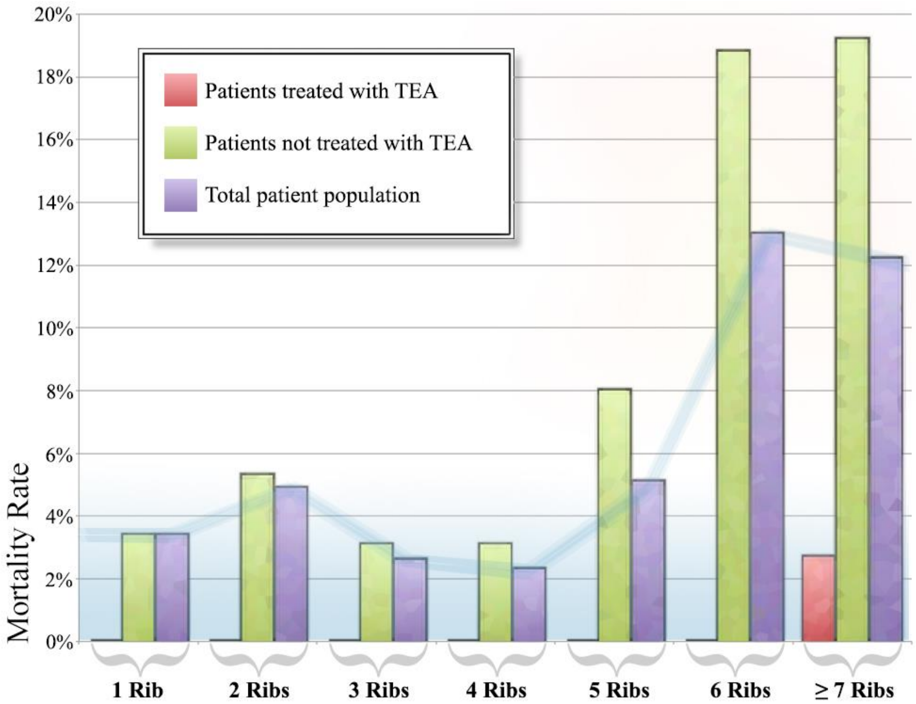
Among all assessments of injury severity, ISS was the strongest predictor of patient billing. When tested on its own, the number of ribs fractured was a relatively strong predictor (r = 0.202; p<0.001) and there was an inflexion point at 6 ribs (Figure 4.5).

Figure 4.5: Average patient charges based on number of ribs fractured (total sample)



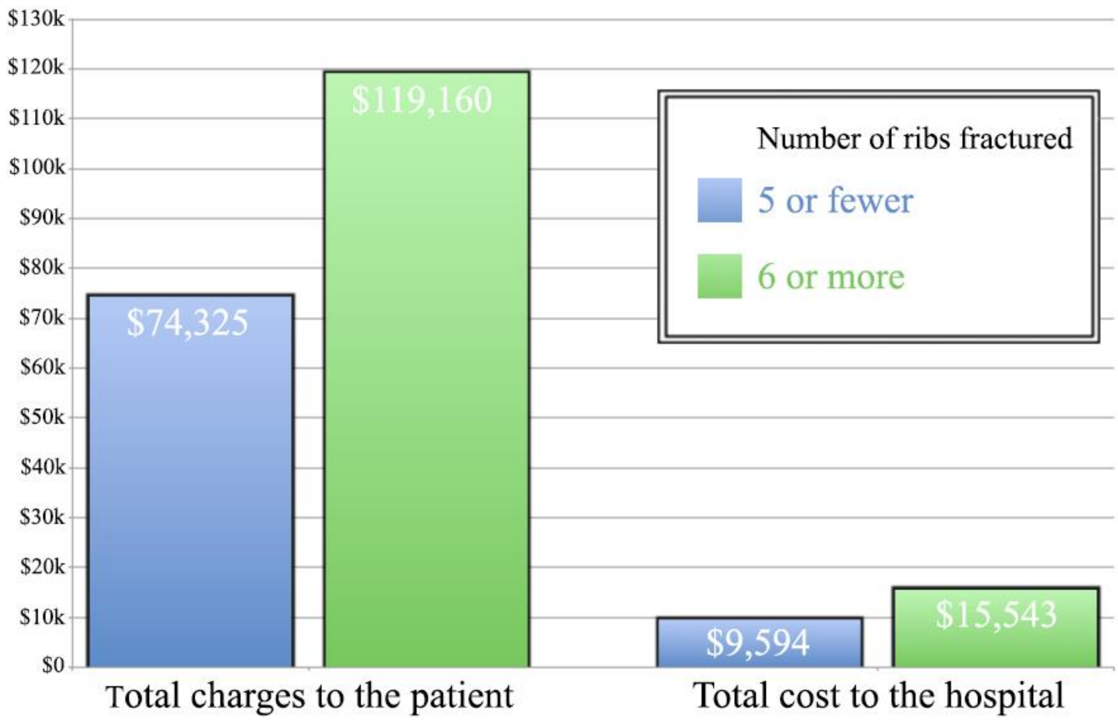
This same inflexion point (6 ribs) predicted patient mortality (Figure 4.6).

Figure 4.6: Mortality rate based on number of ribs fractured (total sample)



If patients were below the inflexion point of 6 ribs, there was a significant reduction in the amount of money billed to the patient ($p<0.001$) as well as the cost to the hospital of delivering that care ($p<0.001$). Figure 4.7 illustrates these differences.

Figure 4.7: Average price and cost of treatment based on number of ribs fractured (total sample)



In the full model, the number of ribs fractured and ISS shared predictive power. Only ISS remained significant. With all other variables held constant, each additional point of severity (scores range from 1 to 75) predicts a $1,163 increase in the patient's bill.

The number of days a patient spent both in the hospital and the ICU predicted patient billing as well. In the hospital, with all other variables held constant, each

additional day added $9,278 while each additional day in the ICU added $3,240. The use of mechanical ventilation increased the predicted bill by $13,272 while the use of TEA decreased the bill by $15,359. There was a trend (p=0.069) for the incidence of acute respiratory failure to predict a $16,774 increase in the patient's bill. On average, patients who developed pneumonia were charged $222,124.51 while patients who did not develop pneumonia were charged $65,809.13 (p<0.001). However, in the model, if all other variables are held constant, incidence of pneumonia predicted a $21,144 decrease in the patient's bill. The diagnosis of pneumonia was related to a number of other variables, including sex, number of fractured ribs, incidence of bilateral fractures, presence of flail segments and pulmonary contusions, ISS, the use of mechanical ventilation, LOS in both the hospital and ICU, respiratory distress syndrome, acute respiratory failure, and sepsis. Among unmatched samples, it's difficult to understand the complexity of the relationship between pneumonia and patient billing.

Variables that predict total cost to the hospital:

When tested individually, the variables that predict treatment cost to the hospital are: age (r = -0.139; p<0.001), number of fractured ribs (r = 0.169; p<0.001), presence of bilateral fractures (r = 0.248; p<0.001), presence of a flail segment (r = 0.092; p=0.003), presence of pulmonary contusions (r = 0.195; p<0.001), presence of a pnumothorax (r = 0.135; p<0.001), presence of a hemothorax (r = 0.063; p = 0.047), ISS (r = 0.498; p<0.001), use of mechanical ventilation (r = 0.567; p<0.001), duration of ventilation (r = 0.710; p<0.001), hospital LOS (r = 0.866; p<0.001), ICU LOS (r = 0.826; p<0.001), incidence of pneumonia (r = 0.447; p<0.001), incidence of respiratory distress syndrome

(r = 0.230; p<0.001), acute respiratory failure (r = 0.197; p<0.001), and sepsis (r = 0.148; p<0.001)

The use of TEA (p=0.519) was not a significant predictor on its own, but emerged as significant when tested in the full model. Other variables lost significance when tested in combination with other predictors. The only variables that maintained significance were:

$R^2 = 0.806$
Error: 7,683.905
F = 361.920
p < 0.001
DF (regression): 11
DF (residual): 959
DF (total): 970

Age: β = -40.15 (standardized: -0.047); p=0.002
Number of fractured ribs: β = -430.60 (standardized: -0.072); p<0.001
ISS: β = 192.49 (standardized: 0.116); p<0.001
Bilateral fractures: β = 3,749.13 (standardized: 0.076); p<0.001
Pulmonary contusion: β = -1,405.69 (standardized: -0.032); p=0.036
Pneumothorax: β = 1,639.04 (standardized: 0.038); p=0.009
Hospital LOS: β = 1,255.92 (standardized: 0.597); p<0.001
ICU LOS: β = 738.47 (standardized: 0.288); p<0.001
Use of TEA: β = -2,114.01 (standardized: -0.048); p=0.002
Acute respiratory failure: β = 3,247.63 (standardized: 0.027); p=0.068
Pneumonia: β = -2,931.41 (standardized: -0.055); p=0.002

All tolerance values were >0.20 and variance inflation factors <5. In this model, holding all other variables constant, the use of TEA predicted a reduction of hospital expenses by $2,114.

