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# Rib Fracture Patterns in Fatal Motor Vehicle Accidents

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# Rib Fracture Patterns in Fatal Motor Vehicle Accidents

by

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## ABSTRACT

Rib fractures are present in 25 percent of all trauma-related deaths, making the mechanism and pattern of rib fractures an important area of trauma research (Lien et al. 2009). Rib fractures are important to consider when researching trauma because they can cause serious complications contributing to an individual's mortality.

This retrospective research study focuses on rib fracture patterns in fatal motor vehicle accidents (MVAs). The sample consists of 105 MVA victims—68 males and 37 females. Data was collected at the Hillsborough County Medical Examiner's Office in Tampa, Florida. The study investigates motor-vehicle-related deaths from 2011 to 2013 to establish rib fracture patterns in association with several variables. Fractures of the manubrium and sternum are included in the analyses since the ribs articulate in several places with the manubrium and sternum and they are frequently injured in MVAs.

First, this research study investigates the rib fracture patterns that exist in correlation to soft tissue organ injury. Injuries to the heart, lungs, liver, diaphragm, and spleen were analyzed based on their direct contact with the ribcage. The results show that several significant relationships exist, including that lung injury is about 12 times more likely to occur when a fracture is present in the left middle ribs and 4 times more likely to occur when there is a fracture

on the manubrium. Heart injury is found to be 9 times more likely to occur when the sternum is fractured and the liver is found to be 4 times more likely when the right middle ribs are fractured and 0.3 times more likely when the right high ribs are fractured.

Second, this study examines rib fracture patterns controlling for seatbelt use, airbag deployment, and cardiopulmonary resuscitation (CPR) administration. Each of these variables is tested to determine their influence in causing injury and the fracture patterns resulting from accidents. For drivers, specifically, it is also tested if fracture patterns can predict seatbelt use. The results show a significant relationship between fracture of the left low ribs and seatbelt use. In drivers, it is 5 times more likely that the individual was wearing a seatbelt if the left low ribs are fractured. Lastly, a significant relationship was found for fractures of the manubrium and CPR administration.

Finally, this research study aims to predict the number of ribs fractured by an individuals' age. Progressive mineralization of the skeleton and other age-related changes increase the risk of fracture in elderly individuals. The results of this study indicate a significant, positive correlation between age and the total number of rib fractures sustained in MVAs, supporting the presumption that elderly are at a higher risk for rib fractures.

## CHAPTER ONE:

## INTRODUCTION

Trauma analysis is necessary for the interpretation of injury and death. In the same way that external and internal trauma patterns are used in autopsy to determine a method and mechanism of injury, traumatic injuries to the skeleton can also provide indicators for understanding an individuals' death (Spitz and Thomas, 1993). The analysis of trauma aims to answer critical questions such as "when the trauma occurred, how it was induced, and how much force was involved" (Galloway, 1999:6). The role of forensic anthropology in trauma analysis is to determine if the abnormality is the result of blunt, sharp, or projectile trauma or a natural marker of human variation or pathology; if the abnormality is the result of an isolated incident or several incidents; and if the abnormality was present antemortem, perimortem, or postmortem (Galloway, 1999). Skeletal trauma analysis provides the opportunity for forensic anthropologists to assist medical examiners and law enforcement personnel to contribute in cases where circumstances surrounding death are uncertain, especially in cases that may go to court (Galloway, 1999).

Trauma is defined as damage to living tissue, caused by a force outside of the body (Lovell, 1997). Skeletal trauma is differentiated into three types: blunt force, sharp force, and gunshot or projectile force. Blunt force trauma is present when force is applied from a blunt object, resulting in fractures or other internal and external injuries (Nayduch, 2009). In the United States, trauma is the leading cause of death for individuals under the age of 40 years (Injury Prevention and Control, 2014). Twenty-five percent of all trauma-related fatalities involve the thoracic region, affecting the ribs, manubrium, sternum, and thoracic soft tissue organs (Lien et al., 2009). Of all fatal and nonfatal thoracic injuries, approximately 70-80 percent are the result of blunt force trauma in motor vehicle accidents (MVAs) (Lien et al., 2009). Blunt force trauma to the thoracic region often results in the fracturing of one or more ribs, making the ribs an important area of study when researching MVA fatalities and thoracic trauma. In addition to providing a framework for respiratory function, the structure of the ribcage provides some additional protection for the thoracic organs. Blunt impact with sufficient force to result in skeletal fracture is likely to compromise both functions of the ribcage.

This research looks at rib fracture patterns in fatal MVAs to better understand the rib fracture patterns in MVAs and the related thoracic soft tissue injuries. This study also evaluates rib fracture patterns in relation to the age of the individual, and other factors such as seatbelt use, airbag deployment, and cardiopulmonary resuscitation (CPR) administration. Chapter 1 outlines the significance of rib fracture studies, the incidence of blunt thoracic trauma in MVAs, research problems, research objectives and hypotheses, and the significance of this research project in the context of forensic anthropology, pathology, medicine, and public safety.

**Problem Statement**

This study addresses several important problems regarding fatal MVAs. The five research questions addressed in this study investigate the relationship between rib fractures and their adjacent soft tissue organs; the effect of age on fracture risk; fracture classification among MVAs; best practice recommendations for legal medicine; and recommendations for improved safety standards for motor vehicle occupants who are at risk for blunt thoracic injury.

Fatal MVAs commonly result in severe thoracic injuries. In 2013, there were 32,850 individuals killed in MVAs in the United States (USDOT, 2014). In the state of Florida, 2,402 individuals were killed in MVAs in the year 2013 (Florida Department of Highway Safety and Motor Vehicles, 2013). Hillsborough County, Florida ranks third in the list of Florida counties with the highest number of MVAs fatalities (Traffic Crash Statistics, 2009). The high volume of MVA cases investigated at the Hillsborough County Medical Examiner's Office (HCMEO) allowed for this retrospective study. From 2011-2013, the years used for this study, 609 autopsies of individuals from MVAs were conducted at the HCMEO (Medical Examiner Workload Statistics, 2013).

In order to understand blunt thoracic injury patterns in MVAs, the dynamics of thoracic anatomy must first be addressed. Together, the 12 ribs on each side of the body form a curved cage-structure around the thoracic organs. The ribcage forms a relatively rigid structure and articulations that provide a range of motion combined with resistance to collapse necessary for respiratory functions. At the same time, the elasticity of the ribs allows for considerable deformation of the structure prior to its failure (Burke, 2012). All of the ribs share a similar wedge shape on cross-section, but each of the ribs varies slightly in shape and size depending on their location in the rib cage. The variability in rib shape, size, and position in the ribcage puts some ribs at a higher risk for fracture than others (Galloway, 1999). For example, ribs 1 to 3 are protected by the clavicle and therefore sustain fewer fractures than other ribs. The first rib is more difficult to fracture for several reasons. Unlike other ribs, the first rib has a higher cross-section area-to-height ratio, it is positioned in a horizontal plane, and it is almost entirely covered by the clavicle. A significant amount of force to the chest is required to fracture ribs 1 to 3, and the likelihood of thoracic soft tissue injury is high. Similarly, fractures in ribs 8 to 11 increase the likelihood of having abdominal soft tissue injury (Burke, 2012). Ribs 6 to 8 are the most commonly fractured ribs (Galloway, 1999). Figure 1.1 shows the anatomy of the ribcage including the ribs, manubrium, and sternum.

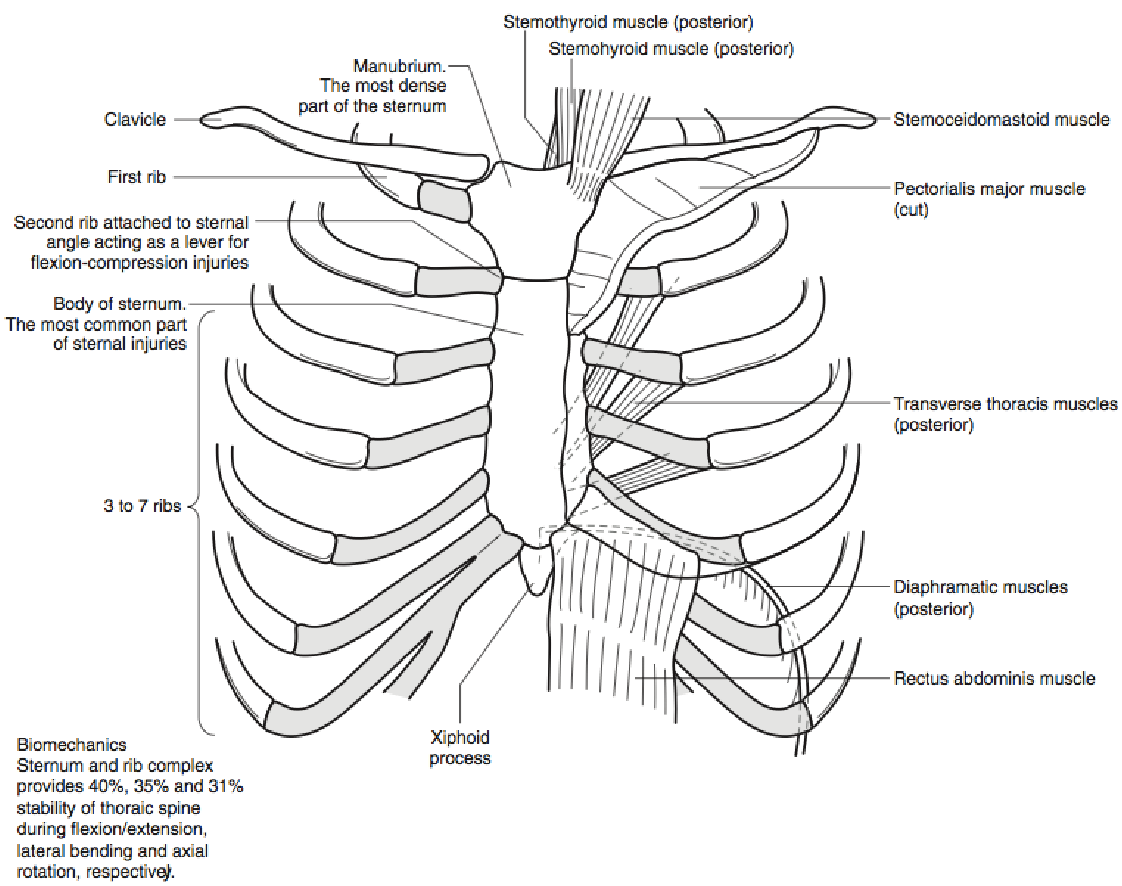


**Figure 1.1.** Anatomy of the ribs, manubrium, and sternum. Image used with permission from author (Raghunathan and Porter 2009).

The outer cortical layer of bone in a rib is thinner than most bones, which on one hand increases their pliability, and on another, makes them more susceptible to fracture. The unique curvature of the ribs makes the fracture patterns observed in the ribs different than most other bones. This pliability of ribs results also in the facilitation of transfer of force along the bone. This causes its failure, or fracture, to be away from the impact site more often than in other bones (Watson-Jones, 1941). Clinical studies have indicated that when force is applied to the chest anteroposteriorly, the ribs tend to break at the point of curvature—anterolaterally (DiMaio and DiMaio, 1989). This type of force is often seen in MVAs and in patients who receive CPR. If force is applied in a way that compacts the chest laterally, the reverse is true. Lateral compaction results in rib fractures along the sternum and the spinal column (Galloway, 1999).

The relationship between soft and hard tissue in the event of an injury or death is imperative to understand, since the two tissues greatly affect one another and work in collaboration to achieve body functions. This research emphasizes the importance of the intertwined relationship of soft and hard tissue and assesses the effects of fractured ribs, manubria, or sterna on adjacent soft tissue organs. By understanding the soft tissue injuries associated with rib fractures in specific locations of the rib cage, it may be possible to predict soft tissue injuries from rib fracture patterns. The predictive value of rib fracture patterns can also be beneficial in some forensic cases that go to court.

Many factors can affect the fracture patterns and injury mechanisms that occur as the result of an MVA. Whether the driver is restrained or unrestrained by a seatbelt at the time of the accident may play a major role in the fracture patterns of the ribcage. A three-point seatbelt comes in contact with several ribs and crosses over the sternum. Seatbelts protect an individual from being ejected in the event of a crash; however, the force of the seatbelt against the chest may cause injury along the line of the seatbelt. If a three-point seatbelt is worn across the chest during a crash, the seatbelt may cause several fractures in the ribs that come into contact with the seatbelt. These fractures, however, may not be along the line of the seatbelt due to the transfer of forces at the impact site. Depending on if the occupant is a driver or passenger, different sides of the rib cage will be affected by the seatbelt.

Age has been determined as paramount for determining both fracture risk and mortality rate in blunt thoracic trauma, especially in MVAs (Bergeron et al., 2003; Bulger et al., 2000; Flagel et al., 2005; Sariego et al., 1993; Sirmail et al., 2003). It is well understood that fracture risk increases with age, due to skeletal changes at the cellular level. Much of the research that focuses on the elderly population fails to include younger individuals in the samples, which may bias the results. The large number of young individuals dying in fatal MVAs poses a need to investigate fracture patterns for these types of accidents for individuals at all ages. In addition, the risk factors associated with fatal accidents need to be explicitly outlined, such as what types of crashes are most fatal or what position in the car puts an individual at the most risk for fatal blunt thoracic trauma.

An imperative task performed by forensic anthropologists and forensic pathologists is determining if traumatic injuries are caused by an accidental or non-accidental event. For example, Kimmerle and Baraybar (2008) discuss rib fractures from intentional stomping injuries and how the injury pattern could be mistaken for accidental trauma. Cases with intentional stomping disguised as accidental trauma are excellent examples of why understanding injury patterns is vital for the fields of both forensic anthropology and forensic pathology (Kimmerle and Baraybar, 2008). Knowing these patterns can clarify details surrounding an individual's death. These details can be crucial in cases that go to court and could be the deciding factor for a jury. The research objectives in this study will build on the extensive knowledge base of trauma literature by classifying what types of thoracic fracture patterns are consistent with fatal MVAs and what type of soft tissue injuries are consistent with these skeletal patterns.

In terms of best practice standards for medicine, the research objectives in this study are aimed to outline specific injuries that are not only common in MVAs, but are crucially important to diagnose and treat early to decrease mortality rates. The results from this study will build on the current knowledge of which ribs affect which soft tissue organs and which ribs may cause the most internal damage if fractured in a blunt thoracic trauma incident. Since 100% of the cases in this sample are fatal, further research is needed on mortality in a sample with individuals who obtain these types of injuries but survive the accident. The rib fractures in this study were observed directly during autopsy, but the results can be implemented in cases where rib fractures can only be observed through radiographic images for living individuals or non-autopsied individuals.

The aim of this research is to improve public safety regarding MVAs in a way that will protect individuals who are especially at risk for potentially fatal blunt thoracic trauma from MVAs. By identifying the types of individuals who are most often dying in MVAs and determining what types of injuries they are most often sustaining, safety information can be disseminated in a way that targets these individuals. For example, younger drivers and elderly drivers have been found to be at a high risk of being involved in MVA fatalities as both drivers and passengers. Accidents involving younger drivers may potentially be explained by being younger and therefore, newer, to driving. Younger drivers may also be associated with risk-taking behaviors more than older individuals. Elderly drivers are at a higher risk for fatality due to their skeletal frailty or physiological factors that may influence their ability to drive safely. There is currently no age limit for retaining a drivers' license, but enforcing driving or mental tests in order to keep a license after a certain age may be a consideration. In addition, perhaps medical doctors should be responsible for clearly stating the risks associated with driving and riding in motor vehicles as an elderly individual. If it is true that elderly individuals are at a much higher risk for fatal injury in the event of a crash, the risks need to be clearly explained to elderly individuals.

Public safety information regarding MVAs is of vital interest to vehicle manufacturers, as it can solve safety problems related to motor vehicles. A safer seatbelt or restraint system may be developed based on the findings of this study and other similar studies. The loading force of the seatbelt can be redistributed depending on the shape of the safety restraint, and this may prevent some of the life-threatening skeletal injuries caused by MVAs, especially for elderly individuals. It is has even been suggested that an entire line of vehicles tailored to elderly drivers would be beneficial.

**Research Objectives and Hypotheses**

The **first objective** in this study is to determine if rib, manubrium, and sternal fracture patterns can predict soft tissue injuries. Fractures of the manubrium and sternum are included in addition to ribs since they are part of the ribcage structure. Injury of the lungs, heart, diaphragm, liver, and spleen are included in this study due to their direct contact with the ribcage and the high incidence of their injury in fatal MVAs. It is expected that the soft tissue directly adjacent to a fractured rib will be injured. In normal, healthy individuals, the left lung spans from rib 1 to 6 anteriorly and rib 1 to 10 posteriorly. The lateral sides of the left and right lungs span from rib 1 to 8. The lungs are also at risk for injury when the manubrium and sternum are fractured. The heart is adjacent to the sternum, left ribs 1 to 6 and right ribs 1 to 5 (Tortura and Nielsen, 2013). In clinical settings, the manubrium and sternum have frequently been associated with heart injury. The spleen sits inferiorly in the ribcage and is adjacent to ribs 9 to 11 with long axis along rib 10. In pre-existing conditions associated with splenomegaly, the spleen expands inferiorly. The liver has a large surface area with adjacent surfaces to ribs 6 to 9 on the left side and ribs 5 to 7 on the right side. The liver also comes into contact with the lower portion of the sternum and xiphoid process. The shape and length of the sternum and xiphoid process can affect liver laceration patterns. Finally, the diaphragm is adjacent to ribs 6 to 12 on the left side of the ribcage and ribs 5 to 12 on the right side of the ribcage (Tortura and Nielsen, 2013). Table 1.1 summarizes which skeletal elements are adjacent to each soft tissue organ.

