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# Injury patterns in motor vehicle accident victims from a sample taken at the Southern Cluster Forensic Pathology Service

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# Injury Patterns in Motor Vehicle Accident Victims from a Sample Taken at the Southern Cluster Forensic Pathology Services

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A dissertation submitted to the Faculty of Health Sciences, University of the Witwatersrand, in fulfilment of the requirements for the degree of MSc Med

Johannesburg

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**DECLARATION**

I declare that this thesis is my own unaided work. It is being submitted for the degree of Masters of Sciences in Medicine, in Forensic Science at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or any examination in any other University.

_____

DATE

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**Abstract**

Motor vehicle collisions are one of the leading circumstances of death worldwide and are contributory to the second most common circumstance of death in South Africa, “transport-related deaths”. A total of 3248 transport-related deaths were recorded in Gauteng alone in 2009 and for that reason motor vehicle collisions pose a substantial threat to the South African population. This study was undertaken to determine if specific patterns of injuries in victims of fatal motor vehicle collisions existed. For the purposes of this study, “patterns of injury” can be defined as similar injuries of similar severities repeatedly and predictably occurring in similar body regions. The study consisted of all individuals involved in fatal collisions who fit the inclusion criteria during the period between 13 May 2011 and 1 June 2012. The external, visceral, and skeletal injuries sustained by the individuals involved in fatal motor vehicle collisions were observed via x-ray and photographic procedures performed by the investigator, as well as documentation from the Forensic Medical Practitioner/scribe notes. The South African Police Force attending officer’s affidavit and the Johannesburg Metropolitan Police Force Accident Reports were used to determine the make and model of the vehicle, the occupant’s position, type of collision and object with which the vehicle collided. The study’s results indicated that distinct patterns of injuries existed for those individuals involved in fatal motor vehicle collisions. The most frequently observed patterns of injuries included either severe head injuries in isolation, severe thoracic and/or abdominal injuries in isolation, or a combination of the two. Distinct patterns of injuries were noted for individuals occupying different types of vehicles but not for individuals occupying different positions within a single vehicle which is contrary to other international findings.

## 1. Introduction

*This section provides a brief overview of the statistics surrounding fatal and non-fatal motor vehicle collisions in Johannesburg (South Africa) and details the necessity of a study of this nature.*

The "patterns of injuries" noted throughout this study refers to the occurrence of injuries of similar severities (according to the investigators grading system) in similar regions of the body. The study intended to note if injuries in certain regions of the body in fatal motor vehicle collisions (MVCs) occurred frequently, repeatedly and predictably or not. Both the magnitude (severity) of the injuries as well as the region of the body to which the injury was inflicted was important in determining the patterns of injuries in occupants of MVCs.

The terms "accident" and "collision" are used interchangeably throughout this report. However, it must be noted that while all motor vehicle accidents (MVAs) are motor vehicle collisions (MVCs), not all MVCs are MVAs. With regard to medicolegal terminology, an MVC is a more accurate descriptor of an incident as the term is more inclusive. An MVA on the other hand implies that an unforeseen event occurred, the facts of which (at the time of a medicolegal autopsy) are not available to the Forensic Pathology Service. The term MVC therefore, more accurately describes an incident from a medicolegal perspective, without attributing manner of death (accidental or intentional/homicidal). For the purposes of this study, no medicolegal inferences should be drawn from the varying use of the terms "accident" and/or "collision" (Vellema, Pers. Comm.). It should be noted that when an individual is logged into the mortuary logbooks, he/she is noted as a victim of an MVA and for the purposes of this study will be

henceforth referred. The collisions themselves however, will be referred to as MVCs.

According to the Medical Research Council's 2009 National Injury Mortality Surveillance Survey (NIMSS), 11329 non-natural deaths were recorded in Gauteng (South Africa), of which 28.7% (n=3248) were noted to be transport-related deaths (Donson, 2010). This rendered transport-related deaths the second leading external cause of non-natural deaths in Gauteng (External cause of death denotes the circumstance or event resulting in the death). Of those transport-related fatalities, 32.8% (n=1064) were occupants of the vehicle at the time of the collision (approximately half drivers and half passengers). The demise of motor vehicle collision occupants was found to have been the second most frequent external cause of death in the transport-related deaths category, surpassed only by pedestrian-vehicle fatalities 41% (n=1333) (Donson, 2010).

Of the 1064 transport-related vehicle occupant deaths in Gauteng, 559 were admitted to the Johannesburg Forensic Pathology Service (FPS). These included pedestrians and individuals involved in motorcycle accidents as well as individuals involved in motor vehicle collisions that demised at the scene of the accident and those that demised later in hospital. (Vellema, Pers. Comm.).

The Medical Research Council's 2010 NIMSS data displayed similar figures and trends to the 2009 data (Donson, 2012). In addition, transport-related deaths were found to have been the leading external cause of death in individuals aged 35 and above as well as in females of all ages. It was also noted that four times as many males were involved in fatal transport-related incidents than females. These

statistics display the staggering loss of life that occurred during 2009 and 2010 as a result of MVCs in Gauteng (Donson, 2010, 2012).