Matched samples: Characteristics of eliminated patients

The criteria for exclusion were: 1) mortality within 24 hours of admission, 2) intubation within 12 hours of admission, and 3) use of anticoagulation medication prior to treatment. All patients who met one or more of those criteria were eliminated form the database.

29 patients died within 24 hours of arrival. The characteristics of these patients are displayed in Table 4.4.

Table 4.4: Characteristics of patients who died within 24 hours of admission

	Died within 24h	Survived 24h	Significance
N	29	979	
Sex	79.3% male	65.8% male	$p = 0.129$
Age (years)	50.6 ± 23.0	55.4 ± 20.2	$p = 0.270$
# Ribs Fractured	6.8 ± 5.1	3.9 ± 2.8	**$p = 0.007$**
Injury Severity Score	31.1 ± 15.8	15.7 ± 9.9	**$p < 0.001$**
% Flail Segment	24.1%	5.8%	**$p < 0.001$**
% Bilateral Fracture	48.1%	13.7%	**$p < 0.001$**
% Pulmonary Contusion	44.8%	19.2%	**$p = 0.001$**
% Pneumothorax	20.7%	20.9%	$p = 0.982$
% Hemothorax	34.5%	4.7%	**$p < 0.001$**
Total Charge to Patient	$28,694.13	$86,568.97	**$p < 0.001$**
SD	$19,386.86	$111,686.65	
Direct Cost to Hospital	$2,890.83	$11,236.86	**$p < 0.001$**
SD	$3,311.86	$17,529.99	
Charge:Cost Ratio	13.0:1	10.2:1	$p = 0.059$
SD	7.5:1	4.3:1	
Per Night Charge	$30,448.85	$11,294.12	**$p < 0.001$**
SD	$20,061.56	$7,289.93	

202 patients were intubated within 12 hours of admission. The characteristics of these patients are displayed in Table 4.5.

Table 4.5: Characteristics of patients who were intubated within 12 hours of admission

	Intubated within 12h	Not intubated during first 12h	Significance
N	202	806	
Sex	73.8% male	64.3% male	**$p = 0.011$**
Age (years)	48.7 ± 18.3	56.9 ± 20.4	**$p < 0.001$**
# Ribs Fractured	5.0 ± 4.1	3.7 ± 2.5	**$p < 0.001$**
Injury Severity Score	20.7 ± 13.5	13.4 ± 7.4	**$p < 0.001$**
% Mortality	22.3%	2.0%	**$p < 0.001$**
% Flail Segment	11.9%	5.0%	**$p < 0.001$**
% Bilateral Fracture	28.9%	11.0%	**$p < 0.001$**
% Pulmonary Contusion	40.6%	14.8%	**$p < 0.001$**
% Pneumothorax	26.7%	19.4%	**$p = 0.021$**
% Hemothorax	11.9%	4.0%	**$p < 0.001$**
Total Charge to Patient	$203,806.10	$55,065.53	**$p < 0.001$**
SD	$172,367.43	$58,457.75	
Direct Cost to Hospital	$28,181.02	$6,684.37	**$p < 0.001$**
SD	$27,706.01	$9,567.03	
Charge:Cost Ratio	8.9:1	10.6:1	**$p < 0.001$**
SD	3.8:1	4.5:1	
Per Night Charge	$16,817.30	$10,494.54	**$p < 0.001$**

SD	$11,582.12	$6,748.00	

91 patients were on an anticoagulation medication upon arrival at the hospital. The characteristics of these patients are displayed in Table 6.

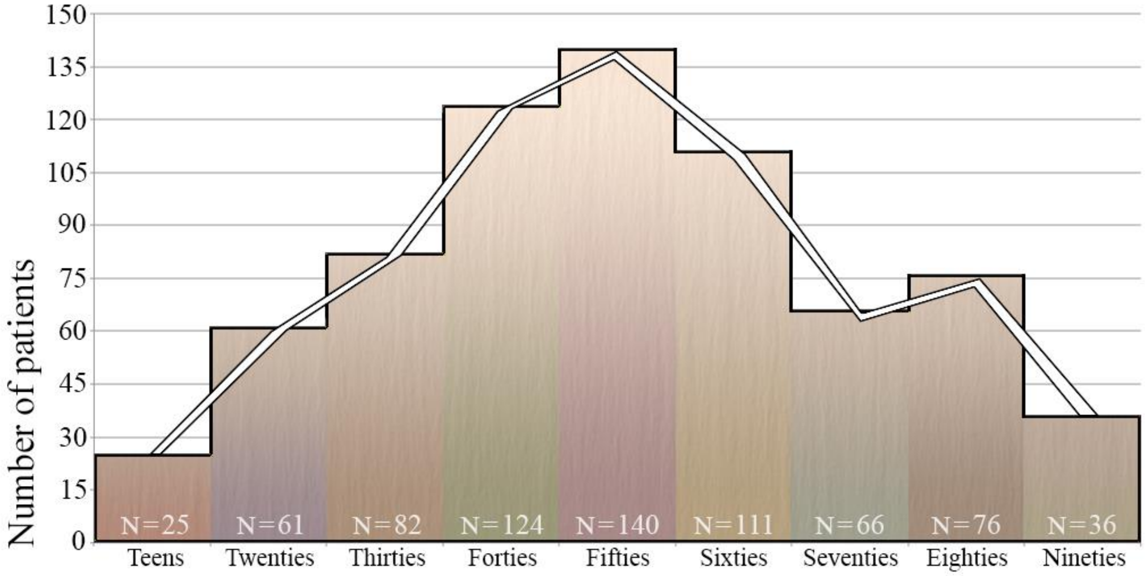
Table 4.6: Characteristics of patients who were on anticoagulation medication upon arrival at the hospital

	Anticoagulation on arrival	**No anticoagulation on arrival**	**Significance**
N	91	917	
Sex	61.5% male	66.6% male	p = 0.327
Age (years)	73.2 ± 13.3	53.5 ± 20.0	**p < 0.001**
# Ribs Fractured	3.9 ± 3.1	3.9 ± 2.9	p = 0.915
Injury Severity Score	12.7 ± 7.3	16.5 ± 10.7	**p < 0.001**
% Mortality	2.2%	6.4%	p = 0.106
% Flail Segment	8.8%	6.1%	p = 0.318
% Bilateral Fracture	15.6%	14.6%	p = 0.799
% Pulmonary Contusion	7.7%	21.2%	**p = 0.002**
% Pneumothorax	7.7%	22.2%	**p = 0.001**
% Hemothorax	6.6%	5.5%	p = 0.652
Total Charge to Patient	$78,596.59	$85,528.71	p = 0.569
SD	$104,814.03	$111,125.16	
Direct Cost to Hospital	$9,539.27	$11,141.28	p = 0.401
SD	$14,367.70	$17,608.69	
Charge:Cost Ratio	10.1:1	10.3:1	p = 0.683
SD	3.7:1	4.5:1	
Per Night Charge	$10,744.37	$11,838.00	p = 0.234
SD	$8,791.09	$8,267.10	

Patient characteristics across matched samples (n=721)