**Table 1.1.** Summary of skeletal elements and adjacent soft tissue organs.

| | Lungs | Heart | Liver | Diaphragm | Spleen |
|---|---|---|---|---|---|
| **Left High Ribs** | X | X | | | |
| **Left Middle Ribs** | X | X | X | X | |
| **Left Low Ribs** | X | | X | X | X |
| **Right High Ribs** | X | X | | | |
| **Right Middle Ribs** | X | X | X | X | |
| **Right Low Ribs** | X | | | X | X |
| **Manubrium** | X | X | | | |
| **Sternum** | X | X | X | | |

Based on the associations of ribs, manubrium, and sternum to soft tissue according to anatomy, **hypothesis 1** states that the fractures on any of the ribs, manubrium, or sternum will result in lung injury; fractures on the left high and middle ribs, right high and middle ribs, manubrium, and sternum will result in heart injury; fractures on the left middle and low ribs, right middle ribs, and sternum will result in liver injury; fractures on the left low ribs and right low ribs will result in spleen injury; and fractures on the left middle and low ribs and right middle and low ribs will result in diaphragm injury.

According to recent medical literature, fractures of the right lower ribs are most commonly associated with liver injury and fractures of the left lower ribs are most commonly associated with splenic injury (Athanassiadi et al., 2010; Liman et al., 2003; Park, 2012; Reddy et al., 2014; Thor and Gabler, 2008). Laceration, contusion, or both in these soft tissue organs can be fatal; however, with aggressive diagnosis there is an increased chance of survival (Shorr et al., 1987). In this study, the likelihood of soft tissue injury in the lungs, heart, diaphragm, liver, and spleen are compared with the presence or absence of fractures in the ribs, manubrium, and sternum to determine if fracture patterns have predictive value for soft tissue injury. Table 3.4 in Chapter 3 summarizes the literature findings on which ribs often affect which soft tissue organs.

The **second objective** of this research study is to assess rib fracture patterns present in restrained versus unrestrained drivers in fatal MVAs. Based on the application of human anatomy and biomechanics, **hypothesis 2** states that seatbelt use will cause different fracture patterns. To test the effect of seatbelt use in more detail, fracture patterns will be investigated for restrained drivers versus unrestrained drivers. Passengers are excluded from this further testing due to the small sample sizes of front passengers and back passengers. An important consideration when investigating thoracic trauma in individuals who were wearing seatbelts in MVAs, is the effect of loading from the seatbelt on the chest. Individuals who were wearing a seatbelt at the time of the MVA will be more likely to sustain fractures along the line of contact with the seatbelt across the chest or where the steering wheel would come into contact with the chest. Table 1.2 summarizes the expected areas of fracture for restrained and unrestrained vehicle occupants.

**Table 1.2.** Summary of skeletal elements affected for restrained and unrestrained occupants.

| | Driver Restrained | Driver Unrestrained | Front Passenger Restrained | Front Passenger Unrestrained |
|---|---|---|---|---|
| **Left High Ribs** | X | X | | X |
| **Left Middle Ribs** | X | X | X | X |
| **Left Low Ribs** | | | X | |
| **Right High Ribs** | | X | X | X |
| **Right Middle Ribs** | X | X | X | X |
| **Right Low Ribs** | X | | | |
| **Manubrium** | X | X | | X |
| **Sternum** | X | X | | X |

A laboratory study using human cadavers by Yoganandan et al. (1996) showed that rib fractures occur along the line of the shoulder belt in restrained individuals in vehicles where airbags deployed and bilaterally in unrestrained individuals in vehicles where airbags deployed. For restrained drivers, the results from Yoganandan et al. (1996) suggest that fractures will be most likely found in the left high and middle ribs and the right middle and low ribs. Restrained passengers should have a similar, but mirrored pattern along the line of the shoulder belt. Therefore, fractures should be most prevalent in the right high-to-middle ribs and the left middle-to-low ribs. In this study, ribs 1 and 2 will be considered "high ribs," ribs 3 to 8 will be considered "middle ribs," and ribs 9 to 12 will be considered "low ribs."

The dynamics of vehicular injury are important to consider when addressing this research question. Tissue injury is caused by the change in force, whether it is deceleration or acceleration. The force applied per unit of surface area on the body determines the extent of the trauma obtained by the individual (Saukko and Knight, 2004). According to Saukko and Knight (2004), most MVAs result in rapid deceleration of the individual. In restrained individuals, the transfer of force during deceleration is elongated. The body being thrust forward is an indirect force, while the force from the seatbelt and steering wheel is direct (Kimmerle and Baraybar, 2008). Restrained drivers will therefore experience more left rib fractures and restrained front passengers are expected to have more rib fractures on the right side of the ribcage. Seatbelts that are worn properly cross over the sternum and therefore it is expected that the sternum may be fractured in restrained drivers.

The **third objective** of this research study is to determine the relationship between rib fractures and airbag deployment in fatal MVAs. **Hypothesis 3** states that the ribs will be affected bilaterally in cases where airbags deployed. Stoneham (1995) discusses the prevalence of bilateral first rib fractures in cases where airbags were deployed. The bilateral fracture pattern is the result of the force from the airbag inflation against the chest (Stoneham, 1995). The rib patterns for airbag deployment may vary depending on which airbags deploy, the type of MVA, and the use of a seatbelt. Due to the small sample size for airbag deployment information, this study only tests whether or not a relationship exists between airbag deployment and fracture patterns in the rib cage.

The **fourth objective** of this research study is to establish the fracture patterns that persist with CPR administration. **Hypothesis 4** states that the upper and middle ribs bilaterally, as well as the sternum will be affected by CPR administration due to chest compressions. A study by Hoke and Chamberlain (2004) shows rib fractures from CPR in 13-97 percent of the adults in their sample. Similarly, Krischer et al. (1987) found that of their sample of individuals, who received CPR, 31.6% had rib fractures and 21.1% had sternal fractures. The ribs that were fractured are not provided in either of these studies, but it seems that the ribs that articulate with the sternum would most likely be affected.

The **fifth objective** of this research study is to determine what correlation exists between decedent age and the number of rib fractures sustained in fatal MVAs. **Hypothesis 5** states that a positive correlation between decedent age and number of rib fractures will be found. This study will include only individuals who are 18 years of age or older at the time of death, since the majority of the skeleton is mature and fused at this time. Many studies have shown that mortality increases with each rib that is fractured and that mortality increases with age (Bulger et al., 2000; Lien et al., 2009; Jones et al., 2011). Research by Todd et al. (2006) investigated the relationship between age and the number of ribs fractured in blunt trauma patients. Todd et al. (2006) found that individuals over the age of 45 with four or more ribs fractured had high mortality (Todd et al., 2006). Following the literature by Bulger et al. (2000); Lien et al. (2009); Jones et al. (2011); and Todd et al. (2006), it is expected that there will be more ribs fractured in the elderly individuals and that a positive correlation will be seen for the number of rib fractures and increasing age.

**Research Significance**

This study aims at analysis of patterns of skeletal trauma in the chest and its correlation with injuries of internal organs. Such interpretation will hopefully add to the body of knowledge and assist forensic anthropologists and pathologists in their understanding of mechanisms of injuries and their predictive value. Identification of high-risk groups of individuals, such as the elderly, may also provide some helpful information for safety improvement purposes.

The purpose of this study is to determine which soft tissue organs are injured in conjunction with skeletal fractures of the ribs, manubrium, and sternum in the thoracic region. By understanding the soft tissue injuries associated with rib fractures in specific locations of the rib cage, it may be possible to predict soft tissue injuries from rib fracture patterns. This predictive value can also be beneficial in a courtroom setting in forensic cases. Again, like in forensic anthropology and pathology, medical doctors may use the results of this study to differentiate accidental trauma from non-accidental trauma, which can have important implications in cases where abuse is in question.

# CHAPTER TWO:

# LITERATURE REVIEW

The purpose of this chapter is to provide an overview of the existing literature on the following topics related to the research questions addressed in this thesis: Blunt Thoracic Trauma and MVAs; Rib Fractures; Manubrium and Sternal Fractures; Rib, Manubrium, and Sternal Fractures and Associated Soft Tissue Injuries; Fracture Patterns from Seatbelt Use and Airbag Deployment; Fracture Patterns from CPR Administration; Skeletal Aging and Fracture Risk; and Elderly Drivers and Motor Vehicle Safety.  Chapter 2 synthesizes the body of knowledge already published on these topics, with special attention to addressing potential gaps that exist in the current literature and describing how the questions in this research study will contribute to filling these gaps.

## Blunt Thoracic Trauma and MVAs

Blunt thoracic trauma can range greatly in severity, encompassing minor bruises and small fractures as well as major crush injuries affecting various organs or bones (Battle et al., 2012).  Ten percent of emergency department patients worldwide have some form of blunt trauma to the thoracic region, with a reported mortality rate of 4 to 20 percent (Battle et al., 2012). Trauma to the thorax is second only to head injury for trauma-related injury and death in the United States (Jones et al., 2011). Ten to 15 percent of all trauma-related hospital admissions and 25 percent of all trauma-related deaths are the result of trauma to the thorax (Todd et al., 2006). The high incidence and severity of thoracic blunt trauma makes it a particularly important area of trauma research.

In more than two-thirds of thoracic blunt trauma patients, at least one rib is fractured (Todd et al., 2006). Rib fractures are associated with increased mortality rates, either alone or in conjunction with other injuries (Lien et al., 2009). This associated incidence makes rib fracture research an important contribution to the study of trauma. Blunt thoracic trauma, specifically with rib fractures, is common in MVAs.

Motor vehicle accidents are a major contributor to accidental deaths. Each year approximately 1.2 million people are killed and 50 million injured in MVAs worldwide (Dovom et al., 2013). It has been observed across different cultures and countries, that men are injured more frequently than women (Lien et al., 2009). A study by Dovom et al. (2013) investigates age and gender distributions in accident scenes in Iran. The results of their study show that males have more accident fatalities than females. One possible explanation is that men tend to be more active and more willing to engage in daring or risky behaviors (Harris and Jenkins, 2006). Similarly, a study by Reddy et al. (2014) looks at fatal MVAs and reports that most cases were young male drivers, with fatal crashes occurring most often on the weekends. In the United States, it is reported that men are three times more likely than women to be involved in fatal MVAs (U.S. Department of Transportation, 2004). This demographic information is important to consider when researching thoracic trauma as a result of MVAs. The sample for this research study contains more males than females, and therefore reflects the inequality in sex described by the U.S. Department of Transportation (2004).

A study by Bansal et al., (2010) investigates rib and sternum fractures in elderly and extremely elderly victims of MVAs. Although he focused only on elderly (classified as individuals age 65-79) and extremely elderly individuals (classified as individuals 80 and older), he found that 92.0% of the elderly had rib fractures, 19.6% of the elderly had sternum fractures, 90.4% of the extremely elderly had rib fractures, and 27.7% of the extremely elderly had sternum fractures. The results by Bansal et al. (2010) show that almost all of the MVA victims surveyed in his sample suffered from rib fractures. This study is discussed in more detail later in Chapter 2.

**Rib Fractures**

Fractures are defined as any break in “the continuity of a bone” (Lovell, 1997). Bone fractures are either complete or incomplete, depending on whether there is whole separation of the bone into separate pieces. There are several different types of fractures that can occur in the body from direct or indirect trauma including transverse, spiral, oblique, and crush fractures (Lovell, 1997). Due to the unique shape and curvature and structure of the ribcage, fracture patterns are different for ribs than in other areas of the body. Complicated fracture patterns affecting multiple ribs in multiple locations can occur from one traumatic blow (Love and Symes, 2004). In 2004, Love and Symes published results from analysis on the skeletal remains of individuals age 21-76 at death and who had experienced some form of blunt trauma, the majority of which are incomplete rib fractures (Love and Symes, 2004).

Daegling et al. (2008) conducted an experimental research study that intentionally fractured adult ribs in cadavers to determine fracture patterns. Complete and incomplete fractures were observed, as well as several other breaking patterns including buckle, transverse, spiral, and butterfly fractures (Daegling et al., 2008). Rib fractures, specifically, are most often classified as transverse or oblique. Oblique fractures are the most common type of rib fractures in MVAs (Galloway, 1999). Rather than focus on the types of fractures, this research investigates the number of fractures sustained and which ribs are fractured.

Ribs are at risk for fracture from any type of blunt force due to a thin layer of cortical bone. Each of the twelve ribs is unique in size and shape, requiring a slightly different amount and direction of force to fracture. Fractures of the first rib are uncommon, except for cases of blunt force trauma involving high intensity force (Hamilton et al., 2011). Unlike the other ribs, the first rib sits on a horizontal plane and is protected by the clavicle. It is also more robust in overall shape and thickness, making it harder to fracture than the other 11 ribs (Galloway, 1999). The fracture mechanics of ribs are unique due to the curved nature of the ribcage. Most other bones in the body fracture at the point of impact; however, the ribs rarely fracture at the point of impact (Watson-Jones, 1941). If force is applied anteroposteriorly, compressing the ribcage from front to back, the ribs tend to fracture along the curvature on the anterolateral portion (DiMaio and DiMaio, 1989). The reverse is true if force is applied in the transverse direction, compressing the ribcage laterally. Fractures most often occur where the ribs articulate with the sternum or the vertebra when the ribcage is compressed laterally (Galloway, 1999). These directional forces and fracture mechanisms are important to consider when investigating fracture patterns in MVAs.

The total number of ribs fractured may be linked to mortality rates of thoracic trauma cases. A study by Lien et al. (2009) investigates risk factors for patients hospitalized for rib fractures after MVAs. Their results suggest that an increasing number of rib fractures coincide with a higher percentage of comorbidities (Lien et al., 2009). In addition, they suggest that with six or more rib fractures, mortality rate for a 24-hour time period is extremely increased (Lien et al., 2009). Similarly, Kimmerle and Baraybar (2008) state that when multiple rib fractures are present on a rib, fractures on adjacent ribs are usually present as well. In this study, the first rib is grouped with the second rib and classified as “high ribs.”

Rib fractures from intentional or non-accidental trauma can sometimes look very similar to rib fractures from accidental trauma, such as an MVA. It is essential to be able to differentiate the two, especially in cases that go to trial. One example of this would be victims of torture that endured stomping to the chest (Kimmerle and Baraybar, 2008). Stomping is considered blunt force trauma but the fracture patterns differ substantially, as does the force and mechanisms involved.

**Manubrium and Sternal Fractures**

The manubrium and sternum must be considered when investigating rib fracture patterns, due to their close proximity and articulation with the ribs. In MVAs specifically, it is reported that the incidence for sternal fracture is 3 percent higher than sternal fractures from other types of injury, at 6.8% incidence (Brookes et al., 1993; Hills et al., 1993). It is hypothesized that this higher frequency of sternal fractures in MVAs is the result of seatbelt use; however, the relationship between sternal fractures and seatbelt use is not fully understood. The use of a seatbelt or the impact of a steering wheel in MVAs is the most common source of sternal fractures. The manubrium is fractured less often than the sternum since it is much denser than the sternal body (Raghunathan and Porter, 2009). Raghunathan and Porter (2009) point out the difference in bone density in the manubrium, which does affect fracture.

**Rib, Manubrium, and Sternal Fractures and Associated Soft Tissue Injuries**

By understanding the patterns of rib fractures in relation to associated soft tissue injuries in fatal MVAs, an individuals' death is better understood. This research study investigates the relationship between rib fracture patterns and the corresponding soft tissue injuries. The majority of the literature on this topic involves trauma patients in medical centers, rather than patients from fatal cases. The results of this thesis will contribute to the existing body of literature on this topic by determining fracture patterns for fatal MVAs.

Hamilton et al. (2011) states that first rib fractures are rarely present, except in cases with extreme force or blunt trauma, such as MVAs. The association of thoracic vascular injury and first rib fractures is well documented in adult patients (Hamilton et al., 2011). Similarly, Harris and Soper (1990) describe an association of thoracic great vessel injury with the fracture of ribs 1 and 2. In addition to the first rib, the manubrium and the sternum are also associated with thoracic great vessel injury. Fractures of the manubrium pose an even greater risk of thoracic great vessel injury; however, the manubrium is fractured much less often than the sternal body (Raghunathan and Porter, 2009). While this study does not include injury data for the great vessels, it does include injury data for the heart, so this will be considered in the analysis.

A study by Park (2012) investigates rib fractures and associated intra-abdominal injury (IAI) in order to improve early diagnosis and treatment options for trauma patients. The results of this study classified rib fractures by side (left, right, or bilateral) and rib location (high, middle, or low). Park states ribs 1 and 2 are considered “high”, ribs 3-8 are considered “middle,” and ribs 9-12 are considered “low” ribs (Park, 2012). Liver injury is the most common injury associated with rib fractures, found in 40% of the individuals in the study by Park (2012). Spleen injury is the second most common, following with presence in 23% of the individuals (Park, 2012). These results are true for all ribs as a whole, not focusing on individual rib groupings. However, when looking at rib groupings, there is a significant increase in IAI when ribs are fractured below the $8^{th}$ rib, $p=0.03$ (Park, 2012). Even more specifically, Park (2012) shows a significant correlation between fractures on the left side of the ribcage and spleen injury. He also concludes that the liver seems to be affected fairly equally from both left and right rib fractures (Park, 2012). This is probably due to the large surface area of the liver. One limitation to the study by Park (2012) is that radiology staff members recorded the rib fractures by looking at radiographs. Alternatively, the rib fractures for this research study are recorded from medical examiners during autopsy, which is likely a more definitive method for recording rib fractures and therefore may provide more accurate accounts of rib fractures than studies that use only radiographs.