Over the 2011/2012 “festive season” (1 December 2011 – 10 January 1012) alone, 1475 (preliminary data) motor vehicle occupant fatalities were reported in South Africa (Road Traffic Management Corporation, 2012). This number however, was found to have been lower than the 1551 fatalities recorded over the 2010/2011 “festive season” (1 December 2010 – 5 January 2011) (Dembovsky, 2011). Of the 1230 fatal MVCs, 207 occurred in Gauteng of which two were noted to be “major fatal crashes” (crashes in which five or more individuals are killed in the same incident) (Arrive Alive, 2011).

The Road Traffic Management Corporation of South Africa reported the most common causes of road traffic fatalities to be speed, reckless driving (predominantly in inclement weather and at night), alcohol abuse, fatigue, vehicle fitness and pedestrian negligence. They also noted trends in fatal MVCs such as the most vulnerable population age group being 19 – 29 year olds; the most common time of day being between 19h00 and 23h00; the most common types of roads being urban and peri-urban (unmarked tar) roads; and the three most common road factors being sharp bends, poor road surfaces and poor visibility (Road Traffic Management Corporation, 2012)

The high numbers of deaths as a result of MVCs is of great concern to South African Health Care Practitioners and Police Officials in their attempt to decrease the death toll. This research was undertaken in the hopes of identifying the most common injuries sustained in MVCs, such that Clinicians can anticipate and manage these injuries accordingly.

## 1.1. Aim and Objectives

*This section outlines the main idea or intent of the study as well as the contributing ideas to the study, which will be individually examined.*

The aim of this study was to determine the injury patterns in vehicle occupants involved in fatal motor vehicle collisions.

The objectives of this study are as follows:

1. To determine if injuries of similar severities in related body regions existed in vehicle occupants involved in fatal motor vehicle collisions.

2. To compare the patterns of injuries in individuals occupying different vehicles, such as those in sport utility vehicles (SUV), minivans (MV), pick-up trucks or “Bakkies” (PU/Bakkie), and passenger vehicles, as well as those individuals in two-door passenger vehicles versus four-door passenger vehicles.

3. To compare the patterns of injuries in vehicle occupants involved in different kinds of collisions, such as front-impact collisions, adjacent-side impact collisions, opposite-side impact collisions and rear-impact collisions.

4. To compare the injury patterns in drivers and passengers within the same vehicle.

5. To compare the patterns of injury of those vehicle occupants utilizing safety features in vehicles with those individuals who did not utilize the safety features.

6. To note whether the demographics of the vehicle occupants' involved in fatal motor vehicle collisions influenced the patterns of injury.

7. To note whether a certain time of day, week, month or year influenced the patterns of injuries and frequency of motor vehicle collisions.

Much research has been done into injury patterns in road traffic deaths (Daffner *et al.*, 1988; Hendey & Votey, 1994; Santamariña-Rubio *et al.*, 2007) however; many of these studies include pedestrians, motorcyclists and cyclists in their sample. This is relatively nonspecific as the types of collisions are diverse and the forces, surfaces and objects encountered by the individuals involved in these incidents are extremely varied. Studies focusing on occupants of fatal MVCs have been done but none as specific as this study, and none in a South African context with the diverse ethnicity and large volume of motor vehicle accident fatalities admitted to the Gauteng Forensic Pathology Service Medicolegal Mortuaries.

Other studies focusing of MVC occupants tend provided a broader picture of the injuries sustained involved in motor vehicle collisions. However, the many factors that influence these injury patterns have not all been collectively considered in one study. A review of the literature displays the many different research topics that have been investigated regarding motor vehicle collisions, the vehicle safety, the injuries that result, and the potential for economic and long term disability for those individuals having survived collisions. However, no study has fully incorporated all the aspects involved in a complex motor vehicle collision in one. This study aimed to integrate many of the different variables from the literature and look at fatalities in motor vehicle collisions and the injury patterns

that result from the various types of collisions, types of vehicles, occupant positions and safety features utilised.

The research question was: Are there differences or similarities in the patterns of injuries in vehicle occupants involved in motor vehicle collisions with respect to the individuals' occupancy, the vehicle type, the collision type, safety feature usage, and the object or other vehicle involved in the collision?

## 2. Literature Review

*This section comprises an evaluation of the literature discussing the various aspects of motor vehicle collisions, and the injuries sustained by individuals involved in both fatal and nonfatal motor vehicle collisions.*

Injury patterns in both motor vehicle accident/motor vehicle collisions (MVA/MVC) and pedestrian vehicle accident (PVA) victims have been extensively documented in various articles worldwide; however, very limited research has been performed in South Africa. With the demographically diverse population and poor road conditions and users, motor vehicle collision data in South Africa is extremely unique (Lotter, 2000).

Many factors have been found to influence the severity of injuries sustained by individuals involved in motor vehicle collisions. These include the sex, age and size of the occupants as well as their position of occupancy in the vehicle; the type of vehicle utilised by the occupants; the type of vehicle or other object involved in the collision; the site and direction of impact; the safety features employed by both the individual and the individual's vehicle, such as seatbelts, airbags and side-impact strengthening devices; and the weather conditions (Chang & Mannering, 1999; Nygren, 1983; Siegel *et al.*, 2001). The two most influential factors regarding

injuring capabilities according to Siegel *et al.* (2001) are the type of vehicle occupied by the individual in question, and the type of collision that ensued, *i.e.* the site and direction of impact.