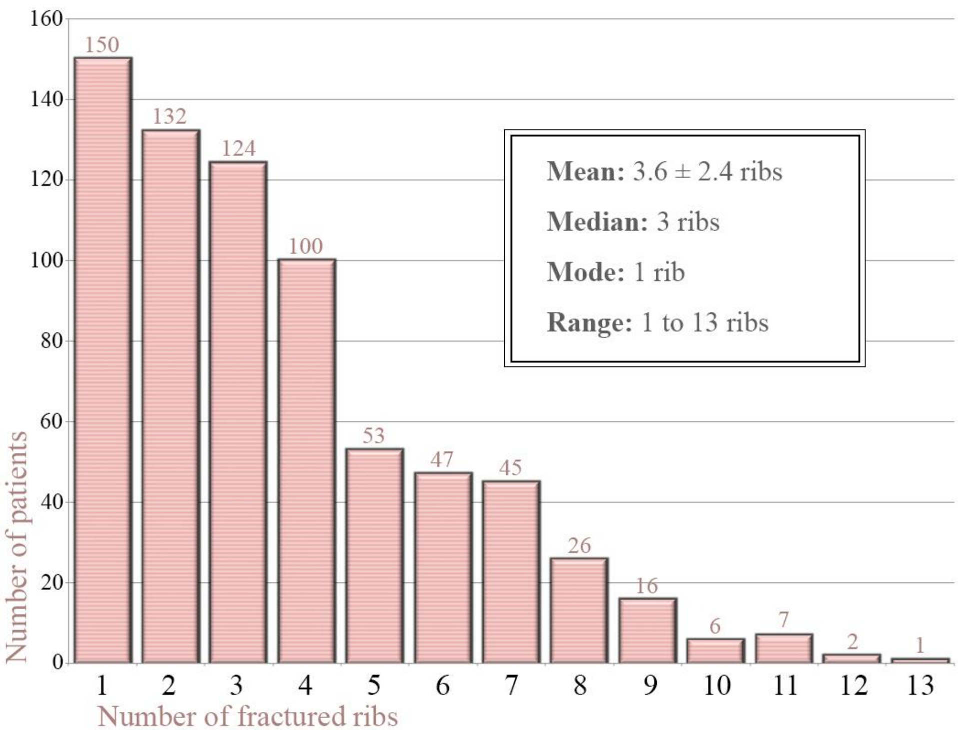
287 patients met criteria for exclusion and were eliminated from the database. Among the remaining patients, the average age was still 55 years, and still spanned 15 to 98 years (Figure 4.8).

Figure 4.8: Patient ages by decade (matched sample)



On average, patients fractured 3.6 ribs (compared to 3.9 prior to exclusion). The distribution of rib fracture counts is displayed in Figure 4.9.

Figure 4.9: Frequency of rib fracture counts (matched sample)



After eliminating patients who met exclusionary criteria, the mean ISS was 0.4 points lower, the overall mortality rate fell from 6.1% to 1.7%, the rate of pneumonia fell from 12.2% to 6.7%, and the average patient charges were decreased by $29,691 (Table 4.7).

Table 4.7: Demographics, injury characteristics, treatment outcomes, and financial data (matched samples)

	Non-TEA	**TEA**	**Total Sample**	**Significance**
N	558	163	721	
Sex	64.7% male	65.0% male	64.8% male	p = 0.937
Age (years)	54.5 ± 20.6	56.9 ± 8.6	55.0 ± 20.2	p = 0.188
# Ribs Fractured	3.1 ± 2.1	5.5 ± 2.4	3.6 ± 2.4	**p < 0.001**
Injury Severity Score	13.0 ± 7.2	15.7 ± 7.5	13.6 ± 7.4	**p < 0.001**
% Flail Segment	2.0%	12.9%	4.4%	**p < 0.001**
% Bilateral Fracture	9.0%	16.4%	10.6%	**p = 0.008**
% Pulmonary Contusion	12.9%	23.9%	15.4%	**p = 0.001**
% Pneumothorax	19.0%	27.6%	20.9%	**p = 0.018**
% Hemothorax	3.1%	5.5%	3.6%	p = 0.137
Glasgow Coma Score (scene)	14.5 ± 1.8	14.5 ± 1.5	14.5 ± 1.7	p = 0.728
Glasgow Coma Score (hospital)	14.7 ± 1.5	14.7 ± 1.0	14.7 ± 1.4	p = 0.432
Mortality	2.0%	0.6%	1.7%	p = 0.233
Pneumonia	5.4%	11.0%	6.7%	**p = 0.011**
Sepsis	0.5%	0.6%	0.6%	p = 0.909
Respiratory Distress	0.5%	1.8%	0.8%	p = 0.107
Respiratory Failure	0.9%	2.5%	1.2%	p = 0.115
LOS in the Hospital (days)	5.0 ± 5.0	7.9 ± 5.1	5.6 ± 5.2	**p < 0.001**
% Admitted to ICU	37.1%	58.2%	41.9%	**p < 0.001**
LOS in the ICU (days)	3.5 ± 3.8	4.9 ± 5.9	4.0 ± 4.6	**p = 0.047**
% Needing Ventilation	5.6%	9.8%	6.6%	p = 0.056
Ventilation duration (days)	6.8 ± 5.1	11.5 ± 7.4	8.4 ± 6.3	**p = 0.013**
Total Charge to Patient	$51,017.77	$69,543.28	$55,211.74	**p < 0.001**
Standard Deviation	$57,148.23	$62,645.14	$58,906.15	
Direct Cost to Hospital	$6,259.20	$8,374.47	$6,738.07	**p = 0.015**
Standard Deviation	$10,062.93	$8,652.35	$9,795.83	
Charge:Cost Ratio	11.2:1	9.0:1	10.7:1	**p < 0.001**
Standard Deviation	5.0:1	1.9:1	4.6:1	
Per Night Charge	$11,210.34	$8,308.50	$10,546.01	**p < 0.001**
Standard Deviation	$7,206.33	$3,203.64	$6,622.14	

Patients who received TEA had more severe injuries than those who did not. The TEA patients fractured 2.4 more ribs, were 6.5 times more likely to present with a flail segment, had nearly double the rates of bilateral fractures and pulmonary contusions,

were 1.5 times more likely to present with a pneumothorax, and had a mean ISS that was 2.7 points higher. The TEA patients were also 1.6 times more likely to be admitted to the ICU and 1.8 times more likely to require mechanical ventilation. Among all patients who received ventilation, the TEA group remained on it for an additional 4.7 days. They also remained in the ICU an additional 1.4 days and in the hospital for an additional 2.9 days. Patients receiving TEA had 1.8 times the incidence of pneumonia, but there were no other differences in complication rates. Despite large differences in injury severity, there were no significant differences in mortality.

Patients were billed about $55,000 for treatment, ranging from $3,792 to $496,315. Billing was proportionate to hospital LOS; on average, patients were billed $10,546 per day. The actual cost of care was $6,738 per patient, but ranged from $143 to $124,522 (Table 4.8).

Table 4.8: Treatment cost among survivors and mortalities (matched samples)

	Survivors	**Mortalities**	**Total Sample**	**Significance**
N	709	12	721	
Total Charge to Patient	$54,101.34	$120,725.74	$55,211.74	**p = 0.018**
Standard Deviation	$57,850.53	$83,339.22	$58,906.15	
Direct Cost to Hospital	$6,576.26	$16,284.82	$6,738.07	**p = 0.016**
Standard Deviation	$9,687.85	$11,781.33	$9,795.83	
Charge:Cost Ratio	10.7:1	8.2:1	10.7:1	p = 0.056
Standard Deviation	4.6:1	1.9:1	4.6:1	
Per Night Charge	$10,449.08	$16,200.74	$10,546.01	p = 0.063
Standard Deviation	$6,526.31	$9,613.73	$6,622.14	

Overall, the patients who died were charged 2.2 times more than those who survived and their treatment cost the hospital 2.5 times more. Treatment of patients who received TEA cost the hospital an additional $2,115, but they were charged $18,526 more. Despite these differences, the charge-to-cost ratio among patients not treated with TEA was 24% higher.

Group differences between patients who received TEA and survived, patients who received TEA and died, patients who did not receive TEA and survived, and patients who did not receive TEA and died are displayed in Table 4.9.