Reddy et al. (2014) find different results in their study on thoraco-abdominal injuries from fatal MVAs. The lungs are the most commonly injured soft tissue organs, followed by the heart. The study by Reddy et al. (2014), unlike the study by Park (2012), looked at both lung laceration and contusions, like this research study. The results by Reddy et al. (2014) show that lung lacerations are more common than contusions, possibly due to the sharp edges of fractured ribs and their proximity to the lungs. The results by Park (2012), which show liver injury to be the most common injury, do not consider the lungs or heart in the analysis. Reddy et al. (2014)

suggest that it is important to look at the type of vehicle in fatal accidents when considering trauma injuries, because different types of vehicles may play an important role.

Similarly to Park (2012) and Reddy et al. (2014), Thor and Gabler (2008) find significant relationships between lung, liver, and spleen injuries in MVA victims with rib fractures, ($p<0.001$). Thor and Gabler (2008) attempt to characterize the risks according to crash type. In frontal crashes, they see lung injury most often, followed by spleen injury, then liver injury. For side crashes, spleen and lung injuries are more common, although liver injury is still significant (Thor and Gabler, 2008). The results from Thor and Gabler (2008) generally support the findings from previously discussed literature, with a focus on liver, spleen, and lung injury risk.

Although Thor and Gabler (2008) did not discuss a heightened risk for liver injury based on side of the rib cage, a study by Shweiki et al. (2001) shows that the probability of liver injury increases with rib fractures on the right side of the rib cage. The inconsistencies in the results may be related to the type of sample—Shweiki et al. (2001) looks at all patients hospitalized for rib fractures, while Thor and Gabler (2008) focus on victims from MVAs. The findings for rib, manubrium, and sternal fractures and the associated soft tissue injuries are summarized in Table 2.1.

**Table 2.1.** Summary of literary sources for rib, manubrium, and sternal fractures and associated soft tissue injuries.

| **Thoracic Skeletal Fracture** | **Associated Soft Tissue Injury** | **Source** |
|---|---|---|
| Rib 1 | Thoracic great vessel | Hamilton et al. (2011) |
| Ribs 1, 2 | Thoracic great vessel | Harris and Soper (1990) |
| Manubrium, sternum | Thoracic great vessel | Raghunathan and Porter (2009) |
| Ribs 8-12 | Liver, spleen | Park (2012) |
| All left ribs | Spleen | Park (2012) |
| All left and right ribs | Liver | Park (2012) |
| All right ribs | Liver | Shweiki et al. (2001) |

Table 2.1 illustrates that the literature exists for rib, manubrium, and sternal fracture data and associated soft tissue injury; however, it is incomplete. The results of this study aim to fill this gap in the literature and describe what soft tissue is likely to be affected by fractures for every part of the ribcage, manubrium, and sternum.

**Fracture Patterns from Seatbelt Use and Airbag Deployment**

It is important to understand look at the pathways to injury common in MVAs in order to better understand the types of fracture patterns expected. Biomechanics is an important part of trauma analysis, since tissue injury is caused from a change in rate of movement, either deceleration or acceleration. Any change of rate in movement is measured in gravities (Gs) and is more traumatic when applied to a smaller surface area and in shorter exposure time. The majority of MVAs are frontal impact crashes where the victim is rapidly decelerated when the vehicle strikes an object. Conversely, in less-common, rear-impact MVAs, the victim is rapidly accelerated due to a force coming from behind the vehicle (Saukko and Knight, 2004). According to Saukko and Knight (2004), traumatic injuries are similar in most types of vehicles; however, injury patterns vary more drastically depending on where the victim is positioned in the vehicle and the location of impact site. Injury patterns also vary depending on whether or not the victim was wearing a seatbelt at the time of the accident or if the airbags deployed.

Unrestrained drivers most often follow the “up and over” pathway in frontal and rear-end MVAs. In this pathway, the chest comes into contact with the steering wheel or airbag causing thoracic trauma and the head, face, and neck come into contact with the windshield or sunroof. Drivers without restraints are also prone to the “down and under” pathway in which the lower extremities may be crushed and the pelvis maybe injured. Abdominal injury and chest injury is possible, but is less likely than in the "up and over" pathway.

If only a lap belt is worn, injury to the head, neck, and chest is common from hitting the steering wheel and airbag. If only a shoulder belt is worn, the upward motion from the "up and over" pathway is likely to occur and the abdomen is most likely injured from impact with the steering wheel. When three-point seat belts (lap and shoulder belt) are worn properly, only minimal movement is allowed and the airbag has space to deploy without further injuring the victim (Mechanisms of Injury). From these pathway models, it is expected that individuals not wearing restraints will have more rib fractures and thoracic soft tissue injury than individuals wearing restraints.

Rib fractures are the most prevalent injury seen in individuals wearing seatbelts in MVAs (Pattimore, 1992). Crandall et al. (2000) found that when seatbelts were used and airbags were not deployed, individuals had fractures mostly on the superior part of the ribs on the left side of the body and on the inferior part of the ribs on the right side of the body. This shows a fracture pattern along the area of loading from the seatbelt (Crandall et al., 2000).

Results from a study by Bansal et al. (2010) on rib and sternum fractures in elderly victims of MVAs show that the seatbelt, steering wheel, and airbags are the main source of rib and sternal fractures, especially in front impact crashes. Their results showed rib or sternal fractures from these sources in a combined 74.5% of their sample. This is information is noteworthy; however, the results are limited since a breakdown of rib fractures and sternal fractures independently are not provided. This is the result of direct contact with these forces during the crash. Bansal et al. (2010) only includes individuals classified as "elderly" and "extremely elderly" in their sample, so it is unclear what rib fracture risk is predicted for younger individuals.

In cases where the airbag deployed, the fractures were more dispersed, rather than only along the line of the seatbelt. In addition, more posterior rib fractures were detected when airbags had deployed during the accident (Crandall et al., 2000). There is a need for much more research on fracture patterns from airbags, as this is an area of trauma and fracture patterns that is severely lacking in the literature. In cases with airbag deployment, the driver often follows the "up and over" pathway, followed by a secondary impact as the body accelerates back into the seat. This secondary force may cause posterior rib fractures and fractures of the spine as the back comes into contact with the back of the seat. The initial impact of forward deceleration of the body still results in injury to the head, neck, chest, and abdomen in unrestrained individuals when airbags deploy. Airbags are considered a safety feature and are supposed to prevent further extensive injuries in the event of a crash; however, there is little known about what types of injury patterns airbags may cause in return.

It is important to consider the decedent's position in the vehicle here because drivers and passengers have opposite loading patterns for seatbelts. This is also true for left and right back seat passengers. A study by Arajarvi and Santavirta (1989) on traffic fatalities in Finland investigates chest injuries in individuals who had been wearing seatbelts at the time of a fatal accident. They found that the side of the body on which rib fractures were present, was related to the location of the occupant in the vehicle. Drivers sustained more rib fractures on the right side of the body, while front passengers sustained more fractures on the left side of the ribcage (Arajarvi and Santavirta, 1989).

Tavris et al. (2001) conducted a study in Wisconsin that showed that, overall, more drivers than passengers are injured in MVAs. This may be due to the fact that passengers were not always in the car at the time of the accidents in which the driver was injured. In addition, the authors state that collisions involving other vehicles resulted in passenger injury more often than other types of crashes (Tavris et al., 2001).

**Fracture Patterns from CPR Administration**

Some research has been conducted to determine the patterns of rib, manubrium, and sternal fractures as a result of both manual and, more recently, mechanical cardiopulmonary resuscitation (CPR) administration (Baubin et al., 1999; Hoke and Chamberlain, 2004; Krischer et al., 1987). Rib fractures as a result of CPR are more common in adults than children, due to the flexibility of ribs and higher percentage of cartilage in juveniles. Hoke and Chamberlain (2004) state that the incidence of rib fractures as a secondary injury from CPR ranges from 13 to 97 percent in adults. Krischer et al., (1987) conducted a study on individuals who received CPR and found that 31.6% had rib fractures and 21.1% had sternal fractures. Neither study investigates fracture patterns in detail or explains which ribs are more at risk in the event that CPR is administered.

A study by Baubin et al. (1999) concludes that age plays the largest role of any factor in determining the incidence of rib fracture in cases with CPR administered. The study by Baubin et al. (1999) conducted 60 seconds of chest compressions on 38 cadavers, age 18 an older, prior to autopsy to observe the fracture patterns of the manubrium, sternum, and ribs. The results showed a significantly high risk for sternal fractures in females ($p=0.008$) and a significantly higher risk for rib fractures in older individuals ($p=0.008$) (Baubin et al., 1999). Older individuals in the study by Baubin et al. (1999) were considered to be individuals 70 years of age or older. The results of a stepwise logistic regression showed the most noteworthy factors to be age, sex, and use of force, with age being the most influential factor (Baubin et al., 1999).

## Skeletal Aging and Fracture Risk

Individuals under the age of 45 are more likely to be involved in dangerous incidences resulting in trauma; however, elderly individuals are at a higher risk for rib fractures in these types of events (Flagel et al., 2005). It is well established in the literature that skeletal changes due to aging put older individuals at a higher risk for fracture overall, especially in the event of a MVA (Bergeron et al., 2003; Bulger et al., 2000; Flagel et al., 2005; Sariego et al., 1993; Sirmali et al., 2003).

Bones become more prone to fracture as an individual ages, due to changes in the skeletal tissues (Kotiya and Silva, 2012). As skeletal muscle mass decreases with age, less force is being put on the skeleton and the bones become weakened, more brittle, and more prone to fracture through a process called resorption (Genetos and Jacobs, 2011). The effects of aging on the skeleton are heightened in females, due to changes in hormone levels during menopause (Genetos and Jacobs, 2011). These changes in skeletal tissue most likely explain much of why the risk for fracture is greater in older individuals, especially in MVAs.

A study by Bansal et al. (2010) looks for differences in injury source and type in “elderly” and “extremely elderly” individuals. Bansal et al. (2010) classify individuals 65-79 years of age as “elderly” and individuals 80 years of age or older as “extremely elderly.” The results show that younger vehicle occupants did not sustain rib fractures from safety restraints in most cases, but older patients did exhibit rib fractures. The authors suggest that degenerative changes in the shape and stability of the ribcage play an important role in fracture susceptibility in MVAs (Bansal et al., 2010). This is interesting and pertinent to the research questions addressed in this study; however, Bansal et al. (2010) fails to compare these results to younger individuals. The results from Bansal et al. (2010) would be even more effective if compared to similar data for younger individuals in order to elaborate on the differences between the age groups.

Augenstein et al. (2005) recommend that automobile manufacturers consider the development of an adjusted safety restraint that can accommodate frail thoracic regions in elderly individuals. A wider restraint that can more evenly distribute the force placed on the ribcage during an accident is suggested (Augenstein et al., 2005). The questions addressed in this research study will contribute to the knowledge base on age and rib fracture risk, by looking at the number of ribs fractured in relationship to the age of the individual.

Studies have shown that an individual's risk for being involved in an MVA and the risk of being injured in an MVA is positively correlated with increasing age (Bansal et al., 2010; Newgard, 2008). Rib fractures are more likely to occur from blunt trauma in older individuals due to muscle atrophy and weaker bone tissue (Bansal et al., 2010). Mortality from MVAs in older individuals increases in both rural and urban areas per every mile traveled (Newgard, 2008). Essentially, the more miles an individual travels, the higher the risk of being involved in an accident. By determining which age groups are at a higher risk to be involved in fatal accidents, safety education can be better targeted towards these individuals.

A study by Bulger et al. (2000) separates individuals with thoracic trauma into two age groups: under 65 and over 65. Individuals in the older group are found to be two times as likely than the individuals in the younger group to sustain rib fractures. This is a significant increase in risk that should be carefully disseminated through safety information to elderly drivers. While rib fractures have clearly been identified as a major factor for mortality in blunt thoracic trauma, Jones et al. (2011) conclude that it is imperative to consider the injuries sustained in association with rib fractures, rather than considering only the number of rib fractures sustained and the individuals' age when determining mortality.

**Elderly Drivers and Motor Vehicle Safety**

Elderly drivers are an important subgroup to consider in this type of research. In 2008, approximately 5,500 elderly individuals were involved in fatal MVAs. This equates to an average of 15 fatalities in individuals over the age of 65 every day from MVAs alone (Injury and Prevention Control, 2013). Ethnographic research on elderly drivers by Rothe (1990) discusses various reasons for why elderly individuals have a higher risk of being involved in MVAs. His model includes physical frailty, psycho-physiological ailments, and visual and hearing impairment as factors for increased risk (Rothe, 1990). The previous section describes, in detail, the literature on skeletal fracture risk for elderly individuals due to age-related changes. Rothe's model suggests that there are other factors that put elderly individuals at a higher risk for involvement in fatal crashes (1990).

Elderly individuals, either as drivers or passengers, are at a heightened risk for injury during a crash. Several authors suggest that many of these injuries are the fault of a seatbelt (Bansal et al., 2010; Augenstein et al., 2005; Driving Safety, 2007). Bansal et al. (2010) suggest that vehicle manufactures redesign seatbelts to accommodate for age-related changes in skeletal morphology and strength or at least develop an interchangeable restraint option for older individuals. Similarly, Augenstein et al. (2005) offer recommendations for a "four-point safety belt" for elderly drivers and passengers.  This type of design can disperse loading forces from the seat belt more evenly across the chest, rather than a sharp line across the ribcage (Augenstein et al., 2005).  Another option is to simply make a seatbelt, or an attachment, that is wider than the current seatbelt size (Bansal et al., 2010).  Some research investigates a bit further, suggesting that automobile manufacturers should be developing "silver" lines of vehicles that are specifically designed for elderly individuals (Bansal et al., 2010).  This supports the idea that the entire vehicle plays a role in the risk for fracture, injury, and even fatality in MVAs.

There are several vehicle modifications tailored to elderly drivers and passengers currently available (Driving Safety, 2007).  However, none of the vehicle modifications listed in the National Highway Traffic Safety Administration brochure for "Adapting Motor Vehicles for Older Drivers" are preventative measures for safety.  Rather, they are modifications that will help elderly individuals continue to drive despite slight handicaps (Driving Safety, 2007).  There are several issues surrounding elderly drivers and their risk in MVAs that are key components to the purpose of this research study.  The results of this study can be used to better implement safety strategies for vehicle

# CHAPTER THREE:

# MATERIALS AND METHODS

The focus of this research project is to predict thoracic soft tissue injuries from rib fracture patterns in fatal MVAs; determine the relationship between rib fracture patterns and seatbelt use, airbag deployment, and CPR administration; and establish the effect of age on the number of ribs fractured in fatal MVAs.  Chapter 3 presents a description of the sample and data collection process for MVA decedent data and analytical trauma data, followed by the statistical methodology used for both MVA decedent data and analytical trauma data.

## Description of Sample and Data Collection

Each year, there are about 200 traffic-related deaths investigated at the HCMEO (Medical Examiner Workload Statistics, 2013).  Records of deaths from previous years are accessible and organized, including detailed descriptions of trauma through initial case summaries, autopsy reports, digital radiographs, photography, and histological samples.  Using on-site computers and databases, data were collected at the HCMEO from June 2, 2014 to June 26, 2014 for 105 traffic-related deaths occurring from 2011 to 2013.

The HCMEO database was searched for all traffic-related deaths for the years 2011 to 2013. The search compiled a list of 609 traffic-related deaths, organized by vehicle type and position in vehicle. Only individuals who were autopsied at the time of death were included in the sample, excluding phone inquiries and external-only examinations. Phone inquiries are reports of deaths in cases where the body does not need to physically be taken to the HCMEO. External examinations are performed in cases when autopsy would not add any new information. For example, if an individual had a prolonged hospital stay with complete diagnostics prior to death, only an external examination would be performed. Motorcycle drivers and passengers, bicyclists, and pedestrians were excluded due to the injuries sustained being expected to differ too much from individuals inside vehicles. Drivers and passengers of semi-trailer trucks were also excluded for the same reason. To avoid differences in skeletal biology due to immaturity, individuals under the age of 18 were also excluded. Only data on drivers and passengers of motor vehicles, of age 18 or older, were collected. Given these parameters, the final sample consists of 105 individuals including 68 males and 37 females, ages 18 to 94. Age frequencies by sex are shown in Figure 4.1. The complete data collection protocol used for each case can be found in Appendix A.