Another factor that was found to influence the frequency, severity and patterns of injuries in MVA victims was drug and/or alcohol use. The relationship between drug use and MVC-related fatalities has not been documented in a South African context for approximately ±9 years due to the delays in forensic toxicological results. Consequently, no recent toxicological information was available to determine if drug usage influenced MVC-related fatalities in this study or in South Africa as a whole (Vellema pers. comm.).

## 2.1. Physics of Motor Vehicle Collisions

In order to understand how injuries are inflicted on an individuals' body during a collision, the forces and mechanisms behind the collision must first be understood. If one can understand what a vehicle experiences during a collision, one can extrapolate the data to determine what occurs to an individuals' body. This would then allow for more easily explained injury mechanisms. Therefore, this section focuses on the mechanisms and the physics of MVCs and thus the physics involved in inflicting injuries to individuals' bodies during collisions.

Prahlow (2010) described MVCs as being blunt force trauma incidents in which sudden deceleration or acceleration forces are transferred onto or into the individual's body, thereby causing injuries.

Three of the most important principles that govern the interactions between a vehicle and an individual's body within the vehicle are Newton's three laws of Motion (King & Yang, 1995). Newton's first law states that the velocity of an object

will remain constant, provided it is not acted upon by an external force or object (Inertia) (Heght, 1996). In an MVC, a vehicle is moving at a constant velocity, but when an impact occurs, the vehicle will undergo rapid deceleration. An individual inside the vehicle however, provided they are unbelted, will continue to move at the original velocity of the vehicle preceding impact. The unbelted individual's body, in a forward motion, will encounter various surfaces inside the vehicle. This is when Newton's second law of motion becomes an important factor. Newton's second law of motion states that the force of an object (*i.e.* the individual's body) is equivalent to the product of the object's mass and it's acceleration, F = m x a (Heght, 1996). Therefore, due to the fact that the individual's body undergoes deceleration (negative acceleration) as it impacts the inner surfaces of the vehicle [F = m x (-a)], the resulting forces will oppose the forward motion of the individual's body and cause it to decelerate.

It was noted by King and Yang (1995) that the deceleration experienced by the individual's body depends on the rigidity of not only the body but the impacting surface as well. The combined rigidity influences the maximum deceleration attainable, and thus the magnitude of the force with which the individual's body impacts with the vehicle's inner surfaces. In order to decrease the injuring capacities of the impacting surfaces, the deceleration time of the individual's body must be lengthened, which allows for a decreased contact force (King & Yang, 1995). This has been accomplished by the introduction of seatbelts and padding or energy absorbing materials on the inner surfaces of the vehicle (King & Yang, 1995). The padding absorbs some of the individual's body's force and thus slows the body down, resulting in a decreased contacting force which in turn reduces the injury capacity. Newton's third law of motion states that the mutual forces of an

action and a reaction between two objects are equal (Heght, 1996). Therefore, the force exerted on the individual's body by the padding is equivalent to the force exerted on the padding by the individual's body. Consequently, if the padding is not dense enough and cannot withstand the impacting force of the body it will collapse or "give out". This collapse occurs in an attempt to absorb the impacting energy and in turn reduce the force exerted outwardly on the body. Seatbelts also aid in lengthening the deceleration time and individual will experience which is accomplished by the elasticity that the seat belt possesses (Saukko & Knight, 2004).

Newton's third law has also been noted to play a role in the presentation and interpretation of injury patterns (Daffner *et al.*, 1988). Daffner *et al*. (1988) found that because certain injury mechanisms produce specific injuries, these injuries should be predictable and perhaps even reproducible.

## 2.2. Injuries in Motor Vehicle Accident Victims

Various types of external, visceral, and skeletal injuries occur as a result of different types of trauma such as abrasions, contusions, lacerations, and skeletal fractures. These injuries can be found in numerous combinations in and on the body of an individual involved in an MVC. The most common types of injuries are described below.

### 2.2.1. Soft Tissue Injuries and the Classification Thereof

Kumar *et al.* (1992) described in detail the different kinds of external injuries and the forces which could have inflicted them. They classified external injuries into lacerations, contusions, abrasions, incisions, and puncture wounds. Lacerations are a result of the skin and deeper tissues rupturing due to the