Table 4.9: Patient characteristics and financial data among TEA survivors, TEA mortalities, non-TEA survivors, and non-TEA mortalities (matched samples)

	TEA Mortality	**TEA** Survivors	**noTEA** Mortality	**noTEA** Survivors
N	1	162	11	547
Age (years)	86	56.7 ± 18.5	70.8 ± 22.6	54.2 ± 20.5
# Ribs Fractured	7	5.5 ± 2.4	4.2 ± 2.5	3.1 ± 2.1
Injury Severity Score	17	15.7 ± 7.5	14.1 ± 6.7	12.9 ± 7.2
% Flail Segment	No	13.0%	0%	2.0%
% Bilateral Fracture	No	16.5%	0%	9.1%
% Pulmonary Contusion	No	24.1%	0%	13.2%
LOS in Hospital (days)	24	7.8 ± 5.0	8.0 ± 7.2	4.9 ± 4.9
% Admitted to ICU	Yes	58.0%	90.9%	36.0%
LOS in ICU (days)	23	4.7 ± 5.7	6.9 ± 4.9	3.4 ± 3.7
% Needing Ventilation	Yes	9.3%	63.6%	4.4%
Vent duration (days)	15	11.3 ± 7.6	7.6 ± 4.7	6.5 ± 5.3
Total Charge to Patient	$220,118.52	$68,613.81	$111,690.03	$49,795.44
SD	NA	$61,701.65	$81,007.83	$55,996.73
Direct Cost to Hospital	$31,007.43	$8,234.76	$14,946.40	$6,084.18
SD	NA	$8,492.75	$11,359.30	$9,969.20
Charge:Cost Ratio	7.1:1	9.0:1	8.3:1	11.2:1
SD	NA	1.9:1	1.9:1	5.1:1
Per Night Charge	$9,171.61	$8,303.17	$16,839.75	$11,095.24
SD	NA	$3,212.85	$9,812.04	$7,109.12

Among patients who did not receive TEA, those who died had larger bills (p=0.030) and were more expensive to treat (p=0.004). Although they had a lower charge-to-cost ratio (p=0.053), their charges per day were much higher (p=0.009). Only 1 patient who received TEA died. Patients who received TEA and survived can be compared to those who did not receive TEA and died.

Compared to patients who were not treated with TEA and died, the survivors who received TEA were 14 years younger (p=0.017) but exhibited trends of more severe injuries: they fractured 1.3 more ribs (p=0.079) and nearly a quarter presented with

pulmonary contusions, compared to none (p=0.064). Despite differences in injury severity, survivors who received TEA were less likely to be admitted to the ICU (p=0.031) and less likely to require mechanical ventilation (p<0.001). Owing to small samples, differences in ICU LOS (p=0.233) and duration of ventilation (p=0.251) were not significant.

Compared to survivors who were treated with TEA, patients who did not receive TEA and died were charged 63% more ($43,076; p=0.112) and cost the hospital 82% more ($6,712; p=0.081). Larger samples would be needed to confirm these trends. The daily charge to patients who receive TEA and survive is half that of patients who do not receive TEA and die (p=0.016).

Variables that predict the price and cost of treatment across matched samples (n=721)

Variables that predict total charges to the patient:

When tested individually, the variables that predict patient billing are: Number of fractured ribs (r = 0.220; p<0.001), presence of bilateral fractures (r = 0.227; p<0.001), presence of a flail segment (r = 0.086; p=0.021), presence of a pulmonary contusion (r = 0.163; p<0.001), ISS (r = 0.449; p<0.001), use of TEA (r = 0.132; p<0.001), use of mechanical ventilation (r = 0.600; p<0.001), duration of ventilation (r = 0.752; p<0.001), hospital LOS (r = 0.853; p<0.001), ICU LOS (r = 0.799; p<0.001), incidence of pneumonia (r = 0.411; p<0.001), incidence of respiratory distress syndrome (r = 0.339; p<0.001), acute respiratory failure (r = 0.148; p<0.001), sepsis (r = 0.238; p<0.001), and mortality (r = 0.145; p<0.001).

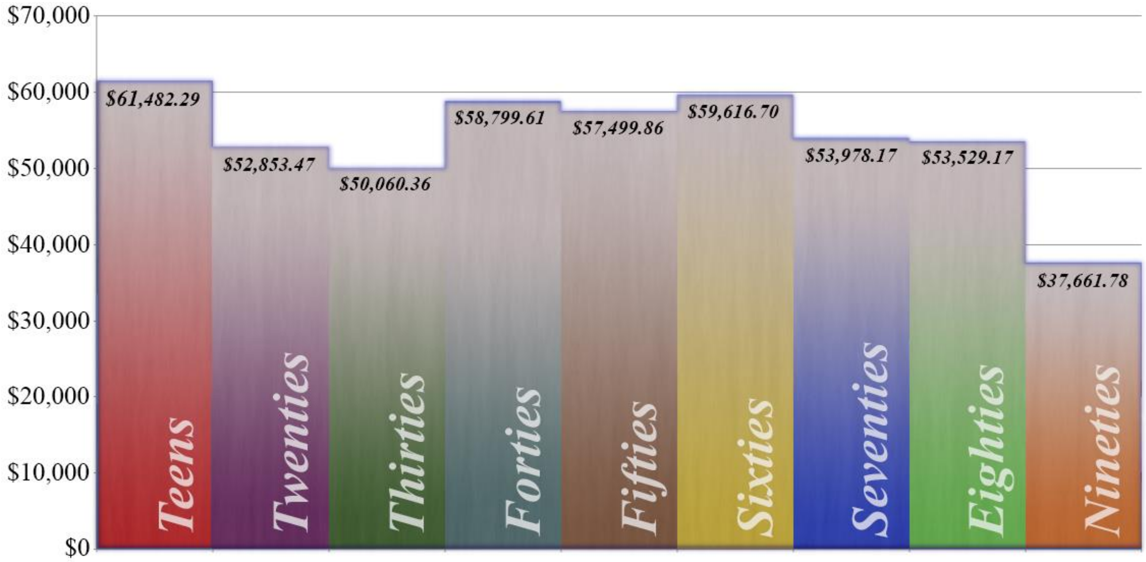
Age (r = -0.024; p=0.526) was not a significant predictor on its own, but emerged as significant when tested in combination with other variables. When tested in the full equation, the only variables that maintained significance were:

$R^2 = 0.803$
Error: 26,279.510
F = 399.419
p < 0.001
DF (regression): 7 DF (residual): 686 DF (total): 693

Age: β = -191.02 (standardized: -0.066); p<0.001
ISS: β = 869.56 (standardized: 0.109); p<0.001
Bilateral fractures: β = 11,220.99 (standardized: 0.059); p=0.001
Hospital LOS: 6,747.57 (standardized: 0.593); p<0.001
ICU LOS: β = 4,771.47 (standardized: 0.289); p<0.001
Use of TEA: β = -12,072.81 (standardized: -0.086); p<0.001
Respiratory distress syndrome: β = 26,391.65 (standardized: 0.041); p=0.025

All tolerance values were >0.30 or variance inflation factors <3. In this model, with all other variables held constant, each additional year of age predicts a $191 reduction in the patient's bill (95% CI: -291.83 to -90.22). Patient charges per decade of life are displayed in Figure 4.10.

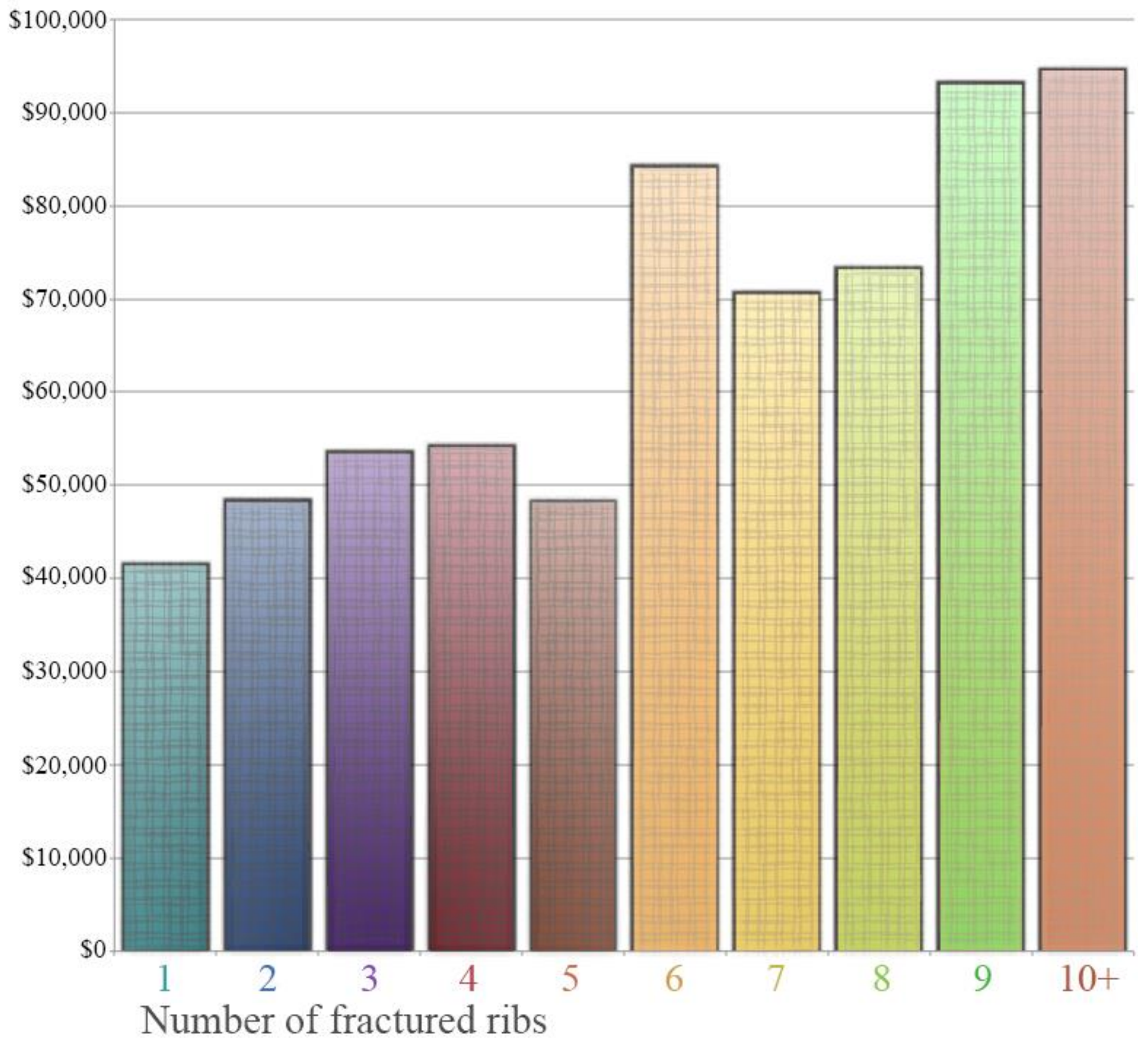
Figure 4.10: Average patient fees based on decade of age (matched sample)