The decedent demographic data and analytical trauma data collected for this study come from two primary sources provided by the HCMEO—initial case summaries and autopsy reports. Death investigators complete initial case summaries whenever a death is reported. This includes demographic information about the decedent as well as pertinent information regarding the MVA. Since this research project focuses only on individuals who died in MVAs, information about the accident was recorded for each case from the initial case summary. This included the following variables: type of vehicle, type of MVA, occupant role in the vehicle, seatbelt use, airbag deployment, and CPR administration. A detailed list of these variables can be found in Table 4.2

Autopsy reports are completed by a medical examiner once an autopsy is complete and the manner and cause of death have been determined. This report describes skeletal and soft tissue injuries in detail, including the explicit location of fractures and the type of soft tissue injuries. The following variables from the autopsy reports are included in this study: presence or absence of rib fractures on each rib, location of fracture on each rib, presence or absence of soft tissue injury by organ including the lungs, heart, diaphragm, liver, spleen, and pancreas. A complete list of variables tested and sample sizes for each can be found in Chapter 4.

### MVA Decedent Data

Age-at-death and sex were recorded from autopsy reports, while data for MVA type, vehicle type, and position in vehicle were recorded from the initial case summaries. Data for seatbelt use, airbag deployment, and CPR administration were also recorded from the initial case summaries. The sample sizes and breakdown of the collected data are shown in the tables below.

**Table 3.1** Total sample sizes for MVA decedent data by sex (n=105).

| Data Collected | Male (n) | Female (n) | Total (n) |
|---|---|---|---|
| **Age at death** | 68 | 37 | 105 |
| **Sex** | 68 | 37 | 105 |
| **MVA type** | 67 | 37 | 104 |
| **Vehicle type** | 64 | 37 | 101 |
| **Position in vehicle** | 68 | 37 | 105 |
| **Seatbelt use** | 55 | 30 | 85 |
| **Airbag deployment** | 10 | 6 | 16 |
| **CPR administration** | 58 | 29 | 87 |

Table 3.1 lists the complete data collected for age-at-death, sex, and position in vehicle. Not all cases had information provided for MVA type, vehicle type, seatbelt use, airbag

deployment, and CPR administration. Cases with missing data were excluded for the respective analyses. The sample sizes for seatbelt use, airbag deployment, and CPR administration are broken down by sex in Table 3.2 below.

**Table 3.2** Sample sizes for seatbelt use, airbag deployment, and CPR administration by sex.

| Variable | Male (n) | Male (%) | Female (n) | Female (%) | Total (n) |
|---|---|---|---|---|---|
| **Seatbelt Use (n=85)** | | | | | |
| Yes | 21 | 50% | 21 | 50% | 42 |
| No | 34 | 79.1% | 9 | 20.9% | 43 |
| **Airbag Deployment** (n=16) | | | | | |
| Yes | 8 | 57.1% | 6 | 42.9% | 14 |
| No | 2 | 100% | 0 | 0% | 2 |
| **CPR Administration (n=87)** | | | | | |
| Yes | 19 | 65.5% | 10 | 34.5% | 29 |
| No | 39 | 67.2% | 19 | 32.8% | 58 |

Table 3.2 lists the sample sizes for seatbelt use, airbag deployment, and CPR administration by sex. Cases with unspecified information for these variables are excluded and the sample sizes used for the analyses are listed in Table 3.2.

### Analytical Trauma Data: Skeletal Fractures

The number and location of rib fractures on both sides of the ribcage were collected from the autopsy reports. Each rib fracture is recorded as anterior, anterolateral, lateral, posterolateral, or posterior, according to the anatomical location of the fracture on the rib; however, only the presence or absence of a fracture on each rib is used for the analyses in the following chapter. A complete list of the fracture data collected, but not used in this study, can be found in Appendix A.

**Table 3.3** Sample sizes for analytical trauma data.

| Data Collected | Male (n) | Male (%) | Female (n) | Female (%) | Total (n) |
|---|---|---|---|---|---|
| **Rib Fractures** | 65 | 64.4% | 36 | 35.6% | 101 |
| **Lung Injury** | 66 | 64.1% | 37 | 35.9% | 103 |
| **Heart Injury** | 66 | 64.1% | 37 | 35.9% | 103 |
| **Diaphragm Injury** | 66 | 64.1% | 37 | 35.9% | 103 |
| **Liver Injury** | 66 | 64.1% | 37 | 35.9% | 103 |
| **Spleen Injury** | 66 | 64.1% | 37 | 35.9% | 103 |

### Analytical Trauma Data: Thoracic Soft Tissue Injuries

Location of thoracic soft tissue injuries by organ and type of injury were collected from the autopsy reports. The lungs, heart, diaphragm, liver, spleen, and pancreas were included, due to their proximity to the ribcage. For each organ, the soft tissue injury was recorded as one of the following: no injury, laceration, contusion, combination of laceration and contusion, or other type of injury; however, only the presence or absence of an injury is tested in the following analyses. A complete list of the thoracic soft tissue injury data collected but not used in this study, and the coding for each variable can be found in Appendix A.

## Statistical Methodology

### MVA Decedent Data

Basic frequencies for sex, MVA type, vehicle type, position in vehicle, seatbelt use, airbag deployment, and CPR administration were compiled in addition to the range, mean, and standard deviation for decedent age at death. Chi-square analyses were used to test for independence for sex to seatbelt use, airbag deployment, and CPR administration.

**Analytical Trauma Data**

Descriptive statistics were compiled for all fracture and soft tissue trauma variables. This included the range, mean, and standard deviation for the number of ribs fractured and basic frequencies for the location of fractures on each rib, and all soft tissue injuries by type of injury.

To test the first four hypotheses, the ribs are grouped for statistical testing. Table 3.4 lists the groupings used in this study for the ribs, manubrium, and sternum. The groupings used in this study are based on a similar study by Park (2012), which divides the ribs into high, middle, and low ribs. The groupings are duplicated for the left and right side of the ribcage for a total of 6 groupings for the ribs. The manubrium and sternum are tested separately.

**Table 3.4** Skeletal fracture groupings used for analysis based on Park (2012).

| Skeletal Element | Fracture Grouping |
|---|---|
| Rib 1 | High Ribs |
| Rib 2 | High Ribs |
| Rib 3 | Middle Ribs |
| Rib 4 | Middle Ribs |
| Rib 5 | Middle Ribs |
| Rib 6 | Middle Ribs |
| Rib 7 | Middle Ribs |
| Rib 8 | Middle Ribs |
| Rib 9 | Low Ribs |
| Rib 10 | Low Ribs |
| Rib 11 | Low Ribs |
| Rib 12 | Low Ribs |
| Manubrium | Manubrium |
| Sternum | Sternum |

The fracture data was recorded as either present or absent for each grouping of ribs. Manubrium and sternum fractures were recorded, separately, as present or absent. To test for independence for fractures in rib groups, the manubrium, or the sternum, chi-square analyses were performed for each group in comparison to each of the other groups.

The first research objective is to determine if rib fracture patterns can predict thoracic soft tissue injury. Binary logistic regression was performed to assess the odds ratios for each of the ribs, manubrium, and sternum to each of the soft tissue organ injuries. The second, third, and fourth research questions are assessed using present or absent coding for fractures, seatbelt use, airbag deployment, and CPR administration. Several chi-square analyses were performed to address the relationship between rib, manubrium, and sternum fractures to seatbelt use, airbag deployment, and CPR administration. To further address this research question, a binary logistic regression is performed to determine the predictive value of fracture patterns for seatbelt use. Passengers are excluded from this regression due to the fact that opposite fracture patterns would be expected in passengers due to the reversed direction of the seatbelt across the chest. An additional binary logistic regression was not performed for passengers due to the small sample size for passengers. Finally, to address the fifth research objective, correlations are performed between age and the total number of ribs fractured, age and the total number of ribs fractured on the left side of the ribcage, and age and the total number of ribs fractured on the right side of the ribcage.

# CHAPTER FOUR:

# RESULTS

Chapter 4 discusses the statistical results for the analysis of MVA decedent data and analytical trauma data. Descriptive statistics, including the range, mean, and standard deviation are reported for decedent age. Basic frequencies are shown for sex, MVA type, vehicle type, position in the vehicle, seatbelt use, airbag deployment, and CPR administration. Cross tabulations and chi-square analysis are shown for sex to each of these variables.

Descriptive statistics are given for the trauma data. The range, mean, and standard deviation are given for the total number of rib fractures and for the number of rib fractures on each side of the ribcage. Basic frequencies are listed for the location of fractures on each rib, all other skeletal fractures in the body by bone, and all soft tissue injuries by injury type.

To address the first research objective, regression analysis is reported for age and total number of rib fractures, age and total rib fractures on the left side of the ribcage, and age and total rib fractures on the right side of the ribcage. To address the second research question, chi square analyses were performed for fractures of the ribs, manubrium, and sternum to seatbelt use, airbag deployment, and CPR administration. To answer the third research question, chi-square analyses for fractures of the ribs, manubrium, and sternum to one another are shown to address any relatedness between ribs, the manubrium, or the sternum. Finally, the results for binary logistic regression of the rib, manubrium, and sternum fractures to the soft tissue injuries are reported.

**MVA Decedent and Accident Statistics**

Of the 105 individuals in the sample, 68 are males (65%) and 37 are females (35%). The minimum age is 18 years and the maximum is 94 years. The mean age is 49 years with a standard deviation of 22.5 years. Figure 4.1 shows a bar chart of frequencies for decedent age for all individuals in the sample. Figure 4.2 shows a bar chart of frequencies for age with the individuals in the sample separated by sex.

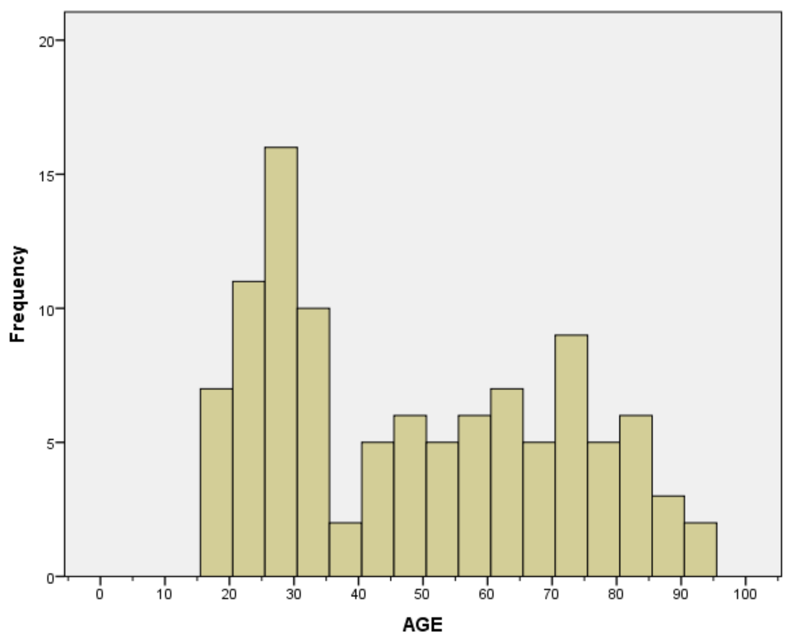


**Figure 4.1.** Age frequencies for all individuals in the sample.

Figure 4.1 shows the frequencies for age for all individuals in the sample. The bar chart indicates peaks around 25 to 30 years of age and again around 60 to 75 years of age.

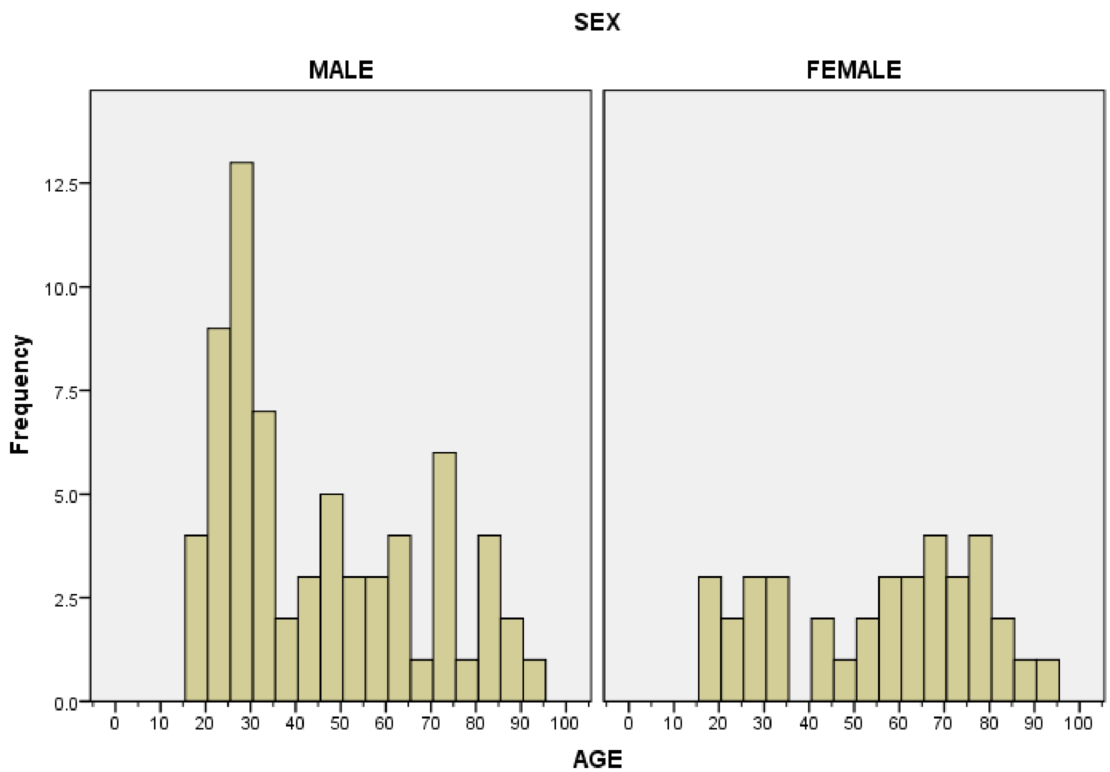


**Figure 4.2.** Age frequencies by sex.

Figure 4.2 breaks down the frequencies for age by sex. There is a high frequency of males in the sample that are 20 to 35 years of age and another peak around 70 to 75 years of age. The female individuals in the sample are spread out pretty evenly for age with no noteworthy peaks in the data.

Basic frequencies for MVA type, vehicle type, and position in vehicle are shown in Table 4.1. The sample includes 81 drivers (77.1%), 12 front seat passengers (11.4%), 7 unspecified passengers (6.7%), 3 back seat passengers (3.8%), and 1 individual riding in a truck bed (1.0%) in the sample. The most frequent vehicle type in the sample is a sedan, accounting for 54 cases (51.4%). Pickup trucks and SUVs were the next most frequent vehicle type with 17 cases each (16.2%). The most common accident type is motor vehicle-to-motor vehicle accidents, accounting for 71 of the cases (67.6%). This is followed by 19 cases of motor vehicles striking fixed objects (18.1%) and 10 cases of rollover crashes (9.5%).

**Table 4.1** Basic frequencies for MVA type, vehicle type, and position in vehicle (n=105).

| **Variables** | **Percentage** |
|---|---|
| **MVA Type** | |
| Vehicle-Vehicle | 67.6% (71) |
| Rollover | 9.52% (10) |
| Fixed Object | 18.1% (19) |
| Vehicle-Vehicle/Rollover | 2.86% (3) |
| Fixed Object/Rollover | 0.95% (1) |
| Unspecified | 0.95% (1) |
| **Vehicle Type** | |
| Sedan | 51.4% (54) |
| 2-Door Car | 3.81% (4) |
| Pickup Truck | 16.2% (17) |
| Sport Utility Vehicle | 16.2% (17) |
| Minivan | 4.76% (5) |
| Van | 2.86% (3) |
| Truck (Non-Pickup) | 0.95% (1) |
| Unspecified | 3.81% (4) |
| **Position in Vehicle** | |
| Driver | 77.1% (81) |
| Front Passenger | 11.4% (12) |
| Back Passenger | 3.81% (4) |
| Passenger (Unspecified) | 10.9% (7) |
| Truck bed | 0.95% (1) |

Information on seatbelt use, airbag deployment, and CPR administration was collected when available. The sample included 42 individuals wearing seatbelts (40.0%), 43 individuals who were not wearing seatbelts (41.0%), and 20 individuals for whom seatbelt data was not available (19.0%). Only 16 cases included information on airbag deployment, 14 of which the airbags were reported to deploy and 2 of which the airbags did not deploy. Of the 105 individuals in the sample, 29 were reported to have received CPR (27.6%) and 58 were reported to not receive CPR (55.2%). There were 18 cases in which CPR information was unknown or excluded from the reports (17.1%).

**Table 4.2** Basic frequencies for seatbelt use, airbag deployment, and CPR administration (n=105).

| Variable | Frequencies (n) |
|---|---|
| **Seatbelt Use** | |
| Yes | 40.0% (42) |
| No | 40.9% (43) |
| Unspecified | 19.0% (20) |
| **Airbag Deployment** | |
| Yes | 13.3% (14) |
| No | 1.90% (2) |
| Unspecified | 84.8% (89) |
| **CPR Administration** | |
| Yes | 27.6% (29) |
| No | 55.2% (58) |
| Unspecified | 17.1% (18) |

Figure 4.3 shows the frequencies of seatbelt and non-seatbelt users by sex for this sample. This is important to consider in the analysis because wearing a seatbelt is a conscious decision that the driver or passenger makes upon riding in a vehicle. While airbag deployment and CPR administration are important variables and may show similar risks for fracture, they are not consciously decided upon by the individual in the MVA.