application of blunt force. These can be noted as tears of the skin due to tissue tension and have characteristic irregular edges and tissue bridges (the presence of nerves, blood vessels or tissue fibres traversing the wound, deep to the surface skin) (Prahlow, 2010). Lacerations can be linear, jagged, irregularly shaped, or patterned; such as is seen in superficial stretch lacerations whereby sudden hyperflexion stretches the skin (Prahlow, 2010). Contusions are a result of trauma to the underlying blood vessels, generally due to blunt force trauma. This results not only in subcutaneous haemorrhaging beneath the intact surface skin but also in deeper haemorrhages in and around internal soft tissues, vessels, and organs as well. Abrasions are caused by scraping-type actions applied directly to the skin resulting in the superficial layers of skin, commonly the epidermis, being removed. According to Prahlow (2010), they can be linear, round, irregular or of various specialised types such as friction abrasions. The direction of an applied force during a blunt force trauma incident can be determined from observation of the "peeled-off" edges on the margins of an abrasion (Prahlow, 2010). Superficially incised wounds, caused by sharp-edged instruments, result in regular, straight edged wounds, in which the length is greater than the width. Long, narrow instruments that penetrate the body and any underlying tissues result in puncture and stab wounds. These present with external wound dimensions that are less than depths, such as when one is stabbed by a screwdriver or bicycle spoke. The surface wound appears small but penetrates into the body to a great depth (Kumar *et al.*, 1992). Another type of more severe injury is an avulsion, which occurs as a result of blunt force trauma. They are classified by the partial or complete detachment of a portion of a body part from the rest of the body and include

traumatic amputation, decapitation, and total body transection injuries (Prahlow, 2010).

### 2.2.2. Skeletal Fractures and the Classification Thereof

Connolly (1995) detailed a classification of skeletal fractures according to the extent to which the bone is broken. They were classified as either complete or incomplete fractures. Complete fractures are divided into open and closed fractures. Open fractures occur when the broken bone penetrates the overlying muscle and skin, exposing the bone to the environment. Closed fractures however, occur when the broken bone does not protrude through the skin.

Complete fractures are further classified according to the type of force exerted on the bone. This includes transverse, oblique, spiral, comminuted, compression and impacted fractures. Transverse fractures occur perpendicularly to the long axis of the bone. They are frequently found in the shafts of long bones and are typically a result of bending forces applied directly to the fracture site (Connolly, 1995). Oblique fractures are a result of torsional forces applied with upward thrust actions and occur at oblique angles to the long axis of the bone. Spiral fractures occur as a result of twisting or rotational forces. They frequently resemble oblique fractures, with the break being at an angle other than 90° to the long axis of the bone, but can be differentiated by their sharp edged fracture ends. Comminuted fractures are those fractures that typically have three or more fracture fragments, the lines of which intersect. The fracture lines may be transverse, oblique, or spiral. They are identifiable by the numerous bone fragments that result. Compression fractures and impacted fractures are the result of compression or direct impact forces applied along the long axis of the bone. They generally result in complete comminuted fractures.

## 2.3. Types and Patterns of Injuries in Motor Vehicle Accident Victims

The types of injuries sustained by individuals involved in MVCs also depends on the interior structure of the vehicle, as the structures that an individual's body comes into contact with have the capacity to injure (Smock & Nichols, 1995).

Daffner *et al.* (1988) and Saukko and Knight (2004) detailed the various objects an individual's body could come into contact with and the injuring capabilities of each object. The study by Daffner *et al.* (1988) was performed in Pittsburgh, USA in 1985. Their study focused on the patterns of injuries noted in 250 unbelted drivers and 250 unbelted passengers involved in front-impact "high-speed" (>56.3km/h) collisions. All of the 500 individuals included in their study survived the collisions and presented at trauma centers.

### 2.3.1. Driver Injury Mechanisms

When an MVC occurs, an unbelted driver initially makes contact with the steering wheel which would injure the thoracic region of the body. The inertia would carry the individual forward enabling contact between their knees and the dashboard. This may result in tibial, patellar, femoral and/or knee injuries. Further inertia would promote forward movement of the individual's head allowing for contact with the windscreen, which would result in hyperflexion or hyperextension of the individual's neck. This may cause craniofacial and/or cervical spine injuries. At any point during the collision, the driver's feet may become entangled in the foot pedals, which have the capacity to injure the feet and/or legs (Daffner *et al.*, 1988; Saukko & Knight, 2004).

### 2.3.2. Front- and Rear-Seat Passenger Injury Mechanisms

Unbelted front-seat passengers would not encounter the steering wheel or foot pedals. Initial contact generally occurs between the head and the windscreen or A-frame, which could injure the craniofacial and/or cervical spine regions (Daffner *et al.*, 1988). The continual forward motion would then facilitate impact between the individual's thorax, abdomen or knees and the dashboard, causing thoracic and/or abdominal visceral injuries, as well as lumbar spine and/or knee injuries.

Unbelted rear-seat passengers have been found to incur similar injuries to front-seat passengers. This is because they generally make first contact with the back of the front seats, which act in much the same way as the dashboard, and then the side windows (Saukko & Knight, 2004). There have been reported incidences of rear-seat passengers being thrown over the front seat or through the area between the driver and front passenger seats. This has the propensity to cause more injuries to both the front and rear-seat occupants as they collide (Saukko & Knight, 2004).

Certain injuries tend to occur more frequently than others, and have been noted in numerous studies. For example, the study by Daffner *et al.* (1988) on drivers and front-seat passengers involved in front-impact, "high-speed" collisions (>56.3km/h) found that both drivers and front-seat passengers sustained a significant number of injuries to the face, thorax, pelvis and femur. In addition, drivers had high incidences of fractures to the radius and/or ulna as well as the ankles (Daffner *et al.*, 1988).