Although this relationship appears to be driven by the relatively low charges to the eldest patients, if all patients ≥ 90 years of age are eliminated from the analysis, the predictive power of age maintains its strength (β = -198.21; standardized β = -0.062; p<0.001). Some of the relationship with age is a reflection of injury severity. Relative to patients ≥ 70 years of age, those younger than 70 have an ISS that is 3.0 points higher (p<0.001), are twice as likely to present with pulmonary contusions (p=0.002), and 1.7 times more likely to experience bilateral fractures (p=0.028).

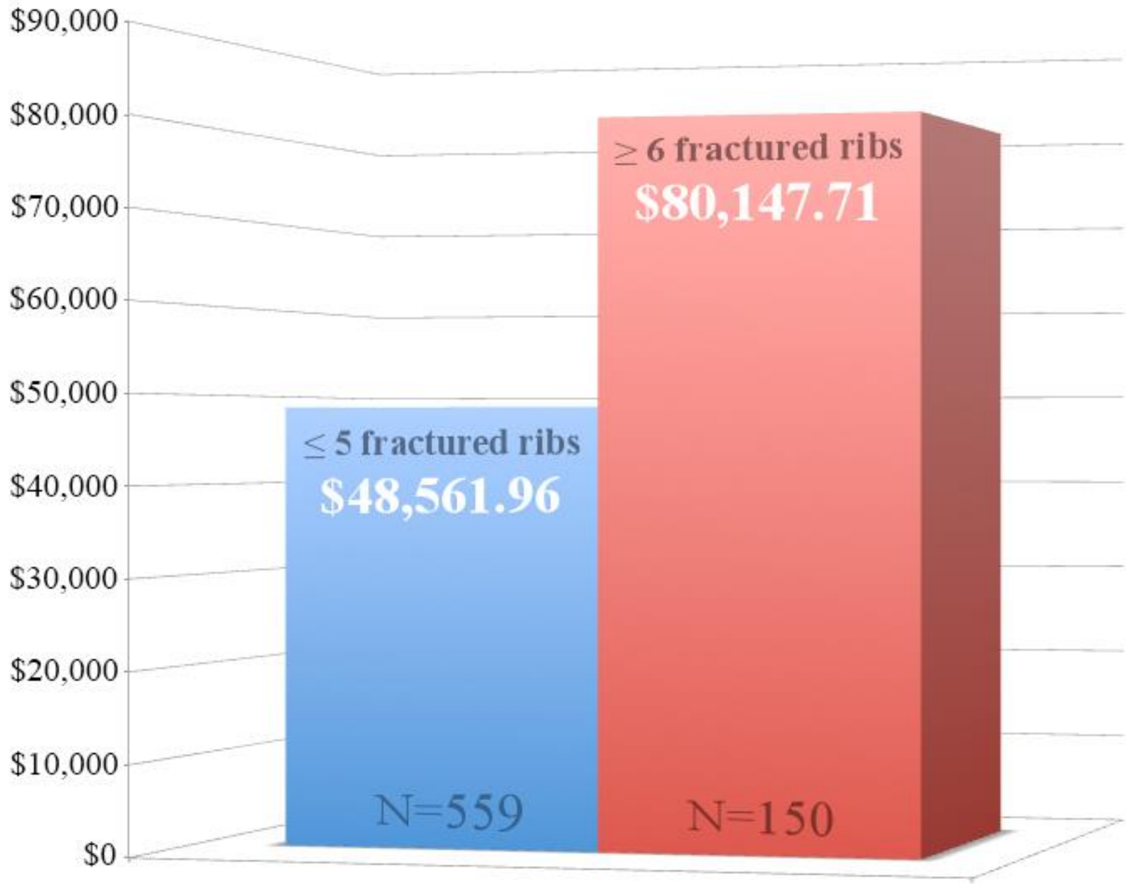
Injury severity is a major predictor of patient billing. When tested by itself, the number of fractured ribs is strongly correlated with patient charges (r = 0.220; p<0.001). The average patient billing per rib fractured is displayed in Figure 4.11.

Figure 11: Average patient charges based on number of ribs fractured (matched sample)



There is an inflexion point at 6 ribs: patients who fractured 6 or more ribs were charged 1.7 times more than patients who fractured 5 or fewer ribs (p<0.001). This inflexion point is illustrated in Figure 4.12.

Figure 4.12: Average patient charges based on inflexion point of ribs fractured (matched sample)



In the full model, the number of ribs fractured and ISS shared predictive power, and only ISS remained as a predictor. With all other variables held constant, each additional point in a patient's ISS predicted an increase of $870 in the patient's bill (95% CI: 566.36 to 1,172.77). The presence of bilateral fractures also remained a predictor in the full model. A patient admitted with bilateral rib fractures would predict a $11,221 increase in the patient's bill (95% CI: 4,705.81 to 17,736.18).

Length of stay in the hospital and ICU were both strong predictors. Each additional day spent in the hospital predicted an increase in patient charges of $6,748 (95% CI: 6,127.26 to 7,367.89) while each additional day in the ICU predicted an increase of $4,771 (95% CI: 3,864.96 to 5,677.98). The use of TEA predicted lower patient charges by $12,073 (95% CI: -16,939.89 to -7,213.73). Incidence of respiratory distress syndrome predicted an increase in patient billing by $26,392 (95% CI: 3,312.26 to 49,471.03).

Variables that predict total cost to the hospital:

When tested individually, the variables that predict treatment cost to the hospital are: number of fractured ribs ($r = 0.184$; $p<0.001$), presence of bilateral fractures ($r = 0.247$; $p<0.001$), presence of a flail segment ($r = 0.077$; $p=0.039$), presence of pulmonary contusions ($r = 0.117$; $p=0.002$), ISS ($r = 0.388$; $p<0.001$), use of TEA ($r = 0.090$; $p=0.015$), use of mechanical ventilation ($r = 0.555$; $p<0.001$), duration of ventilation ($r = 0.637$; $p<0.001$), hospital LOS ($r = 0.775$; $p<0.001$), ICU LOS ($r = 0.745$; $p<0.001$), incidence of pneumonia ($r = 0.393$; $p<0.001$), incidence of respiratory distress syndrome ($r = 0.286$; $p<0.001$), acute respiratory failure ($r = 0.118$; $p=0.001$), sepsis ($r = 0.212$; $p<0.001$), and mortality ($r = 0.127$; $p=0.001$).