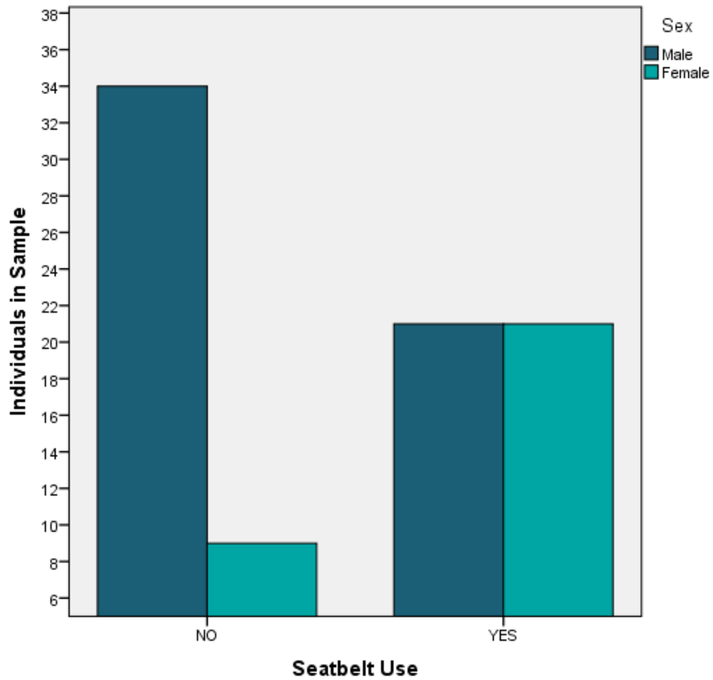


**Figure 4.3.** Frequencies of seatbelt and non-seatbelt users by sex.

The bar chart in Figure 4.3 indicates that the same number of male and female individuals in the sample decided to wear a seatbelt, while many more men than women in this sample decided not to wear a seatbelt.  This may indicate that males are less likely to wear a seatbelt.

Chi-square analyses were conducted to investigate the independence of sex to seatbelt use, airbag deployment, and CPR administration.  For this analysis, any cases with unspecified information for seatbelt use, airbag deployment, and CPR administration were excluded.  Table 4.3 summarizes the results from these tests and indicates a significant relationship between seatbelt use and sex.

**Table 4.3** Chi-square analyses for sex to seatbelt use, airbag deployment, and CPR administration.

| | Sex | | |
|---|---|---|---|
| | $X^2$ | df | p |
| **Seatbelt Use (n=85)** | 7.862 | 1 | 0.005* |
| **Airbag Deployment (n=16)** | 1.371 | 1 | **0.500** |
| **CPR Administration (n=87)** | 0.026 | 1 | 0.872 |

~**BOLD** result indicates Fisher's Exact Test used.
*indicates significance $p \leq 0.05$

The chi-square analyses for sex indicate a significant relationship between seatbelt use and sex (*p=0.005*). Airbag deployment and CPR administration do not appear to have a significant relationship with sex. Of the three variables tested against sex, seatbelt use is the only conscious decision made by the passenger.

## Analytical Trauma Statistics

Descriptive statistics were obtained for the number of rib fractures per individual. The total number of rib fractures, total rib fractures on the left side of the ribcage, and total rib fractures on the right side of the ribcage were computed separately. The frequencies of fractures are shown in Figure 4.4, Figure 4.5, and Figure 4.6.

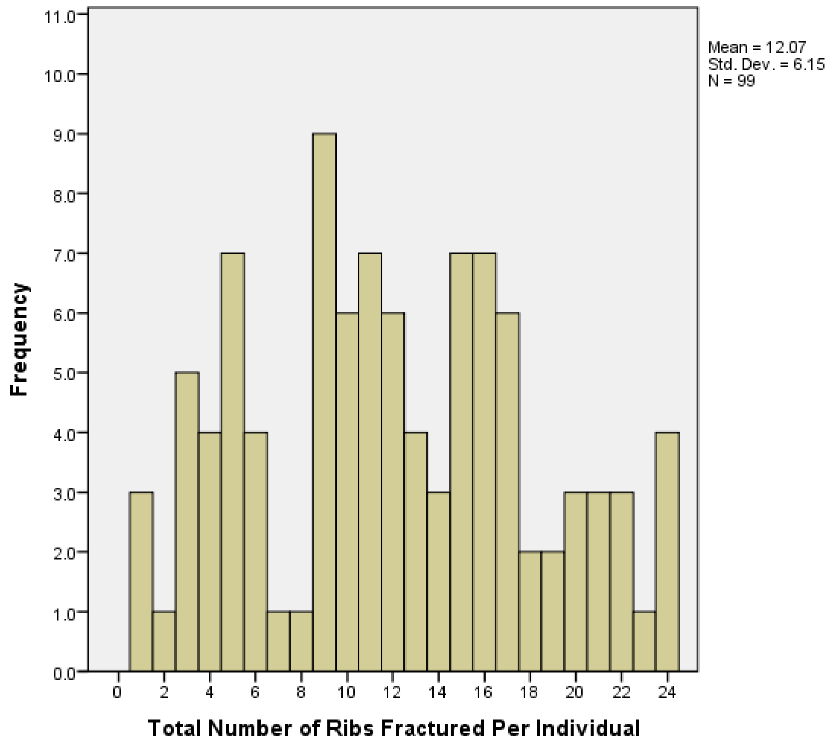


**Figure 4.4.** Frequencies of the number of total ribs fractured per individual.

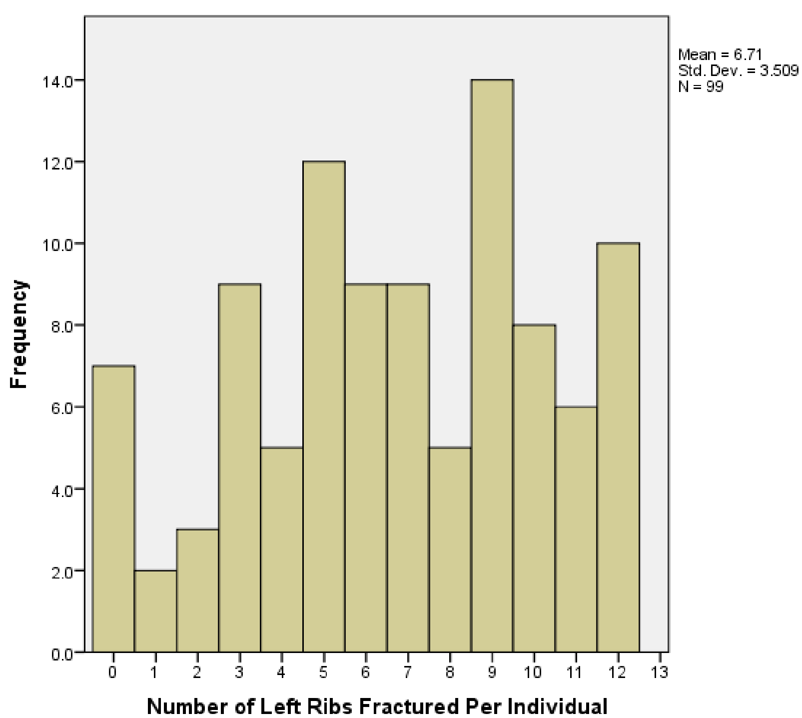


**Figure 4.5.** Frequencies of the number of left ribs fractured per individual.

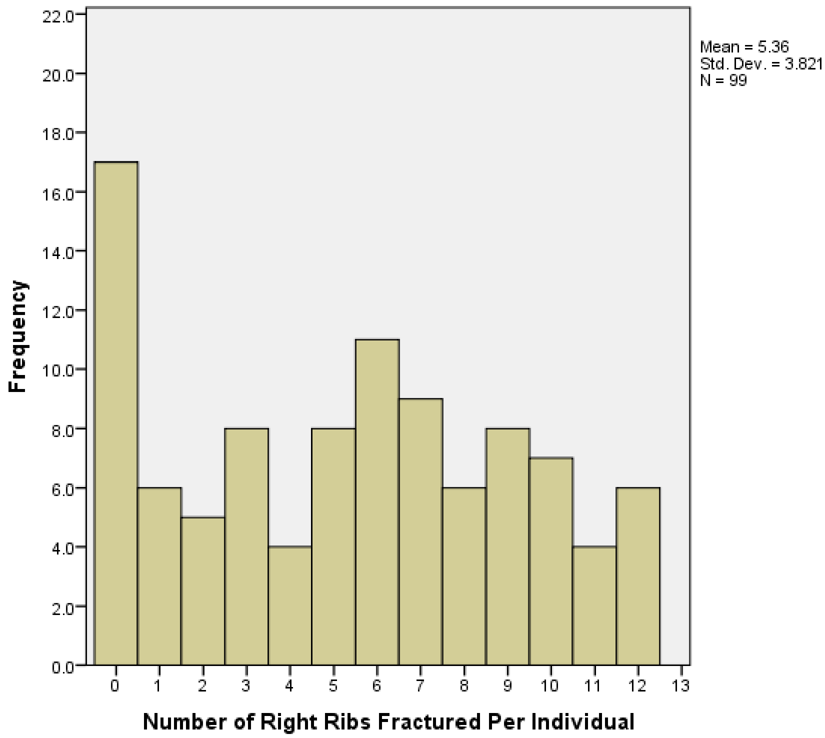


**Figure 4.6.** Frequencies of the number of right ribs fractured per individual.

Overall, more left rib fractures were sustained than right rib fractures. This may be due to the large number of drivers in the sample, as it was hypothesized that drivers will have more left rib fractures due to the position of the seatbelt across more left ribs than right ribs. Depending on the vehicle impact site, the driver may have left side of the car in his or her proximity, which may influence the injuries sustained.

The frequencies of fractures, by sex, are shown in Figure 4.7, Figure 4.8, and Figure 4.9. These figures separate the sample into seatbelt users and non-seatbelt users to determine if differences in the number of fractures exist.

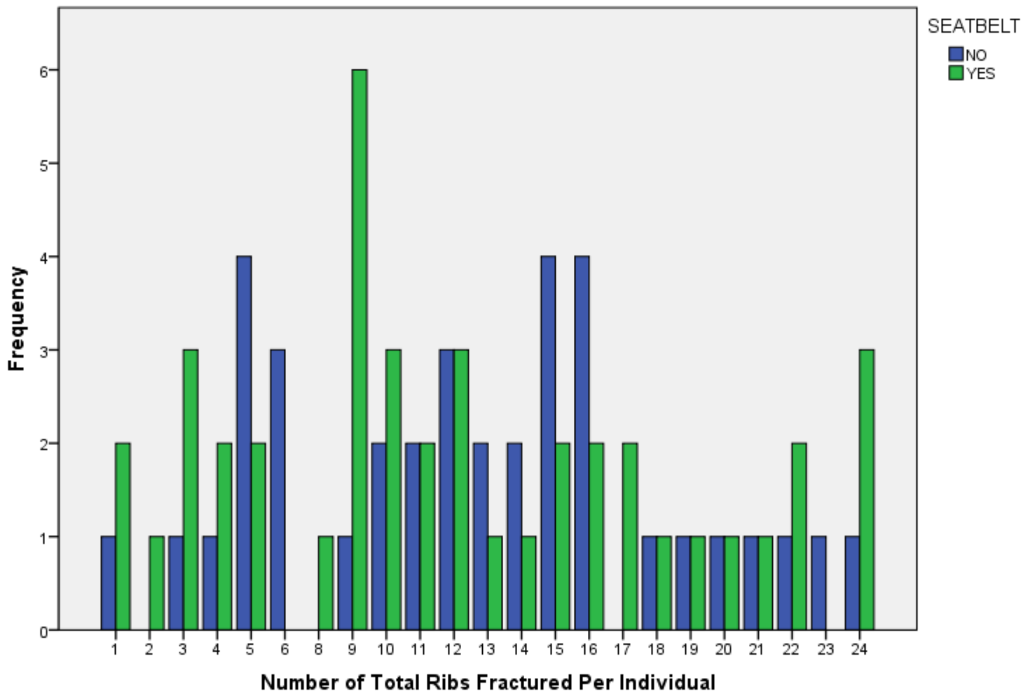


**Figure 4.7.** Frequencies of the number of ribs fractured per individual by seatbelt use.

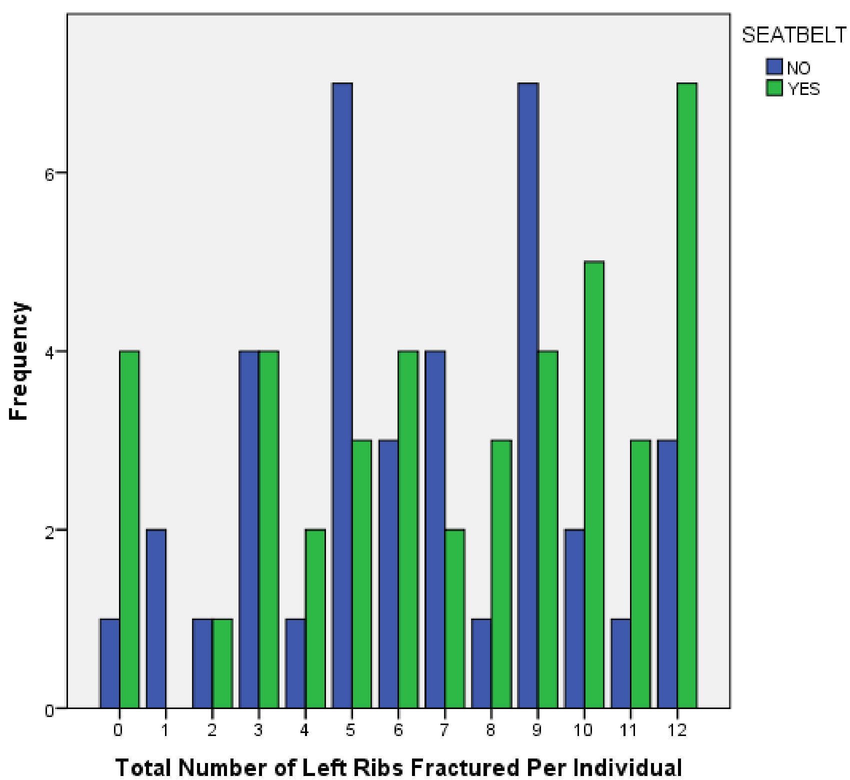


**Figure 4.8.** Frequencies of the number of left ribs fractured per individual by seatbelt use.

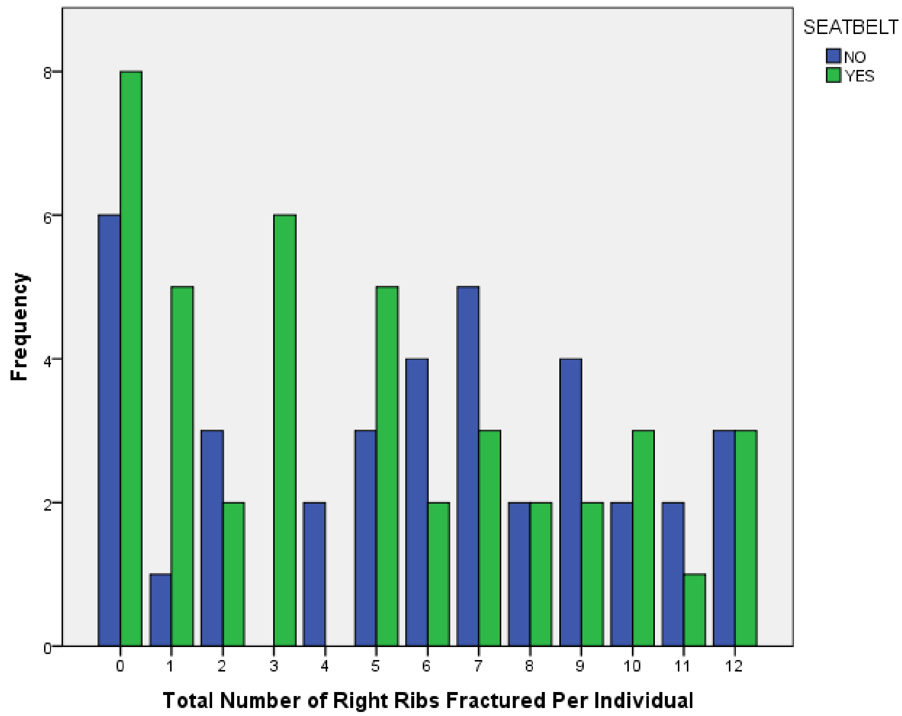


**Figure 4.9.** Frequencies of the number of right ribs fractured per individual by seatbelt use.

No consistent patterns for rib fracture frequencies are found when the sample is separated by sex. This suggests that sex does not influence rib fracture frequencies.

Basic frequencies for rib fracture by location for each rib were compiled. For each rib, frequencies for no fracture, anterior fracture, anterolateral fracture, lateral fracture, posterolateral fracture, posterior fracture, or combination of fractures were calculated. The frequencies are shown in Table 4.4 for the left side of the ribcage and Table 4.5 for the right side of the ribcage.