Hendey and Votey (1994) noted, in a study focused on belted MVA victims, the most commonly injured areas in unbelted individuals to be the head, face, cervical spine, thorax, abdomen and pelvis. In belted individuals (utilising the three point belts) however, they included the bony elements of the thoracic cage (ribs and sternum) and clavicle as well as muscular neck injuries.

Ndiaye *et al.* (2009) also noted the most commonly injured body regions in motor vehicle drivers to be the head, thorax, abdomen and spine. They determined that in just over 70% of fatalities, the cause of death could be attributed to one of the following: isolated thoracic trauma (30% of individuals), isolated head trauma (23% of individuals) or a combination of the two (18% of individuals), regardless of the seatbelt usage status.

These studies provided a generalised picture of the injuries that individuals involved in motor vehicle collisions could sustain during a collision.

### 2.3.3. Frequent Injuries Noted in Various Body Regions

#### 2.3.3.1. Craniocerebral Injuries

The head was commonly noted as the most frequently injured region of the body in MVCs. For example, Nygren (1983) discerned that in Sweden severe head trauma was the leading cause of death, with 66.2% of individuals demising as a result of this particular injury, unbelted more so than belted individuals.

According to Saukko and Knight (2004), non-impact rotation and accelleration-decelleration injuries resulted in more severe brain injuries than those caused by direct impact to the head. This was found to be due to gliding of the brain tissues over one another, which shears the axons and dendrites. This is known as diffuse axonal injury. Although these kinds of brain injuries are extremely

severe, they often present with no external injuries and can often only be noted by the presence of oedema, subdural haematomas or white matter haemorrhages.

Craniocerebral injuries could be attributed to the individual's head being freely mobile and unprotected. This free movement of the head allows it the mobility to come into contact with various surfaces within the vehicle, such as the windscreen and surrounding chassis, as well as the side door window and surrounding chassis (Daffner *et al.*, 1988).

King and Yang, (1995) stated that, in their study on the biomechanics of the protection of vehicle occupants in Michigan, USA, cerebral injuries resulted from two forces acting on the brain during a collision. These included compression forces at the site of direct impact and tension forces at the opposite site, referred to as contrecoup. Contrecoup injuries resulted from shearing forces incurred by the separation of the brain from the surrounding dura mater and skull.

Ndiaye *et al.* (2009), in a study on the fatal injuries of drivers involved in MVCs, concluded that the head was the second most likely region of the body to sustain fatal or potentially fatal injuries. Cerebral injuries were noted as the most common type of head injury; more specifically cerebral haemorrhage, haematoma and axonal injuries, followed by basal skull fractures.

Daffner *et al.* (1988) found that craniofacial injuries were more common in passengers than in drivers. This was due to the fact that a passenger's head would make direct contact with the windscreen, whilst the steering wheel would decelerate the driver thereby decreasing the force of impact between the driver's head and the windscreen. The steering wheel could also prevent the driver's head from making contact with the windscreen all together.

#### 2.3.3.1.1. Skull Fractures

Skull fracture mechanisms are unique, as the skull is structurally distinct from other bones in the body. Its thin inner and outer tables of cortical bone and narrow separating layer of cancellous diploë result in the skull being thinner, less dense, and more easily fractured than other bones (Evans, 1973). The skull buttresses (areas of thickened bone) also add to the distinct fracture patterns, as propagating fractures tend to take the path of least resistance, therefore altering their course in order to circumvent the buttresses (Berryman & Symes, 1998). For this reason, the bones of the skull react differently to the postcranial skeleton in blunt force trauma incidents, and result in unique fracture patterns (Spitz & Fischer, 2006).

There are many different types of fractures that can occur in the base of the skull such as blowout, linear, and comminuted fractures. However certain types of fractures are more frequently detailed in MVCs such as hinge, ring, and longitudinal fractures. Blowout fractures are isolated to the thin orbital plates and can be found in isolation (Shepard, 2003). They indicate that a considerable amount of blunt force has been inflicted to the skull (Shepard, 2003). Linear fractures are long, relatively straight fractures which tend to radiate from the site of impact at the point where the skull deforms inward a result of compression. They can however, also be found at a distance from the impact site. They commonly involve both the inner and outer tables but have been noted to occur on only one table as well (Saukko & Knight, 2004).

Hinge fractures are linear fractures that traverse the base of the skull, through the middle cranial fossa and often involve the sella turcica (Prahlow, 2010;

Shkrum & Ramsay, 2007; Spitz & Fischer, 2006). They are largely as a result of direct impact to the side of the head (Prahlow, 2010).

Ring fractures circumvent the foramen magnum in the posterior cranial fossae (Prahlow, 2010; Shkrum & Ramsay, 2007; Spitz & Fischer, 2006, pp. 518-519). They have been found to be a result of forces applied to the crown of the head, as well as impacts to the feet or buttocks transferred through the spinal column to the skull (Prahlow, 2010; Shkrum & Ramsay, 2007). They have however, also been noted to result from direct impact to the mandible, which thrusts the head backward (Prahlow, 2010). This backward thrusting motion pulls the head away from the cervical vertebrae. If the strength of the atlanto-occipital ligaments and surrounding musculature surpasses that of the occipital bone, the bone will fail and fracture before the ligaments and musculature fail and tear/ shear (McElhany *et al.*, 1995).