Age ($r = -0.003$; $p=0.944$) was not a significant predictor on its own, but emerged as significant when tested in the prediction equation. When tested in the full equation, the only variables that maintained significance were:

$R^2 = 0.679$	*Age*: β = -20.40 (standardized: -0.042); p=0.061
Error: 5,571.288	*ISS*: β = 92.24 (standardized: 0.069); p=0.005
F = 242.570	*Bilateral fractures*: β = 3,133.40 (standardized: 0.099); p<0.001
$p < 0.001$	*Hospital LOS*: β = 977.23 (standardized: 0.517); p<0.001
DF (regression): 6 DF (residual): 687 DF (total): 693	*ICU LOS*: β = 876.04 (standardized: 0.319); p<0.001
	Use of TEA: β = -2,583.96 (standardized: -0.110); p<0.001

All tolerance values were >0.30 or variance inflation factors <3. Excepting only the duration of treatment, the predictor that accounted for the most variance in hospital expenses per patient was the use of TEA. In the full model, with all other variables held constant, the use of TEA predicted a reduction in patient expenses of $2,584 (95% CI: -3,613.98 to -1,553.94).

DISCUSSION

Rib fractures are common injuries. In U.S. trauma centers, 7–10% of all patients admitted have at least 1 fractured rib[2,113] At our trauma center, during the 4-year study period, 9.8% of all patients presented with rib fractures. The demographics and injury characteristics of these patients were typical of other patient populations. While age ranged across the lifespan and the severity of injury was broad, on average, our patients were 55 years old and presented with 4 fractured ribs. The rates of associated injuries such as flail chest were similar to the rates reported at other hospitals.

The primary goal in treating these patients is to minimize the risk of mortality and pulmonary complications. Historically, when a patient with ≥ 1 fractured rib is treated, the risk of mortality is about 10%, the risk of pneumonia ranges between 17 and 31%, and the expected hospital LOS is 7 to 16 nights.[2,5,6,10] At our hospital, the mortality rate was 6.1%, the incidence of pneumonia was 12.2%, and the average hospital LOS was 7.5 nights.

Our approach to rib fracture care differs from most hospitals. According to analyses of the National Trauma Data Bank, 2.0% of all rib fracture patients receive TEA[7] and 7.6% of patients with flail segments.[26] At out hospital, 19.3% of all rib fracture patients receive TEA and 53.1% of patients with flail segments. We have achieved these rates by using a care team that includes dedicated anesthesiologists and nurses trained in pain management. The anesthesiologists are assigned to the trauma patients exclusively for a week at a time. They round all 7 days, assume all pain management responsibilities for those patients, and do not work in the operating room during the week. Although they're not typically onsite during the nighttime hours, they are available all hours for the nurses to page them with questions about pain management. In turn, the nurses are responsible for treatment variations, such as adjustments of dosage. Through this service, we have been able to administer TEA to a higher percentage of patients than most hospitals.

Other authors have found similar improvements in treatment outcomes using alternative strategies, such as the "multidisciplinary clinical pathway". This is an aggressive approach to treating patients who are ≥ 45 years of age and present with ≥ 4

fractured ribs. The treatment involves several pain management techniques (oral, IV, and epidural), respiratory therapy (e.g., aerosolized pharmocoligic therapies and EzPAP positive airway pressure), physical therapy (e.g., range of motion and balance exercises), and nutrition services (dietary monitoring and supplement administration). When using this entire combination of treatments, one hospital reported its mortality rate declining from 13% to 4%, the incidence of pneumonia declining from 18% to 5%, and the hospital LOS shortening from 14.3 to 11.7 days (not statistically significant).[59]

Although effective in terms of outcomes, costs to the hospital and charges to the patient were not reported in the multidisciplinary clinical pathway. Without access to any financial data, it is difficult to know the cost-effectiveness of this treatment. Its extensive nature is likely to be expensive to the hospital as well as to the patient. It is possible that some of the services (e.g., nutrition services) are adding more cost than value and it would be helpful to know the individual contribution of each therapeutic component to the treatment outcomes.

Few authors have reported on the financial costs of treating patients with rib fractures. Although the available data are very limited, the most common finding is that, while additional treatments bear extra costs, if they can eliminate complications, reduce the need for mechanical ventilation and the duration of its use, and facilitate an earlier discharge from the hospital, the total treatment costs are likely to be decreased.[162-164] In our population, the hospital's treatment structure enabled greater reliance on TEA, which in turn reduced both hospital costs and patient bills.

After eliminating patients from the database who were not candidates for TEA, and only comparing patients who received TEA to eligible candidates who did not receive it, the variables that predicted patient charges were: age, ISS, presence of bilateral fractures, hospital LOS, ICU LOS, the use of TEA, and incidence of respiratory distress syndrome. The average patient bill was $55,212 and the combination of those predictors explained 80% of the variance in billing. The strongest predictors were hospital LOS and ICU LOS. In the full model, if all other variables were held constant, the use of TEA could be expected to reduce patient charges by $12,073 ($p<0.001$).

Regarding hospital expenses, the average cost per patient was $6,738 and all of the same variables predicted expense except incidence of respiratory distress syndrome. The model explained 68% of the variance in hospital costs and the two largest predictors were still hospital LOS and ICU LOS. The next most important predictor was the use of TEA. In this prediction model, if all other variables were held constant, the use of TEA could be expected to reduce the cost to the hospital by $2,584 ($p<0.001$).

Limitations

After eliminating patients who were not candidates to receive TEA, there remained only 1 patient who received TEA and died and 11 patients who did not receive TEA and died. These small samples may have resulted in a failure to identify important relationships that might have emerged with larger samples. Likewise, we may have assumed meaningful relationships owing to sampling errors. Additional studies with larger samples will be useful in confirming our observations.

Conclusions

As the first known study to report on the cost effectiveness of TEA in patients with rib fracture injuries, its use appears to significantly reduce both hospital costs and patient charges. From an administrative and insurance perspective, more frequent reliance on TEA may be indicated. As a first step, other hospitals should report the cost-effectiveness of their care models among patients with rib fractures.

Disclaimers

This study is associated with no source of funding. It is a collaboration between the St. Vincent Hospital in Indianapolis, the University of Connecticut, and Sum Integral.

Chapter 5: Conclusion

Rib fractures are a commonly treated injury in U.S. trauma centers. About 10–15% of all admissions are the result of blunt thoracic trauma, which frequently results in chest wall injuries.[2] The most common of these injuries, present in approximately 50% of patients who sustain blunt thoracic trauma, is rib fractues.[1-3,31] In total, rib fractures are detected in nearly 300,000 patients admitted to U.S. trauma centers each year[4] and many more fractures go undetected at admission.[2,3,5] Among all patients who present with at least 1 fractured rib, a mortality rate of about 10% can be expected.[2,3,5,10] With better treatments, hospitals seem capable of achieving better patient outcomes.[59] Given the annual mortality rate attributable to rib fracture injuries, furthering our understanding of ideal care strategies is likely to save many lives.

In the previous chapters, I reported my findings from analyses of a sample of rib fracture patients. This sample was derived from a trauma registry, obtained from St. Vincent Hospital in Indianapolis, Indiana. This hospital operates an ACS-verified Level II trauma center that began accepting patients in November 2010. The data I analyzed were exported in December 2014; thus it comprised 4 years of patient records. During those 4 years, there were 10,242 total patients treated; 1,008 of them (9.8%) had sustained rib fractures. This percentage is consistent with other trauma centers, which report between 7–10% of admitted patients to present with at least 1 fractured rib.[2,19,113]

In treating these patients, age and injury severity affect the likelihood of success.[6,8,10,82] Regarding age, the mean age of survivors tends to be at least 5 years

younger than the mean age of patients who die[5,10] and when patients are separated into young (18–64 years) and old (≥ 65 years) populations, the mortality rate among the older group tends to be at least double that of the younger group.[3,6] Regarding injury severity, among patients who only fracture 1–2 ribs, a mortality rate of 5–6% can be expected.[2,10] In the presence of 8 or more fractures, the mortality may surpass 30%.[10] If both flail segments and pulmonary contusions are present, the mortality rate may exceed 40%.[34] Similar relationships exist with complication rates (e.g., pneumonia) and various treatment variables such as the use of mechanical ventilation and the length of stay (LOS) in the hospital and intensive care unit (ICU).[2,5,6,10]