**Table 4.4** Left rib fracture frequencies by location on rib (n=101).

| | No Fracture | | Anterior | | Anterolateral | | Lateral | | Posterolateral | | Posterior | | Combination | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** |
| **L Rib 1** | 48 | 47.5 | 12 | 11.9 | 3 | 1.02 | 14 | 13.9 | 1 | 0.99 | 9 | 8.91 | 14 | 81.2 |
| **L Rib 2** | 25 | 24.8 | 14 | 13.9 | 8 | 7.92 | 20 | 19.8 | 1 | 0.99 | 8 | 7.92 | 25 | 24.8 |
| **L Rib 3** | 24 | 23.8 | 12 | 11.9 | 10 | 9.90 | 19 | 0.00 | 1 | 0.99 | 6 | 5.94 | 29 | 28.7 |
| **L Rib 4** | 20 | 19.8 | 12 | 11.9 | 10 | 9.90 | 18 | 0.00 | 1 | 0.99 | 12 | 11.9 | 28 | 27.7 |
| **L Rib 5** | 24 | 23.8 | 8 | 7.92 | 7 | 6.93 | 17 | 0.00 | 2 | 1.98 | 14 | 13.9 | 29 | 28.7 |
| **L Rib 6** | 20 | 19.8 | 9 | 8.91 | 6 | 5.94 | 18 | 0.00 | 1 | 0.99 | 17 | 16.8 | 20 | 19.8 |
| **L Rib 7** | 41 | 40.6 | 6 | 5.94 | 6 | 5.94 | 15 | 0.00 | 1 | 0.99 | 13 | 12.9 | 19 | 18.8 |
| **L Rib 8** | 43 | 42.6 | 5 | 4.95 | 3 | 1.02 | 17 | 0.00 | 3 | 1.02 | 15 | 14.9 | 15 | 14.9 |
| **L Rib 9** | 56 | 55.4 | 1 | 0.99 | 2 | 1.98 | 12 | 11.9 | 1 | 0.99 | 17 | 16.8 | 12 | 11.9 |
| **L Rib 10** | 67 | 66.3 | 0 | 0.00 | 2 | 1.98 | 8 | 7.92 | 1 | 0.99 | 16 | 15.8 | 7 | 6.93 |
| **L Rib 11** | 81 | 80.2 | 0 | 0.00 | 0 | 0.00 | 3 | 1.02 | 1 | 0.99 | 12 | 11.9 | 4 | 3.96 |
| **L Rib 12** | 85 | 84.1 | 0 | 0.00 | 0 | 0.00 | 2 | 1.98 | 1 | 0.99 | 11 | 10.9 | 2 | 1.98 |

**Table 4.5** Right rib fracture frequencies by location on rib (n=101).

| | No Fracture | | Anterior | | Anterolateral | | Lateral | | Posterolateral | | Posterior | | Combination | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** |
| **R Rib 1** | 56 | 55.4 | 12 | 11.9 | 2 | 1.98 | 6 | 5.94 | 2 | 1.98 | 12 | 11.9 | 11 | 10.9 |
| **R Rib 2** | 40 | 39.6 | 12 | 11.9 | 4 | 3.96 | 9 | 8.91 | 2 | 1.98 | 9 | 8.91 | 23 | 22.8 |
| **R Rib 3** | 34 | 33.7 | 11 | 10.9 | 5 | 4.95 | 10 | 9.90 | 2 | 1.98 | 11 | 10.9 | 28 | 27.7 |
| **R Rib 4** | 37 | 36.6 | 10 | 9.90 | 4 | 3.96 | 11 | 10.9 | 1 | 0.99 | 10 | 9.90 | 28 | 27.7 |
| **R Rib 5** | 39 | 38.6 | 9 | 8.91 | 5 | 4.95 | 10 | 9.90 | 0 | 0.00 | 9 | 8.91 | 29 | 28.7 |
| **R Rib 6** | 26 | 25.7 | 12 | 11.9 | 6 | 5.94 | 15 | 14.9 | 0 | 0.00 | 10 | 9.90 | 22 | 21.8 |
| **R Rib 7** | 51 | 50.5 | 8 | 7.92 | 5 | 4.95 | 11 | 10.9 | 1 | 0.99 | 10 | 9.90 | 15 | 14.9 |
| **R Rib 8** | 60 | 59.4 | 3 | 1.02 | 4 | 3.96 | 13 | 12.9 | 1 | 0.99 | 10 | 9.90 | 10 | 9.90 |
| **R Rib 9** | 72 | 71.3 | 3 | 1.02 | 3 | 1.02 | 7 | 6.93 | 1 | 0.99 | 9 | 8.91 | 6 | 5.94 |
| **R Rib 10** | 77 | 76.2 | 2 | 1.98 | 1 | 0.99 | 6 | 5.94 | 1 | 0.99 | 10 | 9.90 | 4 | 3.96 |
| **R Rib 11** | 87 | 86.1 | 1 | 0.99 | 0 | 0.00 | 2 | 1.98 | 0 | 0.00 | 8 | 7.92 | 3 | 1.02 |
| **R Rib 12** | 88 | 87.1 | 2 | 1.98 | 0 | 0.00 | 2 | 1.98 | 0 | 0.00 | 7 | 6.93 | 2 | 1.98 |

Of the 105 individuals in the sample, 2 did not have information on soft tissue injuries available and therefore these individuals are excluded when calculating the frequencies. Table 4.6 summarizes the frequencies of soft tissue injuries by organ and type of injury. This information is interesting and describes the types of injuries that are most common in each soft tissue organ; however, for further analyses, only the presence or absence of any type of injury is used.

**Table 4.6** Thoracic soft tissue injury frequencies (n=103).

| | **Lungs** | | **Heart** | | **Diaphragm** | | **Liver** | | **Spleen** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** | **Freq** | **%** |
| **No Injury** | 47 | 45.6 | 73 | 70.9 | 92 | 89.3 | 52 | 50.5 | 68 | 66.0 |
| **Laceration** | 10 | 9.71 | 26 | 25.2 | 11 | 10.7 | 46 | 44.7 | 35 | 34.0 |
| **Contusion** | 27 | 26.2 | 2 | 1.94 | 0 | 0.00 | 2 | 1.94 | 0 | 0.00 |
| **Lac & Cont** | 18 | 17.5 | 1 | 0.97 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| **Other Injury** | 1 | 0.97 | 1 | 0.97 | 0 | 0.00 | 3 | 2.91 | 0 | 0.00 |

Using the groupings of ribs described in the previous chapter, chi-square analyses were run for each rib group, manubrium, and sternum to each other in order to establish and relationships between the different groupings of ribs as well as the manubrium and sternum. The results from these chi-square analyses can be found below in Table 4.7 and Table 4.8.

**Table 4.7** Chi-square analyses for ribs to ribs, manubrium, and sternum.

| | L High | | | L Middle | | | L Low | | | R High | | | R Middle | | | R Low | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X^2$ | df | p | $X^2$ | df | p | $X^2$ | df | p | $X^2$ | df | p | $X^2$ | df | p | $X^2$ | df | p |
| **L High** | --- | -- | --- | 27.3 | 1 | <0.001* | 8.05 | 1 | 0.005* | 6.61 | 1 | 0.010* | 0.001 | 1 | 0.973 | 0.07 | 1 | 0.790 |
| **L Middle** | 27.2 | 1 | <0.001* | --- | -- | --- | 5.81 | 1 | 0.016* | 0.90 | 1 | 0.342 | 0.002 | 1 | 0.961 | 2.35 | 1 | 0.125 |
| **L Low** | 8.05 | 1 | 0.005* | 5.81 | 1 | 0.016* | --- | -- | --- | 2.80 | 1 | 0.094 | 0.678 | 1 | 0.410 | 9.65 | 1 | 0.002* |
| **R High** | 6.61 | 1 | 0.010* | 0.90 | 1 | 0.342 | 2.80 | 1 | 0.094 | --- | -- | --- | 27.96 | 1 | <0.001* | 8.60 | 1 | 0.003* |
| **R Middle** | 0.001 | 1 | 0.973 | 0.002 | 1 | 0.961 | 0.678 | 1 | 0.410 | 27.9 | 1 | <0.001* | --- | -- | --- | 8.70 | 1 | 0.003* |
| **R Low** | 0.07 | 1 | 0.790 | 2.35 | 1 | 0.125 | 9.65 | 1 | 0.002* | 8.60 | 1 | 0.003* | 8.70 | 1 | 0.003* | --- | -- | --- |
| **Manub** | 0.47 | 1 | 0.493 | 0.83 | 1 | 0.362 | 0.68 | 1 | 0.411 | 0.61 | 1 | 0.433 | 1.99 | 1 | 0.159 | 1.19 | 1 | 0.276 |
| **Sternum** | 1.16 | 1 | 0.281 | 1.22 | 1 | 0.269 | 2.68 | 1 | 0.102 | 6.42 | 1 | 0.011* | 0.19 | 1 | 0.665 | 4.48 | 1 | 0.034* |

*indicates significance p≤0.05

**Table 4.8** Chi-square analyses for manubrium and sternum to ribs, manubrium, and sternum.

| | Manubrium | | | Sternum | | |
|---|---|---|---|---|---|---|
| | $X^2$ | df | p | $X^2$ | df | p |
| **L High** | 0.47 | 1 | 0.493 | 1.16 | 1 | 0.281 |
| **L Middle** | 0.83 | 1 | 0.362 | 1.22 | 1 | 0.269 |
| **L Low** | 0.68 | 1 | 0.411 | 2.68 | 1 | 0.102 |
| **R High** | 0.61 | 1 | 0.433 | 6.42 | 1 | 0.011 |
| **R Middle** | | 1 | | 0.79 | 1 | 0.376 |
| **R Low** | 1.19 | 1 | 0.276 | 4.48 | 1 | 0.034 |
| **Manub** | --- | -- | --- | 0.19 | 1 | 0.665 |
| **Sternum** | 0.19 | 1 | 0.665 | --- | -- | --- |

*indicates significance p≤0.05

Table 4.7 shows significant relationships between fractures in many of the groups. Each of the significant relationships found in Table 4.7 is discussed in detail in Chapter 5. These chi-square tests aim to show which rib groups are likely to be fractured in relationship to one another. Table 4.8 shows no significant results for the relationship of the manubrium and sternum with the rib groups.

To address the first research question, binary logistic regression was computed to determine the relationship between the presence and absence of fractures in the rib groupings previously described, the manubrium, and sternum to the presence or absence of thoracic soft tissue injuries. The complete results for the regression can be found below in Table 4.9.

**Table 4.9** Summary of logistic regression analysis for rib, manubrium, and sternum fractures predicting thoracic soft tissue injury.

| Predictor | Lungs | | | Heart | | | Diaphragm | | | Liver | | | Spleen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **β** | **p** | **OR** | **β** | **p** | **OR** | **β** | **p** | **OR** | **β** | **p** | **OR** | **β** | **p** | **OR** |
| **L High Ribs** | -0.529 | 0.436 | 0.589 | 1.70 | 0.057 | 5.870 | 1.515 | 0.227 | 4.551 | -0.075 | 0.751 | 1.217 | 0.825 | 0.249 | 2.282 |
| **L Middle Ribs** | 2.468 | 0.017* | 11.799 | 0.188 | 0.886 | 1.207 | 18.133 | 0.999 | 75016 | -0.246 | 0.976 | 1.025 | 0.001 | 0.999 | 1.001 |
| **L Low Ribs** | 0.117 | 0.812 | 1.124 | 0.148 | 0.773 | 1.159 | 0.132 | 0.854 | 1.141 | 1.095 | 0.177 | 0.531 | 0.364 | 0.451 | 1.439 |
| **R High Ribs** | -0.184 | 0.753 | 0.832 | -0.395 | 0.551 | 0.674 | -1.609 | 0.060 | 0.200 | -0.451 | 0.992 | 0.995 | -1.315 | 0.032* | 0.268 |
| **R Middle Ribs** | -0.351 | 0.601 | 0.704 | 0.749 | 0.326 | 2.114 | 2.217 | 0.077 | 9.183 | -0.074 | 0.028* | 4.328 | 0.696 | 0.297 | 2.005 |
| **R Low Ribs** | -0.774 | 0.144 | 0.461 | -0.837 | 0.176 | 0.433 | 0.343 | 0.669 | 1.409 | 0.443 | 0.591 | 1.313 | 0.482 | 0.374 | 1.620 |
| **Manubrium** | 1.261 | 0.007* | 3.529 | -0.145 | 0.769 | 0.865 | 0.990 | 0.159 | 2.692 | 0.106 | 0.827 | 1.099 | 0.512 | 0.261 | 1.668 |
| **Sternum** | -0.727 | 0.347 | 0.484 | 2.197 | 0.009* | 8.999 | -0.019 | 0.987 | 0.981 | -0.580 | 0.656 | 1.393 | 1.293 | 0.081 | 3.642 |

*indicates significance p≤0.05

Table 4.9 shows the binary logistic regression results for each rib, the manubrium, and sternum to soft tissue injuries. The results show that the lungs are 12 times more likely to be injured when the left middle ribs are fractured (*p=0.017*) and 4 times more likely to be injured when the manubrium is fractured (*p=0.007*). The heart is 9 times more likely to be injured when the sternum is fractured (*p=0.009*) and the liver is 4 times more likely to be injured when the right middle ribs are fractured (*p=0.028*). Finally, the spleen is found to be 0.3 times more likely to be injured when the right high ribs are fractured (*p=0.032*). A very high odds ratio (*OR=75016*) was reported for the diaphragm and left middle ribs. Although it is not significant, it should be mentioned because it is most likely due to having very few values for that particular model.

Three analyses using chi-square tests of independence were used to answer the second, third, and fourth research questions by determining the relationship between rib fractures and the use of a seatbelt, the deployment of airbags, and the administration of CPR. Fisher's Exact Test was used instead of the chi-square statistic when small sample sizes were small. These results are summarized in Table 4.10. The presence or absence of a fracture in each rib grouping was compared with the use of a seatbelt or not, the deployment of an airbag or not, and the administration of CPR or not.

**Table 4.10** Chi-square tests for seatbelt use, airbag deployment, and CPR administration to left and right ribs, manubrium, and sternum fractures.

| | Seatbelt Use (n=85) | | | Airbag Deployment (n=16) | | | CPR Administration (n=87) | | |
|---|---|---|---|---|---|---|---|---|---|
| | $X^2$ | df | p | $X^2$ | df | p | $X^2$ | df | p |
| **L High** | 0.147 | 1 | 0.702 | **1.075** | 2 | 0.584 | 0.470 | 2 | 0.790 |
| **L Middle** | **0.451** | 1 | 0.713 | **0.372** | 2 | 0.830 | 1.641 | 2 | 0.440 |
| **L Low** | 5.936 | 1 | 0.015* | **0.826** | 2 | 0.662 | 2.238 | 2 | 0.327 |
| **R High** | 0.281 | 1 | 0.596 | **0.555** | 2 | 0.758 | 1.248 | 2 | 0.536 |
| **R Middle** | 0.903 | 1 | 0.342 | **0.531** | 2 | 0.767 | 1.145 | 2 | 0.564 |
| **R Low** | 0.391 | 1 | 0.532 | **2.441** | 2 | 0.295 | 0.979 | 2 | 0.613 |
| **Manubrium** | 0.132 | 1 | 0.716 | **3.024** | 2 | 0.220 | 12.342 | 2 | 0.002* |
| **Sternum** | **2.182** | 1 | 0.184 | **4.171** | 2 | 0.124 | 2.772 | 2 | 0.250 |

~**BOLD** result indicates Fisher's Exact Test used.
*indicates significance p≤0.05

The first chi-square test shows a significant relationship between seatbelt use and fracture in the left low ribs (*$X^2$=5.936; p=0.015*). The second chi-square test does not show any significant relationships between airbag deployment and rib fractures. Finally, the third chi-square test shows a highly significant relationship between CPR administration and fracture of the manubrium (*$X^2$=12.342; p=0.002*).

In addition to the chi-square analysis for all individuals in the sample, a binary logistic regression was run to determine if seatbelt use can be predicted from fracture patterns. The results of the binary regression are shown below in Table 4.11.

**Table 4.11** Summary of logistic regression for seatbelt use and fracture patterns in drivers.

| Predictor | Seatbelt Use | | |
|---|---|---|---|
| | β | p | OR |
| **L High Ribs** | 0.271 | 0.736 | 1.311 |
| **L Middle Ribs** | -0.243 | 0.808 | 0.784 |
| **L Low Ribs** | 1.592 | 0.013* | 4.914 |
| **R High Ribs** | -0.630 | 0.446 | 0.533 |
| **R Middle Ribs** | 0.091 | 0.917 | 1.095 |
| **R Low Ribs** | -0.590 | 0.393 | 0.554 |
| **Manubrium** | 0.030 | 0.957 | 1.031 |
| **Sternum** | -1.128 | 0.356 | 0.324 |

*indicates significance p≤0.05

The results in Table 4.11 show that a driver is 5 times more likely to be wearing a seatbelt if the left low ribs are fractured (*p=0.013*).

Finally, to address the fifth research question was addressed using correlations between decedent age and the total number of rib fractures, decedent age to the total number of fractures on the left side of the ribcage, and decedent age to the total number of fractures on the right side of the ribcage. A summary of the results can be found in the correlation matrix below.

**Table 4.12** Correlation matrix for age and number of ribs fractured (n=101).

| | **Age** | **Total # Rib Fx** | **Total # L Rib Fx** | **Total # R Rib Fx** |
|---|---|---|---|---|
| **Age** | 1.000 | 0.030* | 0.013* | 0.123 |
| **Total # Rib Fx** | 0.030* | 1.000 | | |
| **Total # L Rib Fx** | 0.013* | | 1.000 | |
| **Total # R Rib Fx** | 0.123 | | | 1.000 |

*indicates significance p≤0.05

The results of linear regression models for age to total number of ribs fractured, number of left ribs fractured, and number of right ribs fractured is shown in Table 4.12.