Longitudinal fractures divide the base of the skull into left and right portions. They are linear fractures that run from the frontal bone to the occipital bone along the base of the skull, circumventing the foramen magnum. Due to the fact that basal skull fractures generally result from impacts in the same plane as the skull, longitudinal fractures have been postulated to result from direct trauma to either the frontal eminence or the occipital bone (Shkrum & Ramsay, 2007).

#### 2.3.3.2. Cervical Spinal Injuries

Due to the fact that cervical vertebrae are structurally different to other vertebrae and therefore react differently to blunt force trauma; cervical spinal injuries are distinct and are often considered in isolation. Cervical spinal injuries have been commonly noted in individuals involved in fatal MVCs and have been

found to be the terminal cause of death in some circumstances (Tolonen, et al., 1986).

Cervical spinal injuries have been found to occur when an individual's head makes contact with the chassis or windshield and the cervical spine is forced into a flexed or extended position (Daffner *et al.*, 1988; Tolonen *et al.*, 1986). The inertia of the body in a rapidly decelerating vehicle then causes hyperflexion or hyperextension of the cervical spine. The compression of the neck in these positions can result in failure of the ligamentum flavum as well as the interspinous, posterior longitudinal, and/or anterior longitudinal ligaments which will result in cervical spinal injuries (Daffner *et al.*, 1988; King & Yang, 1995).

Tolonen *et al.* (1986) detailed another common mechanism of cervical spinal injury, whereby vertical compression of the cervical spine occurred following contact between the individual's head and the roof of the vehicle. Whilst Tolonen *et al.* (1986) reported that this cervical spine compression was more common in individuals utilising seatbelts, Anderson (1991) and Nygren (1983) noted that the number of severe neck injuries were reduced in belted individuals when compared with unbelted individuals.

Tolonen *et al.* (1986) observed in a study focused on fatal cervical spine injuries in MVCs in Finland, that 10.5% of deaths in MVCs were a direct result of fatal cervical spine injuries. They noted little difference in the incidence of fatal cervical spinal injuries in front and rear-seat passengers. However, a significantly larger portion of front-seat passengers demised as a result of fatal cervical spine injuries than drivers. This was because, whilst a driver will first come into contact with the steering wheel before making contact with the windscreen, a front-seat

passenger will not. Therefore, a front-seat passenger's head will collide with the windscreen with more force than a driver's, resulting in more frequent and severe cervical spinal injuries (Daffner *et al.*, 1988; Tolonen *et al.*, 1986).

Daffner *et al.* (1988) observed contrasting patterns to Tolonen *et al.* (1986) in that they found that more drivers (10%) sustained cervical spinal injuries than front-seat passengers (6%). Of those individuals having sustained cervical spinal injuries, 64% of driver and 93.3% of passenger cervical spinal injuries' were due to flexion of the neck. They also proposed that the high incidence of cervical spinal flexion injuries in passengers was a result of compression forces following contact between an individual's head and the roof.

Otremski *et al*. (1989) observed the effects that age, sex, crash type, seatbelt usage and occupant position had on the incidence and severity of cervical spinal injuries. The age group most at risk in Ofxford, UK, were between 40 and 49 years old. Females, front-seat passengers, and belted individuals incurred more cervical spinal injuries than males, drivers and rear-seat passengers, and unbelted individuals respectively. Rear-seat occupants were found to have sustained fewer cervical spinal injuries than drivers and front-seat passengers.

Head rests have been found to be an important structure in decreasing the incidence of cervical spinal injuries in rear-impact collisions, however, they were found to have no added benefit in preventing or reducing the incidence of cervical spinal injuries in front-impact collisions (Otremski *et al.*, 1989). Both Otremski *et al.* (1989) and Nygren (1983) found that nonadjustable/fixed head rests reduced the incidence of cervical spinal injuries more than adjustable head rests. Nygren (1983) noted that the ability of a fixed head rest to provide instant support to the

head during a rear-impact collision was the primary factor in preventing cervical spinal injuries. Adjustable head rests however, may not provide the same protection when positioned incorrectly.

#### 2.3.3.2.1 Atlantooccipital Fracture Dislocations

Atlantooccipital (AO) fracture-dislocations were considered separately due to the specific mechanisms of injury of these fractures. The AO joint is a synovial joint with multiple tendons and ligaments holding the various components in place, which allow for flexion and extension of the head (Drake *et al.*, 2010). A force applied directly to the head may result in the bending of the neck in an attempt to absorb the inflicted force (Gustilo *et al.*, 1993; Viano *et al.*, 1989; Yoganandan *et al.*, 1996). This bending of the neck can be of the flexion, extension or rotation classifications, which when combined with the applied force, tend to fracture/dislocate the AO joint (Gustilo *et al.*, 1993; Viano *et al.*, 1989; Yoganandan *et al.*, 1996). Therefore, AO fracture-dislocations are more likely to be as a result of direct blunt force trauma to - or deceleration/acceleration forces acting on - the head, than to the neck itself.