While the degree of structural damage that occurs in rib fracture injuries can be profound, it is often the pain itself that precipitates the high rates of morbidity and mortality.[10,19,37] When a patient presents with multiple fractured ribs, normal ventilatory behaviors such as coughing and deep breathing are likely to exacerbate symptoms of pain. In response, patients alter pulmonary mechanics: they begin splinting in attempt to minimize pain.[35,36] As their breathing becomes shallow and coughing infrequent, the normal mobilization of airway secretions gets impaired, resulting in the buildup of sputum.[11,37-39,78,82,83,115] In combination with muscle spasms and progressively diminishing lung compliance, this elevates the risk of secondary complications, such as pneumonia, and increases the likelihood that patients will experience respiratory failure and require ventilatory support.[37,38,40,41] In turn, the likelihood that a patient will die is drastically elevated.[42-45] Thus, effectively managing each patient's pain level is critical to successful treatment outcomes.[41,46,47]

There are multiple ways of controlling pain. Very fundamentally, patients can be treated with either systemic analgesic drugs (oral or intravenous) or regional modes of delivery.[10,37,47] Among the regional modes, thoracic epidural analgesia (TEA) may be the most commonly evaluated.[37,46,47,168] In the previous chapters, I focused on the use of TEA in patients with multiple fractured ribs, evaluating its relationships with mortality, risk of complications, treatment variables such as duration and the use of mechanical ventilation, and its affect on the cost, both to the patient and to the hospital. In this chapter, I will summarize the findings of those chapters. The topics discussed are:

1) How the demographics and injury characteristics of St. Vincent's patients compare to those of other reports.
2) How the use of TEA at St. Vincent compares to the use of TEA at other trauma centers.
3) How the treatment outcomes (mortality, incidence of pulmonary complications, use of mechanical ventilation, and LOS in the hospital and ICU) of St. Vincent's patients compare to those of other reports.
4) How the treatment outcomes of St. Vincent patients treated with TEA compare to those not treated with TEA.
5) How TEA affected the cost of treatment, both to the patient and to the hospital.
6) How St. Vincent's care structure for the treatment of patients with rib fractures may be an ideal model for other hospitals to employ in their own trauma centers.

Patient demographics and injury characteristics at baseline: How St. Vincent's patients compare to those treated at other trauma centers

At St. Vincent, patients were aged across the lifespan, from 15 to 98 years, and the breadth of injury severity was vast. The number of fractured ribs among individual patients ranged from a single rib to all 24 ribs and the injury severity scores (ISS) ranged from 1 (lowest possible score) to 75 (maximum possible score). However, the mean values of all demographic data and injury characteristics were similar to the values reported in other studies.

Sex. At most trauma centers, the majority of patients who are admitted with rib fractures are men. I only found 2 studies that reported the majority of patients to be women.[82,96] I found 2 more studies that reported men to just barely outnumber women[7,98] and an additional 2 in which men totaled less than two-thirds of the population.[28,78] Opposite that, several studies reported men to compose about 90% of the patient population.[61,93,169] In most reports, however, men represented about two-thirds to three-fourths of the patient population.[6,8,9,11,29,30,41,89,91,97,170] At St. Vincent, 66.2% of all patients were men.

Age. Some studies tested younger patients[78,91] and others tested older patients[82,98], but the mean patient age reported in most studies was 40–55 years.[7,9,11,25,28-30,36,61,83,89,92-94,97,169-172] At St. Vincent, the mean age was 55.3 ± 20.3 years.

Number of fractured ribs. Although some patients fractured fewer[97] and some fractured more[11,89,170], the mean number of fractures is typically about 4–6 ribs.[6-9,25,29,36,92-94,169,172] At St. Vincent, the mean number of fractured ribs was 3.9 ± 2.9.

ISS. Some studies report a relatively low mean ISS[29,82,96] and others report a relatively high ISS[11,78], but most report values between 17–22.[6-10,36,83,89,91,94] At St. Vincent, the mean ISS was 16.1 ± 10.4.

Incidence of flail segment. Some authors have found flail segments to be present in fewer than 4% of rib fracture cases[26,28] while others have reported incidences over 20%.[11,27] Typically, among patients who present with at least 1 fractured rib, the incidence of flail chest falls in between those amounts, but remains diverse.[3,6,9,29,30] At St. Vincent, 6.4% of patients presented with a flail segment.

Incidence of pulmonary contusion. The incidence of pulmonary contusions in rib fracture studies is broad. The range of rates reported include 10%[30], 16–17%[25,29], 25–30%[3,6,7], 40–50%[9,11,28], and as high as 58%[83]. At St. Vincent, 20.0% of patients presented with a pulmonary contusion.

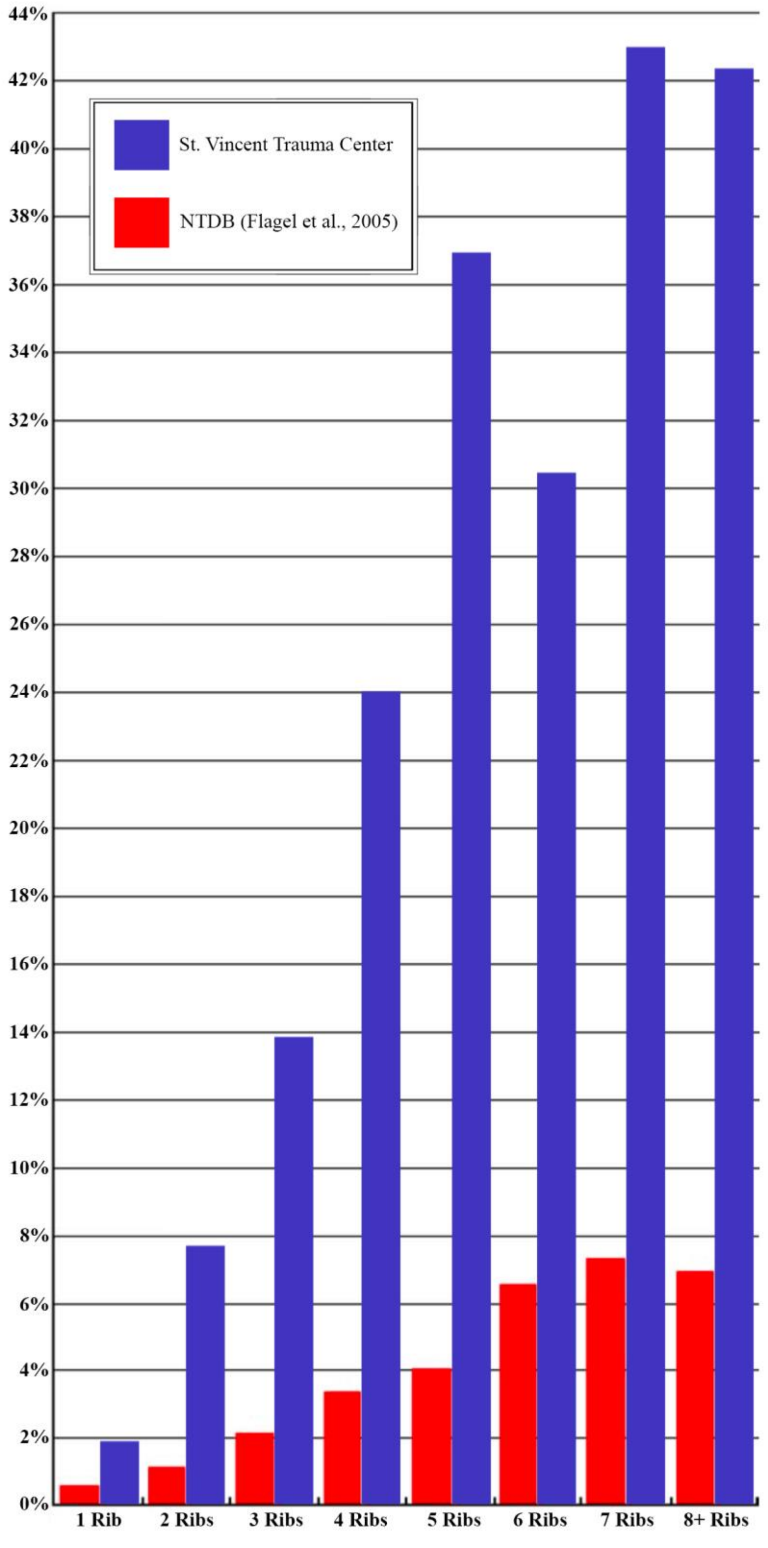
Overall, patients at St. Vincent Trauma Center were similar to patients admitted to other trauma centers in the U.S.