**Table 4.13** Regression model for age and number of ribs fractured.

| Predictors | Total Ribs Fractured | Left Ribs Fractured | Right Ribs Fractured |
|---|---|---|---|
| **Age** | 0.059 | 0.038 | 0.021 |
| **Constant** | 9.153 | 4.813 | 4.341 |
| **p-value** | 0.030* | 0.013* | 0.223 |
| **Adjusted $R^2$** | 0.038 | 0.052 | 0.005 |

*indicates significance p≤0.05

The linear regression models for age and total number of ribs fractured and age and number of left ribs fractured showed significance with p-values of *p=0.030* and *p=0.013* respectively. No significant relationship was found for age and the number of right ribs fractured.

# CHAPTER FIVE:

# DISCUSSION

Demographic and analytical trauma data from fatal MVAs at the Hillsborough County Medical Examiner's Office are used in this study to test the relationship of age and number of ribs fractured; the effect of seatbelt use, airbag deployment, and CPR administration on rib fracture patterns; and the relationship between soft tissue injury and rib fracture patterns. The results of this research are useful and important in several ways. Trauma has been studied in the field of anthropology for many years. Paleopathology research has analyzed trauma in an attempt to explain the sociocultural context of trauma in ancient populations (Lovell, 1997).

The results for rib fracture patterns in conjunction with seatbelt use, airbag deployment, and CPR administration may have safety implications in the future for automobile designs, especially when catering to elderly individuals who are more prone to these types of fractures. Understanding which rib fracture patterns are associated with corresponding soft tissue organ injuries can assist the field of medicine when treating patients who have sustained rib fractures in MVAs. Chapter 5 describes in detail the results of the analyses for the decedent demographic data and the analytical trauma data.

**MVA Decedent and Accident Statistics**

The first set of analyses use MVA decedent and accident data. This information is important to consider because it shows demographic trends, vehicle and accident types, and other situational data that are imperative to consider when analyzing trauma sustained in fatal MVAs. Of the 105 individuals in the sample, there are more men (n=68) than women (n=37). The literature stating that males are more likely to die in fatal MVAs than females, due to a higher tendency to engage in risky behaviors (Harris and Jenkins, 2006; Reddy et al., 2014) is supported in the results here.

Bar charts were created to show the age frequencies for the sample. Figure 4.1 shows the age frequencies for all individuals in the sample and Figure 4.2 breaks down the age frequencies by sex. The bar chart in Figure 4.1 is bimodal with a peak around 25 to 30 years of age and 60 to 75 years of age. This indicates that overall, the sample has high frequency of younger individuals around 25 to 30 years, but also a high frequency of an older population around the ages of 60 to 75 years. When broken down by sex, the bar chart in Figure 4.2 indicates that the frequency of ages for males in the sample is similar to the overall sample with a peak around 20 to 35 years of age and again at around 70 to 75 years of age. The frequency of female individuals in the sample was fairly evenly spread across the ages.

Descriptive statistics are provided for the type of MVA, vehicle type, and position in vehicle in order to understand which types of crashes are most common, which type of vehicle is most often involved in fatal crashes, and what individuals in the car are dying most often in fatal crashes. The most common type of MVA observed is vehicle-vehicle crashes (67.5%), followed by fixed object crashes (18.1%), and rollover crashes (9.52%). Most often, the accident victims in this sample are in sedans (51.4%), followed by both pickup trucks (16.2%) and sport utility vehicles (16.2%). This can most likely be accredited to sedans being the most common type of vehicle driven. Drivers make up the majority of the sample (77.1%), followed by front passengers (11.4%), and back seat passengers (3.81%). These results do not necessarily mean that drivers are dying more often than passengers; it is more so the result of every car involved in a fatal accident having a driver and not necessarily having any passengers. The sample sizes for both front passengers (n=12) and back passengers (n=4) are small and therefore the results are not compared in depth by position in vehicle. This study focuses mostly on drivers due to the small sample size for passengers, but further research with a larger passenger sample size should be considered.

Table 4.2 summarizes frequencies for seatbelt use, airbag deployment, and CPR administration. For the individuals with seatbelt use information available, there are about the same percentage of individuals in the sample wearing a seatbelt to not wearing a seatbelt. Of the accidents that have airbag information, more airbags are listed as deploying than not. Finally, for cases in which CPR information is included, more individuals did not receive CPR than those who did receive CPR. This may be due to many fatal accident victims being pronounced "dead on scene," but the sample size is too small to be conclusive.

The frequencies for seatbelt use by sex are shown in Figure 4.3. Of the females in the sample, more were wearing their seatbelt at the time of the accident than men. It is important to note the larger sample size for male individuals when looking at the frequencies in the bar chart. This may indicate that males are more likely to choose not to wear a seatbelt when they are driving or riding in a vehicle. It could also be the result of bias, meaning that more males without seatbelts died in MVAs due to the fact that they were not wearing a seatbelt. This should be considered as a future research direction.

A highly significant relationship exists between sex and the use of a seatbelt, ($\chi^2$= *7.862; df= 1; p= 0.005)*. This indicates that there is a relationship between being male or female and the choice to wear a seatbelt or not. Chi-square analysis shows no significant relation between sex and airbag deployment, or sex and CPR administration. Of these three variables, only seatbelt use is the result of a conscious choice made by the individuals in the sample. The results from the bar chart for seatbelt use by sex and the chi-square analysis for seatbelt use and sex suggest that males are less likely to wear a seatbelt. This could mean that men are less likely to wear their seatbelt than females or this could mean that the unbelted males have higher fatality due to not wearing a seatbelt.

**Analytical Trauma Statistics**

The second part of the analysis focuses on the analytical trauma data, specifically on rib fracture patterns. Figure 4.4 shows the frequencies of number of ribs fractured per individual in the sample. The data shows that many of the cases have around 9 to 16 ribs fractured. The mean is reported as approximately 12 ribs fractured, which seems very high. That would mean that on average, an individual has half of his or her ribs broken. The high average is probably the result of the several cases with an extremely high number or all of their ribs fractured. This distribution is further broken down showing left and ride sides of the ribcage separately in Figure 4.5 and Figure 4.6. In general, more left ribs are fractured than right ribs.

Figures 4.7, 4.8, and 4.9 show the number of ribs fractured per individual, separated by seatbelt users and non-seatbelt users. No particular pattern is evident in any of the three distributions. This is most likely the result of other various factor playing a role in the number of fractures sustained, despite whether an individual as wearing a seatbelt or not. This could include the force of the impact, the direction of the impact, contact of the individual with the steering wheel, the effects of a rollover crash, any many other possibilities. Many of these factors are difficult to quantify, and there are too many variables to consider in depth in this study.

Lien et al. (2009) states that with six or more ribs fractured, mortality is greatly increased. It is interesting that the mean for total left and right ribs, as well as the total number of ribs are right around six ribs or above. This is expected since all of the accidents researched were fatal and therefore mortality is 100 percent. This difference may be related to the fact that there are more drivers in the sample than passengers, and drivers are expected to have more upper left side fractures if they are wearing a seatbelt (Crandall et al., 2000). This fracture pattern is expected due to the force and positioning of the seatbelt in drivers versus passengers.

Rib fractures were recorded based on the location of the fracture on each rib. Table 4.4 and Table 4.5 show the frequencies for the left and right sides of the ribcage, respectively. On the left side of the rib cage, ribs 2 through 7, and 11 have a combination of fractures most often, followed by lateral rib fractures. Ribs 8 and 10 have lateral fractures most often, followed by a combination of fracture locations. Finally, ribs 1 and 9 have the same percentage of lateral fractures and a combination of fracture locations. On the right side of the ribcage, rib 1 is most often fractured anteriorly and posteriorly, ribs 2 through 7 are most frequently fractured in a combination of locations, rib 8 is most frequently fractured laterally, and ribs 9 through 12 are most commonly fractured posteriorly. This varies quite a bit from the left side of the rib cage, where all ribs are most commonly fractured laterally or in a combination of locations. One limitation to recording fractures in this way is that for the ribs fractured in a combination of locations, it is not specified which locations on the rib are fractured.

Soft tissue data are available for 103 of the individuals in the sample. Although only the presence or absence of an injury on each soft tissue organ is used for further analyses, the frequencies of the types of each injury are interesting to consider. Soft tissue injury frequencies are shown in Table 4.6. The most common soft tissue injuries found in this study are liver laceration (44.7%), spleen laceration (34.0%), lung contusion (26.2%), heart laceration (25.2%), and combination of lung laceration and contusion (17.5%). Although Park (2012) did not record soft tissue injury by type of injury (i.e. laceration, contusion) these results are similar to the study by Park (2012) which states that liver injury is the most common soft tissue injury associated with rib fractures. More specifically, the percentage of cases with liver laceration in Park (2012) was 40 percent, very similar to the 44.7 percent found in this study. Spleen injury is the second most common soft tissue injury found in this study, which is consistent with results from Park (2012), Reddy et al. (2014), and Thor and Gabler (2008), which all state that spleen injury is one of the most common soft tissue organs injured in cases with rib fractures in MVAs.

Chi-square analyses are shown for each rib to rib, and each rib to the manubrium and sternum in order to determine if any relationships exist between fractures on certain ribs or between fractures on certain ribs and fractures of the manubrium or sternum. The chi-square statistics and p-values for each of these analyses are found in Table 4.7and Table 4.8. Many of the tests showed a significant relationship between groups. Significant relationships were found between fractures of left high ribs and left middle ribs ($X^2=27.2; df=1; p<0.001$), left high ribs and left low ribs ($X^2=8.05; df=1; p=0.005$), left high ribs and right high ribs ($X^2=6.61; df=1; p=0.010$), left middle ribs and left low ribs ($X^2=5.81; df=1; p=0.016$), left low ribs and right low ribs ($X^2=9.65; df=1; p=0.002$), right high ribs and right middle ribs ($X^2=27.96; df=1; p<0.001$), right high ribs and sternum ($X^2=6.42; df=1; p=0.011$), right middle ribs and right low ribs

($X^2$*=8.70; df=1; p=0.003*), and right low ribs and sternum ($X^2$*=4.48; df=1; p=0.034*). It is noteworthy that a significant relationship was found for the left and right high ribs and the left and right low ribs, suggesting that the high and low ribs are often fractured bilaterally. There is no literature comparing the fracture risk of rib groupings to one another; however, Brookes et al. (1993) and Hills et al. (1993) stress the importance of looking at fractures of the sternum in MVAs. In this study, fracture of the sternum was found to have a significant relationship with only fractures of the right high ribs and the right low ribs. It is important to consider the results of the rib grouping relationships, since their dependency may influence the results of the binary logistic regression analysis, which assumes that all of the variables are independent of one another.

The first research objective in this study is to determine if relationships exist between rib fracture patterns and soft tissue injuries sustained in the lungs, heart, diaphragm, liver, spleen, and pancreas. A binary logistic regression analysis is shown for rib, manubrium, and sternal fractures to soft tissue injuries. The results for this regression show that lung injury is 12 times more likely to occur when the left middle ribs are fractured (*p=0.017*) and 4 times more likely to occur when the manubrium is fractured (*p=0.007*). The heart is 9 times more likely to be injured when the sternum is fractured (*p=0.009*). Finally, the liver is 4 times more likely to be injured when the right middle ribs are fractured (*p=0.028*) and 0.3 times more likely to be injured when the right high ribs are fractured (*p=0.032*). Based on anatomy, the results for the lungs are consistent with the hypothesis stated in Chapter 1. The results for heart injury also are consistent with the hypothesis. A study by Harris and Soper (1990) found that heart injury is most common when ribs 1 or 2 are fractured. This corresponds to the high ribs in this study. Although the results of this study did not show significant results for heart injury and fracture of the high ribs, the sternum articulates with the high ribs. For liver injury, it is hypothesized that fracture of the right middle ribs would indicate liver injury, but it was not hypothesized that fracture of the right high ribs would indicate liver injury. Similarly, Park (2012) found that the risk for organ injury is significantly greater when fractures are present in rib 8 or lower, specifically in the liver. Based on Park's (2012) results, it would have been expected that the low ribs would also be affected on the right side of the ribcage; however, based on the anatomy this was not included in the hypothesis. The results for the liver and right high rib fractures are suspicious, since the liver does not come in contact with these ribs. The significant result for the liver may be attributed to other variables. There are no significant results for the diaphragm or spleen, contradicting the expected injury patterns.

The second research objective tests what relationships exist between rib fracture patterns and the use of a seatbelt. It is hypothesized that individuals who were wearing their seatbelt at the time of the accident will have different rib fracture patterns than those who were not. The specific fracture patterns expected are summarized in Table 1.2 for restrained and unrestrained drivers. Chi-square analysis was performed to test the overall relationship of fracture patterns and seatbelt use. The results of the chi-square analysis, shown in Figure 4.10, show a significant relationship between seatbelt use and the left low ribs ($X^2=5.936; df=1; p=0.015$). This is inconsistent with the expected fracture patterns for restrained drivers; however, because this test is robust it does not take into account drivers versus passengers. There are only a few passengers in the sample, so it is expected that the results of the chi-square would be more representative of drivers. In addition to the chi-square analysis, binary logistic regression was performed for drivers only to see if seatbelt use could be predicted from rib fracture patterns. The results of the binary logistic regression are shown in Table 4.11 and show a similar result to the chi-square analysis. The results indicate that it is 5 times more likely that the driver was wearing a seatbelt if the left low ribs are fractured ($p=0.013$). These results are inconsistent with the results from Crandall et al. (2000) that state that upper left ribs and lower right ribs are most often fractured in accidents where a seatbelt is used. A study by Porter and Zhao (1998) that investigates patterns of injury in belted and unbelted MVA victims uses likelihood ratios instead of chi-square analyses. The study by Porter and Zhao (1998) found only an increased likelihood of sternal fractures in victims who were unbelted. This research study did not find a significant relationship between seatbelt use and sternal fractures. Although the study by Park (2012) does not look at seatbelt use, it explains that the floating ribs, 11 and 12, are fractured as the result of trauma with extreme force. This may explain why the left low ribs show significance in this study.

The third research objective investigates the relationship between fracture patterns and the deployment of airbags. It is hypothesized that airbag deployment will cause different fracture patterns than when the airbags do not deploy. Chi-square analysis was performed to address this objective and the results are included in Table 4.10. The results of the chi-square analysis do not support the hypothesis, as no significant relationships were found. Small sample size for airbag deployment (n=16) may be a factor in the specific findings of this study. Further analysis with a larger sample size should be considered.

The fourth research objective is to assess the relationship between rib fractures and CPR administration. To address this research question, chi-square analysis was performed for the presence or absence of fractures in each of the rib groupings and the administration of CPR. A highly significant relationship was found between the presence of fracture of the manubrium and CPR administration ($\chi^2=12.342; df=1; p=0.002$). The relationship between CPR administration and secondary injuries as a result of CPR, including rib fractures, is found in 13 to 97 percent of individuals in a sample tested by Hoke and Chamberlain (2004). Considering these results, it seems that CPR administration should have showed significant relationships with the fracture of more rib groupings than just the manubrium. The small sample size for CPR administration (n=87), as well as not knowing if fractures occurred from the MVA or CPR makes it difficult to make conclusions for CPR fracture patterns in this study.

The fifth research objective is to determine what relationships exist between age and the number of rib fractures sustained. It is hypothesized that a positive correlation will exist between the age of the decedent and the number of rib fractures sustained. To answer this question, correlations between age and the total number of ribs fractured, age and the total number of left ribs fractured, and age and the total number of right ribs fractured are shown in Table 4.12. The results show that there is a weak, but significant correlation in a positive direction between age and the total number of ribs fractured, ($r^2=0.219$, $df=98$, $p=0.030$). There is also a weak, but significant correlation in a positive direction for age and the total number of left ribs fractured, ($r^2=0.249$, $df=98$, $p=0.013$). The correlation between age and the number of right ribs fractured is not significant. Linear regression models were also created for age to the total number of ribs fractured, number of left ribs fractured, and number of right ribs fractured. The results, shown in Table 4.13, are significant in the models for total number of ribs fractured and number of left ribs fractured, with p-values of 0.030 and 0.013 respectively. The results for the total number of ribs fractured and the left side of the ribcage support the literature on skeletal aging and fracture risk. Several studies clearly state that elderly individuals are at a higher risk for fracture, especially in the event of an MVA (Bergeron et al., 2003; Bulger et al., 2000; Flagel et al., 2005; Sariego et al., 1993; and Sirmali et al., 2003). This study has found that this relationship between age and number of rib fractures is significant, except for the ribs on the right side of the rib cage.

**Research Challenges, Limitations, and Recommendations for Best Practice**

There are several research challenges and limitations with regards to this study. First, this was a retrospective study and therefore the data collected was from the information that was available. In some cases, rib fracture data were limited, soft tissue injuries were not recorded in detail, or seatbelt, airbag, and CPR information was not available. The lack of seatbelt, airbag, and CPR information made the sample sizes for those variables very low and the results, therefore, inconclusive in many ways. The data for airbag deployment did not specify which airbags within the vehicle deployed at the time of the accident. In addition, it is not determined if the ribs are fractured from the impact of the crash or from the airbag. This may be why the literature on rib fractures, as a result of airbag deployment is somewhat lacking; however, it is very important to consider since airbags serve as a safety attribute to passengers in the vehicle but they may be causing injury as well. Similarly with CPR administration, it is difficult to tell if rib fractures were caused from the impact of the crash or from the chest compressions.