### 2.3.3.3. Thoracic Cage and Visceral Thoracic Injuries

Injuries to the thoracic and abdominal regions of the body were often noted in drivers and front-seat passengers and found to be a result of their proximity to the steering wheel and dashboard respectively (Daffner *et al.*, 1988; Hendey & Votey, 1994). Numerous studies have documented the frequencies of thoracic injuries in unbelted occupants. However, King and Yang (1995) also noted them in belted individuals, and determined that these injuries were generally inflicted directly by the seatbelt. They ascertained that an individual wearing a three-point seatbelt was subjected to substantial belt loading during rapid deceleration in an

MVC, which could produce numerous thoracic injuries. The injuring capability of a seatbelt has been determined to be due to its inelastic properties, which enables the seatbelt to act as a solid object thus producing injuries in MVCs (Hendey & Votey, 1994; King & Yang, 1995).

Ndiaye *et al.* (2009) noted that thoracic injuries were the most frequent injuries in drivers involved in fatal MVCs in Rhône, France. In addition, flail chest injuries accompanied by haemothoraces or pneumothoraces were observed as the most common types of thoracic injuries. Nygren (1983) on the other hand, noted that although thoracic injuries were commonly observed in individuals involved in fatal MVCs, these were not the primary cause of death in all circumstances. The injuries were found to accompany other, more severe injuries (attributed to be the primary causes of death).

#### 2.3.3.3.1. Thoracic Aortic Injuries

The thoracic portion of the aorta is subdivided into three parts, the ascending portion, the arch portion and the descending portion. The ascending aorta begins at the superior part of the base of the left ventricle and terminates at the level of the superior border of the second sternocostal articulation. The arch of the aorta begins at the termination of the ascending aorta and terminates at the lower border of the fourth thoracic vertebrae; and the descending portion originates at the termination of the aortic arch and terminates at the diaphragm (Drake *et al.*, 2010).

Injuries to the descending thoracic aorta were noted by Prahlow (2010), to be a classic injury in MVA victims. Lacerations of the descending thoracic aorta were proposed to have occurred as a result of the rapid acceleration or

deceleration forces acting on the body during an MVC (Prahlow, 2010; Saukko & Knight, 2004). In belted individuals this is due to the inertia of the heart (Saukko & Knight, 2004). Whilst the restrained thorax would undergo rapid deceleration, the heart would continue its forward motion. Due to the fixation of the descending aorta to the posterior thoracic wall (by the anterior longitudinal ligament along the front of the dorsal spine), this forward motion of the heart would stretch the aorta and ultimately result in partial or complete tears in the descending portion of the vessel, usually just below the termination of the aortic arch (Saukko & Knight, 2004).

Aortic injuries however, were not frequently noted in fatal MVCs. For example Törő *et al.* (2005) noted that in Budapest, only 17% of occupants sustained aortic lacerations and Ndiaye *et al.* (2009) noted a 4% incidence of aortic injuries. However, Ndiaye *et al.* (2009) stated that the absence of the documentation of aortic injuries may have been due to the lack of autopsy investigations performed in Rhône, France, where this study was conducted, and thus in the decedents included in their study.

#### 2.3.3.4. Thoracic and Lumbar Spinal Column Injuries

Spinal injuries have been noted to be due to many different forces acting on the body during a collision. The spine can undergo compression, hyperflexion, hyperextension, lateral flexion, shearing and torsional forces at various stages of the collision, which very often result in spinal fractures (Gustilo *et al.*, 1993).

Newton's three laws of motion are fundamental in detailing spinal injury mechanisms. For example, when a vehicle decelerates and/or stops, a belted individual's body will continue to move forward. This would result in hyperflexion of

the body and in turn the spine, around the seatbelt. In unbelted drivers however, thoracic and lumbar spinal injuries were found to be due to contact between the driver's body and the steering wheel. The torso would undergo acute flexion on impact with the steering wheel and result in thoracic and lumbar spinal flexion injuries (Daffner *et al.*, 1988; King & Yang, 1995).

King and Yang (1995) found that the lapbelt (a two point seatbelt traversing the occupant's pelvis or hips from their outboard hip to their inboard hip or vice versa) or lap portion of a three-point seatbelt had serious spinal injuring capabilities. If the lapbelt was too high on the torso or was ill-fitting, the individual's lower limbs could move forward and pull the pelvis and torso underneath the belt in an event called "submarining". The lumbar spine would be injured as a result of the lapbelt moving upward over the iliac alae, into the abdomen and hyperflexing the spine around the belt. This hyperflexion of the spine could bring about failure of the supraspinous and interspinous ligaments, resulting in the splitting of the vertebrae on the posterior aspect. This was more frequent in rear-seat passengers with lapbelts, and not only resulted in lumbar spinal injuries but was also implicated in causing the shoulder portion of the three-point belt to take on most of the restraint action, resulting in more frequent thoracic injuries (King & Yang, 1995).