TEA: How use at St. Vincent compares to use at other trauma centers

TEA was administered more frequently to St Vincent patients than it was to patients at other trauma centers. According to analyses of the National Trauma Data Bank (NTDB), 2.0% of patients who were admitted with 1 or more rib fractures received TEA.[10] At St. Vincent, 19.3% of all rib fracture patients received TEA. According to another NTDB report, 7.6% of patients admitted with a flail segment received TEA.[26] At St. Vincent, 53.1% of patients with a flail segment received TEA.

Although TEA is only used in about 2% of all rib fracture cases nationally, reliance is related to the severity of injury: it increases with each additional rib fractured ($R^2 = 0.96$) and there is an inflexion point at 6 ribs, above which, the use of epidural catheters increases by 50% (figure 1).[10] At St. Vincent, this relationship is less significant; although use does increase with each rib fractured ($R^2 = 0.097$; $p<0.001$), there was no clear inflexion point (Figure 5.1).

Figure 5.1. Percentage of patients who received TEA at St. Vincent Trauma Center compared to the NTDB, as reported by Flagel et al., 2005.



Treatment outcomes: How St. Vincent's patients compare to those treated at other trauma centers

Among all blunt thoracic trauma patients who present with rib fractures, the expected mortality rate is about 10%.[2,3,5,10] Pulmonary complications develop in a third to half of all patients who fracture at least 1 rib.[2,10] The incidence of pneumonia varies depending on the patients' age and injury characteristics[10,46], but Bulger et al.[6] found it to arise in 17% of younger patients and 31% of elderly patients. On average, patients with rib fractures spend 7 to 16 nights in the hospital and 40–50% are admitted to the ICU, where they stay 4 to 8 nights.[2,5,10] About 60% of patients with rib fractures receive mechanical ventilation for an average duration of 13 days.[10]

By comparison, the mortality rate among patients treated for rib fractures at St. Vincent Trauma Center was 6.1%. We don't have reports on all pulmonary complications but the incidence of pneumonia was 12.2%. Despite the lower rates of mortality and pneumonia, the percentage of patients admitted to the ICU (51.2%) was somewhat high. The average hospital LOS (7.5 days) and ICU LOS (6.7 days) were normal. Relatively few patients at St. Vincent received mechanical ventilation (23.3%) and the duration of use was relatively brief (9.1 days).

Treatment outcomes: How St. Vincent patients treated with TEA compare to those not treated with TEA

To evaluate the efficacy of TEA among St. Vincent patients, I eliminated the records of all patients who were not candidates for its use. This enabled comparisons to

be made between patients who received TEA and those who were eligible to receive it, but did not. Criteria for exclusion were: 1) the patient died within 24 hours of admission, 2) the patient was intubated within 12 hours of admission, or 3) the patient was on an anticoagulation medication prior to treatment.

After eliminating those who were not candidates for TEA, there remained 721 patients in the database. Only 1 patient receiving TEA died (0.6%): an 86-year-old man who sustained 7 fractures in a fall. By comparison, 2.0% of patients not receiving TEA died; controlling for no other variables, this difference was not significant ($p=0.233$). Patients receiving TEA were 1.8 times more likely to develop pneumonia ($p=0.011$) but the risk of other complications was similar. TEA patients also spent an extra 2.9 days in the hospital ($p<0.001$), were 57% more likely to be admitted to the ICU ($p<0.001$), and among those admitted, they remained in the ICU 1.4 days longer ($p=0.047$). TEA patients required mechanical ventilation 75% more often ($p=0.056$) and among those intubated, they continued to receive ventilatory assistance for an additional 4.7 days ($p=0.013$).

Much of this can be explained by differences in injury severity. Patients who received TEA had an ISS that was 2.7 points higher ($p<0.001$), fractured 2.4 more ribs ($p<0.001$), were 82% more likely to present with bilateral fractures ($p=0.008$), 85% more likely to have a pulmonary contusion ($p=0.001$), 6.5 times more likely to have a flail segment ($p<0.001$), and 45% more likely to present with a pneumothorax.

Among these patients, the best predictors of mortality were age ($p=0.004$), the use of TEA ($p=0.071$), and the use of mechanical ventilation ($p<0.001$). The model is significant ($p<0.001$), includes 717 patients, and explains about 39% of the variance in

mortality. Regarding age, each additional year increased the odds of mortality by about 7% (95% CI of odds ratio: 0.021–1.112), patients who received mechanical ventilation were about 58 times more likely to die (95% CI of odds ratio: 13.958–237.126), and the use of TEA decreased the odds of mortality by about 87% (95% CI of odds ratio: 0.015–1.186).

Cost of treatment: How TEA affected patient billing and hospital expenses

Across the total population (n=1,008), the average patient bill was about $85k, but it ranged from $2,448 to $985,979 and was proportionate to LOS. The average amount patients were billed per day was $11,727. The average cost to the hospital was about $11k and ranged from $143 to $148,594.

To compare the effect of TEA on a patient's bill and hospital expenses, the same exclusionary criteria were employed (early mortality, early intubation, and pre-treatment anticoagulation). After eliminating the records of all patients who were never candidates for TEA, the remaining patients (n=721) were billed an average of $55k for treatment, ranging from $3,792 to $496,315 and the per-day charge was $10,546. The hospital expense for delivering care was $6,738 per patient, ranging from $143 to $124,522.

Compared to patients who did not receive TEA, those who were treated with TEA cost the hospital $2,115 more ($p=0.015$) but were billed $18,526 more ($p<0.001$). On average, patients who did not receive TEA were billed $2,902 more per day.

The predictors of patient billing were age ($p<0.001$), ISS ($p<0.001$), presence of bilateral fractures ($p=0.001$), hospital LOS ($p<0.001$), ICU LOS ($p<0.001$), incidence of respiratory distress syndrome ($p=0.041$), and the administration of TEA ($p<0.001$). This collection of predictors explained about 80% of the variance in billing ($p<0.001$). The strongest predictors were hospital LOS and ICU LOS. Holding all other variables constant, each additional day in the hospital predicted an increase of $6,748 (95% CI: 6,127.26 to 7,367.89) while each additional day in the ICU increased charges by $4,771 (95% CI: 3,864.96 to 5,677.98). Conversely, treating patients with TEA predicted a $12,073 reduction in patient charges (95% CI: -16,939.89 to -7,213.73).

The predictors of hospital expense were age ($p=0.061$), ISS ($p=0.005$), presence of bilateral fractures ($p<0.001$), hospital LOS ($p<0.001$), ICU LOS ($p<0.001$), and the administration of TEA ($p<0.001$). This collection of predictors explained about 68% of the variance in hospital expenses. After duration of treatment (hospital and ICU LOS), the next most significant predictor was the use of TEA. With all other variables held constant, delivering TEA to a patient predicted a $2,584 reduction in hospital expenses (95% CI: -3,613.98 to -1,553.94).

St. Vincent's care structure: How Anesthesia Pain Services (APS) can be incorporated into other trauma centers

At St. Vincent, the treatment of patients admitted with rib fractures has elicited better outcomes compared to reports by other hospitals. Much of this success appears to be consequent of the increased reliance on TEA, while the ease of TEA administration is facilitated by the APS care model employed at St. Vincent.

APS is a care team that includes dedicated anesthesiologists with expertise in acute pain control and nurses who are trained to manage those patients. The anesthesiologists work for a week at a time, they round all 7 days, and their duties are limited to the trauma center patients. Although they are only onsite and available to install epidural catheters during the daytime hours, they're available to be paged by the nurses 24 hours a day with questions about patient management (e.g., dosage adjustments). Through this structure, the hospital has been able to drastically increase the administration of TEA.

Conclusion

When a patient is admitted with multiple fractured ribs, more severe injuries typically associate with poorer treatment outcomes, most notably elevating the risk of mortality. Administering TEA to these patients appears to attenuate this rise in mortality, resulting in better odds of survival. Furthermore, the use of TEA appears to reduce both the cost of delivering care and the amount the patient is billed. Despite these encouraging results, TEA continues to be an uncommon treatment, used in about 2% of rib fracture patients.

More research still needs to be done to accurately compare the cost-effectiveness of TEA to other treatment options. As a first step, other trauma centers should analyze their data registries and report the efficacy and safety of different treatment options as well as the cost and charges associated with their delivery. If our findings are confirmed – that TEA improves patient outcomes while reducing the overall cost of care – then our

APS model for rib fracture care may be considered as a roadmap for other programs to implement.

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