Due to the large number of variables considered in this study, the results are not divided into age groups. Age is considered in depth in the third research objective and is considered as a continuous variable when compared with the number of ribs fractured. Many of the similar research studies focus only on the elderly population and therefore break up the age groups into “elderly” and “extremely elderly” (Bansal et al., 2010) or by sectioning off the elderly population by under 65 and over 65 (Bulger et al., 2000) or under 45 and over 45 (Flagel et al., 2005). None of these studies listed capture the younger age groups, which make up a large demographic that is at risk for fatal MVAs. This study does not look at each variable by age group, but this is something that should be considered for further research for those variables that showed significant results.

Ribs were grouped into high, middle, and low groups based on a similar study by Park (2012). By grouping the ribs this way, only the presence or absence of a fracture within the group could be recorded and used in analysis, opposed to using the anatomical location of the fracture on the rib. The results are therefore limited because fracture patterns are described in relation to the rib groups only, rather than each rib independently. The results are still valuable, but further research analyzing each rib individually and the anatomical location on the ribs can be beneficial.

Similarly for the soft tissue data, statistical tests were run only on the presence or absence of an injury, rather than the type of injury present. During data collection, the injury type was specified for each soft tissue organ considered. However, type of injury was only used for descriptive statistic analysis. Coding the injuries as present or absent for each soft tissue injury was the most feasible way to deal with the data, but future research should look at each type of injury specifically. Considering the effects of lacerations versus contusions could be beneficial to this research, especially, since sharp edges of fractured ribs may cause more lacerations. There is also no way to directly tell from these data and analyses if the rib fracture itself caused the damage to the soft tissue organ, or if the soft tissue organ is just commonly associated with rib fractures in that area but not caused by the fractures. This can be better understood by doing a more prospective study at the time of autopsy.

Finally, it is unclear how related rib fractures are to other rib fractures. For example, if the first rib is fractured on the left side, how likely is it to be fractured bilaterally on the right side as well? If rib 2 is fractured on the left side, is rib 3 usually fractured as well? The chi-square analysis for this type of question provides some insight into the relationships between rib fractures; however, due to the way the ribs are grouped it should be looked at in more detail to provide a clear picture of these relationships with each rib individually. There are several relationships found to be significant in this study, which may affect the results of the binary logistic regression. Binary logistic regression requires that the variables are independent of one another, which in this case they may not be.

**Research Applications**

The findings from this study, although in need of further research, can be applied in several ways. First, in the field of forensic anthropology, these results can contribute to the already vast knowledge of trauma analysis in skeletal remains. Understanding the types of fracture patterns observed in fatal accidents could provide insight to skeletal analysis of individuals who were in accidents prior to their death or could help differentiate MVA skeletal trauma from other types of skeletal trauma in unsolved cases. Knowing the fracture patterns that are consistent with fatal MVAs can help forensic anthropologist and pathologists differentiate between accidental and non-accidental trauma in cases where it is said that an MVA was the contributing cause of death.

The results of this study can also contribute to safety regulations and dissemination of safety information. Several demographic trends are evident from looking at this dataset, with special concern for young male individuals and both male and female elderly individuals. By better understanding the fracture patterns associated with seatbelts, airbags, and CPR, especially in elderly individuals, safer seatbelts or vehicles can be designed.  For example, seatbelts with different loading patterns for elderly individuals may be considered useful.

# CHAPTER SIX:

# CONCLUSION

Fatal MVA victims often suffer from thoracic blunt force trauma, resulting in one or more rib fractures (Flagel et al., 2005; Hamilton et al., 2011; Lien et al., 2009). Rib fractures have directly been linked to increased mortality rates (Flagel et al., 2005). Rib fracture risk is believed to differ based on the age of the victim, the use of a seatbelt, the deployment of airbags, and the administration of CPR. In addition, rib fractures have been observed to be the cause of soft tissue organ injuries in the thoracic and abdominal region (Park et al., 2012; Reddy et al., 2014; Thor and Gabler, 2008). This thesis is a preliminary analysis of these important variables associated with rib fracture patterns, in an attempt to better understand the rib fracture patterns frequently observed in fatal MVAs, as well as the corresponding soft tissue injuries.

The first research objective in this study is to determine the predictive value for rib fracture patterns and soft tissue injuries sustained in the lungs, heart, diaphragm, liver, and spleen. The ribs were grouped into high, middle, and low ribs for each side of the ribcage and compared with the presence or absence of injury in each of the organs. Based on human anatomy, several hypotheses were made according to the skeletal elements and their adjacent soft tissue organs. Table 1.1 in Chapter 1 summarizes the expected findings. The results for fractures of the left middle ribs and the manubrium predicting lung injury, manubrium fracture predicting heart injury, and right middle ribs predicting liver injury were consistent with the hypotheses, except for right high ribs predicting liver injury.

The second research objective tests what relationships exist between rib fracture patterns and the use of a seatbelt. It is hypothesized that individuals that wear their seatbelt. Specifically, it is expected that restrained drivers will have fractures in the left high and middle ribs, right middle and low ribs, the manubrium, and sternum. Unrestrained drivers are expected to have more sporadic fractures throughout. Restrained passengers are expected to have opposite patterns than drivers. The results from this study indicate a significant relationship between the presence of a fracture in left low ribs and seatbelt use. It was also found, for drivers, that it is 5 times more likely that the driver was wearing a seatbelt if there are left low rib fractures present. These results are consistent with literature by Park (2012) that states that the floating ribs 11 and 12 are most often fractured as the result of high intensity force; however, they are not consistent with the hypotheses.

The third research objective assesses the relationships between rib fracture patterns and the deployment of airbags in fatal MVAs. The hypothesis states that ribs will be affected bilaterally from the impact of an airbag deploying and more sporadically when airbags do not deploy. No significant results are found for the presence of rib fractures and airbag deployment. The effects of airbag deployment on rib fractures is still not well understood or represented in the literature; however, the results of this study did not support results by Crandall et al. (2000) stating that posterior ribs are most often fractured when airbags are deployed. If the individuals in the study by Crandall et al. (2000) were unrestrained at the time of impact, the posterior fractures may be the result of a second impact of the body hitting the back of the seat in the “up and over” pathway.

The fourth research objective determines what relationships exist between rib fracture patterns and the administration of CPR. It is hypothesized that the upper and middle ribs will be fractured on both sides of the ribcage, as well as the sternum. The results of the chi-square analysis showed a significant relationship between fracture of the manubrium and CPR administration. This is inconsistent with the expected fracture patterns in the hypothesis; however, the manubrium does sit just superiorly to the sternum. Fracture of the sternum was expected to show a significant relationship with CPR administration due to the impact of force from chest compressions. A study by Krisher et al. (1987) discusses the prevalence of rib fractures in individuals who receive CPR, but does not discuss which ribs are fractured most often. In the study sample by Krischer et al. (1987), 31.6% of the individuals in the sample had rib fractures and 21.1% had sternal fractures. The sample size in this study is not large enough to compare to the study by Krischer et al. (1987), and does not show clear patterns of rib fractures in association with CPR either.

The fifth and final research objective of this study is to determine if a correlation exists between decedent age and the total number of rib fractures sustained. It is hypothesized that the number of rib fractures will increase with increasing age. A correlation matrix and a linear regression analysis are used to quantify the relationship between age and the number of ribs fractured. The results show that a significant correlation exists for increasing decedent age and an increasing number of total ribs fractured. This is consistent with studies on increasing age and skeletal fracture risk (Flagel et al., 2005; Bergeron et al., 2003; Bulger et al., 2000; Sariego et al., 1993; and Sirmali et al., 2003). The same is true for the number of ribs fractured on the left side of the ribcage. Only the relationship between the number of the right ribs fractured and age did not show significance.

The findings from this thesis classify rib fracture patterns in fatal MVAs. While the results are preliminary and additional research should be pursued to further answer these questions, the results of this study can have an impact in several areas. Implications of this research include transportation safety, fracture risk literature, forensic anthropology trauma analysis, and forensic pathology. By understanding the predictive value of rib fractures for soft tissue injury, the effects of seatbelts, airbags, and CPR, and the effects of age on the number of ribs fractured, fracture risk and mortality can be better understood and safety information can be tailored and disseminated to groups at risk.

These results contribute to the wide knowledge base of trauma analysis used in forensic anthropologists. Recognizing fracture patterns that are consistent with fatal MVAs, especially in relation to seatbelts, airbags, and CPR, is important for skeletal analysis. With more research, detailed fracture patterns from accidents with these variables can contribute to methodology used in trauma analysis. This is most important for differentiating what fracture patterns are common in fatal accidents, in comparison with other types of fracture patterns that may be more consistent with other types of trauma or perhaps domestic abuse. This allows forensic anthropologist to better understand the events surrounding an individual’s death.

Finally, these results will add to the literature for forensic pathologists and medical examiners for fatal accidents. Since fatal MVAs make up a large percentage of traumatic deaths each year, it is important that they are discussed in trauma research. In the fields of forensic anthropology and forensic pathology, understanding rib fracture patterns from fatal MVAs can add to the current knowledge base of skeletal trauma by determining what patterns are consistent with accidental trauma from fatal MVAs.

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## APPENDIX A

## MOTOR VEHICLE ACCIDENT FRACTURE PATTERN DATA COLLECTION PROTOCOL

Developed 6.22.2014 by Cristina L. Kelbaugh, B.S.

**A: HCMEO case number**

**B: Year of Death**
**C: Medical Examiner Assigned to Case**
**D: Age** (years)
**E: Sex**
1=Male
2=Female
**F: Race**
1=White
2= Black
3= Hispanic
6=Other
7=Unknown
**G: Cadaver stature** (in cm)
**H: Cadaver weight** (in pounds)
**I: Cause of death**
1=CODE
2= CODE
**J: Manner of death**
1=Accident
2= Natural
3=Suicide
4= Homicide
**K: Date of Incident**
**L: Time of Incident**
**M: Date of Death**
**N: Time of Death**
**O: Ethanol Level at death**
**P: Alcohol Use History**

0=No History
1= Social Use
2= Heavy Use
3= Unknown

**Q: Drug Type if Intoxicated at Time of Death**
0=No
1= Yes
2= Unknown

**R. Drug Use History**
0=No History
1= Occasional Use
2= Heavy Use
3= Unknown

**S: Drug Type** List drug names, if applicable

**T: Motor Vehicle Accident Type**
1= Motor Vehicle-Motor Vehicle
2=Fixed Object
3=Rollover
4=Motor Vehicle-Motor Vehicle & Rollover
5=Fixed Object & Rollover
6=Unknown

**U: Vehicle Type**
1= Sedan
2=2-Door
3=Pickup
4=Van
5=Other
6=Unknown

**V: Occupant Role**
1= Driver
2=Front Passenger
3=Back Left Passenger
4=Back Right Passenger
5=Unknown

**W: Seatbelt Use**
0=No
1=Yes
2=Unknown

**X: Airbag Deployment**
0=No
1=Yes
2=Unknown

**Y: CPR Administration**
0=No

1=Yes
2=Unknown

**Z: Past Medical History** List, if applicable.

**AA: Rib Fractures Present**
0=None
1=Present

**AB: Number of Left Rib Fractures Present:** (total number of ribs)

**AC: Number of Right Rib Fractures Present:** (total number of ribs)

**AD: Left Rib 1 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AE: Left Rib 2 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AF: Left Rib 3 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AG: Left Rib 4 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AH: Left Rib 5 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral

5=Posterior
6=Unknown

**AI: Left Rib 6 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AJ: Left Rib 7 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AK: Left Rib 8 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AL: Left Rib 9 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AM: Left Rib 10 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AN: Left Rib 11 Fracture**

0=None

1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AO: Left Rib 12 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AP: Right Rib 1 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AQ: Right Rib 2 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AR: Right Rib 3 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AS: Right Rib 4 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AT: Right Rib 5 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AU: Right Rib 6 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AV: Right Rib 7 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AW: Right Rib 8 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AX: Right Rib 9 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**AY: Right Rib 10 Fracture**

0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral

5=Posterior
6=Unknown

**AZ: Right Rib 11 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**BA: Right Rib 12 Fracture**
0=None
1=Anterior
2=Anterolateral
3=Lateral
4=Posterolateral
5=Posterior
6=Unknown

**BB: Rib Fractures Consistent with Chest Compressions**
0=No
1=Yes
2=Not described

**BC: Rib Fractures Consistent with Flail Chest**
0=No
1=Yes
2=Not described

**BD: Pleural Laceration**
0=No
1=Yes
2=Not described

**BE: Blood in Left Pleural Cavity** (cc)

**BF: Blood in Right Pleural Cavity** (cc)

**BG: Blood in Intercostal Space** (cc)

**BH: Skull Fracture(s)**
0=Not Present
1=Present

**BI: Manubrium Fracture(s)**
0=Not Present
1=Present

**BJ: Sternum Fracture(s)**
0=Not Present
1=Present

**BK: Scapula Fracture(s)**
0=Not Present

1=Present

**BL: Left Clavicle Fracture(s)**

0=Not Present
1=Present

**BM: Right Clavicle Fracture(s)**

0=Not Present
1=Present

**BN: Cervical Vertebrae Fracture(s)**

0=Not Present
1=Present

**BO: Thoracic Vertebrae Fracture(s)**

0=Not Present
1=Present

**BP: Lumbar Vertebrae Fracture(s)**

0=Not Present
1=Present

**BQ: Left Upper Extremity Fracture(s)**

0=Not Present
1=Present

**BR: Right Upper Extremity Fracture(s)**

0=Not Present
1=Present

**BS: Left Lower Extremity Fracture(s)**

0=Not Present
1=Present

**BT: Right Lower Extremity Fracture(s)**

0=Not Present
1=Present

**BU: Pelvis Fracture(s)**

0=Not Present
1=Present

**BV: Other Fracture(s)**

0=Not Present
1=Present

**BW: Other Fracture(s) List:** if applicable

**BX: Fracture Comments:** if applicable

**BY: Lung Injury**

0=No Injury
1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

**BZ: Heart Injury**

0=No Injury

1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

**CA: Diaphragm Injury**

0=No Injury
1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

**CB: Liver Injury**

0=No Injury
1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

**CC: Spleen Injury**

0=No Injury
1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

**CD: Pancreas Injury**

0=No Injury
1=Laceration
2=Contusion
3=Laceration and Contusion
4=Other Injury

## APPENDIX B

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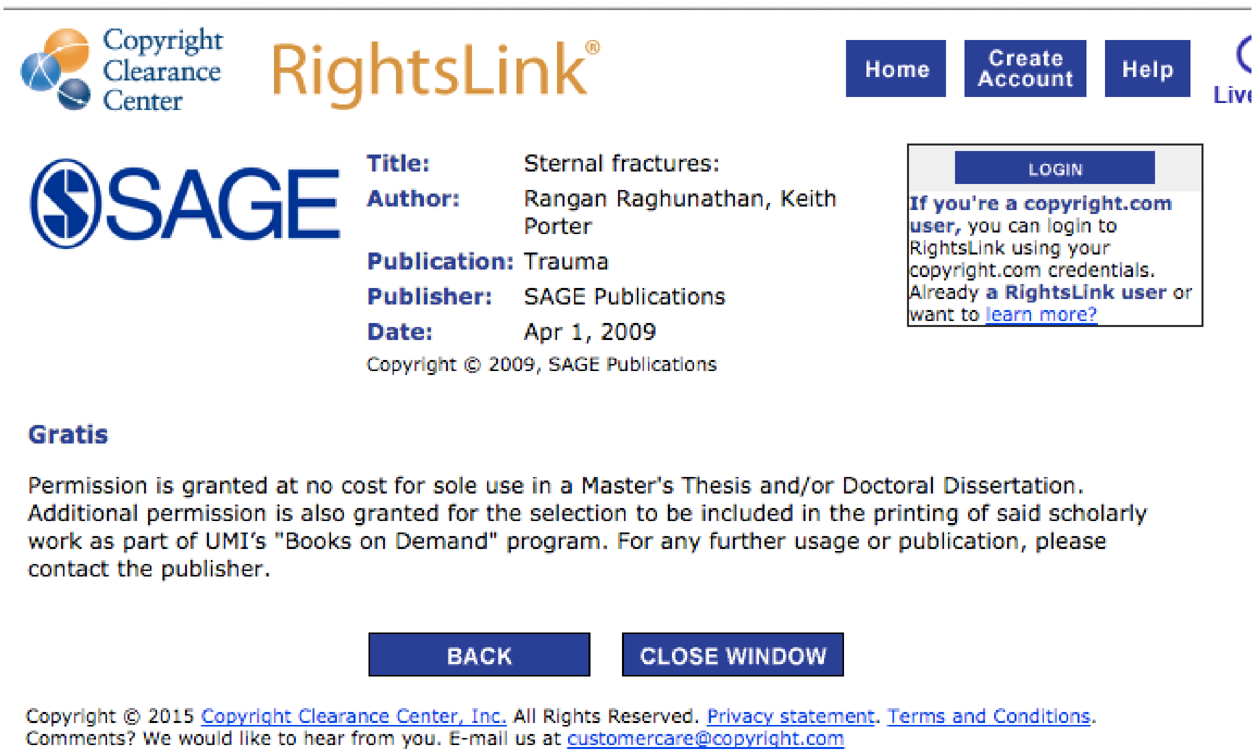

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