Anterior wedge fractures of the thoracolumbar spine were noted to result from the compression of the spine, occurring when the individual's kyphotic thoracic spinal curvature was straightened out by the shoulder portion of the three-point belt (King & Yang, 1995). This would, in turn, put pressure on the anterior portions of the thoracolumbar vertebrae and compress the anterior edges of the vertebra, creating wedge-like vertebrae.

Daffner *et al.* (1988) noted that of 250 drivers and 250 front-seat passengers, eight drivers sustained thoracic spinal injuries and 18 sustained lumbar spinal injuries, whilst no passengers sustained thoracic spinal injuries and only three sustained lumbar spine injuries. This displayed not only the low incidence of spinal injuries (10.4% of drivers and 1.2% of passengers) but also the variance in spinal injury patterns between drivers and front-seat passengers.

#### 2.3.3.5. Abdominal Injuries

According to Yoganandan *et al.* (2000), changes in vehicle design and safety awareness in the USA, have influenced the patterns of injuries noted in individuals involved in MVCs. Injuries have tended to migrate from more cephalothoracic, to abdominocaudal regions. Their study focused solely on the patterns of injuries inflicted to the abdomen in front- and side-impact collisions.

The abdomen has been found to react differently to other body regions in blunt force trauma incidents due to the varying biomechanical responses, and therefore injury mechanisms, of the assorted visceral organs (Yoganandan *et al.*, 2000). In addition, the abdomen does not contain protective skeletal elements but rather structural ones, *i.e.* the spinal column, and as a result the abdominal organs are more vulnerable to injury.

Hendey and Votey (1994) observed that although abdominal visceral (intestinal and mesenteric) injuries were the most commonly noted injuries in individuals utilising lapbelts, the incidence of injuries to the liver and spleen were greatly reduced by seatbelt usage. Proposed intestinal (and lumbar spinal) injury mechanisms by the lapbelt included the seatbelt slipping over the iliac alae and into the abdomen. The belt would then compress the intestines against the spine,

resulting in tears in the intestines. Another described intestinal injury mechanism involved the seatbelt occluding both ends of a portion of intestine and the resultant increase in intraluminal pressure rupturing the intestine (Hendey & Votey, 1994).

Some individuals utilising two point shoulder-lap seatbelts (a “sash-like” belt, running diagonally from the occupant’s outboard shoulder to their inboard hip) were also reported to have sustained abdominal visceral injuries such as liver and splenic lacerations, however, these injuries were usually noted to have accompanying rib fractures (Hendey & Votey, 1994).

Although 31% of individuals were noted to have sustained liver injuries in a study by Törő *et al.* (2005), Yoganandan *et al*. (2000) noted abdominal visceral injuries in only a small number of individuals involved in MVCs (1.75 %). Yoganandan *et al*. (2000), found that approximately 50% of those individuals having sustained abdominal visceral injuries, were involved in front-impact collisions, 33% in left-sided collisions and 20% in right-sided (driver side) collisions. In addition, more severe abdominal visceral injuries occurred in front and right-sided impact collisions.

#### 2.3.3.6. Pelvic Injuries

Many different types of pelvic injuries were documented in the literature, all of which were attributed to different mechanisms. For example, Daffner *et al.* (1988) reported that pelvic injuries occurred when individuals’ knees made contact with the dashboard, forcing the head of the femur into or through the acetabulum. This frequently resulted in posterior dislocations of the hip joints as well as fractures of the pelvic bones (Daffner *et al.*, 1988).

The “open book” pelvic fracture has been a commonly noted injury in motor vehicle occupants due to their close proximity to the steering wheel or dashboard (Spitz & Fischer, 2006). It involves both the pelvic ring and the sacrum and is generally a result of anteroposterior compression of the pelvis. This causes the anterior sacroiliac ligaments to fail and the sacroiliac joint to “open” anteriorly which in turn causes a diastasis of the pubic symphysis and in some circumstances the sacroiliac joints (Spitz & Fischer, 2006).

Approximately 25% of individuals involved in MVCs were noted by Adams *et al.* (2003) and Törő *et al.* (2005) to have sustained pelvic injuries and/or fractures. Adams *et al.* (2003) reported the cause of death, in 80% of those individuals having sustained pelvic injuries, to be blunt force trauma to the abdomen or torso. Adams *et al.* (2003) classified pelvic fractures according to the Orthopaedic Trauma Association (OTA) and found the most common pelvic fractures to be of the most severe classification, type C1 (unilateral fractures involving the sacroiliac joints, auricular surfaces of the iliac bones, the superior and inferior pubic rami and the pubic symphysis). Type C1 fractures resulted from vertical shearing forces, leaving the pelvis both rotationally and vertically unstable (Adams *et al.*, 2003).

Although Adams *et al.* (2003) noted that twice the number of drivers sustained pelvic fractures than passengers in Alabama, USA, Daffner *et al.* (1988) noted no significant difference between the number of drivers and passengers that sustained pelvic fractures (42% of drivers and 42.4% passengers) in Pittsburgh, USA. In addition, it was stated by Daffner *et al.* (1988) that 14% of drivers and 4% of passengers sustained sacral fractures, all of whom had associated pelvic fractures, which demonstrated the rarity of sacral fractures occurring in isolation.

Adams *et al.* (2003) detailed not only the incidence of seatbelt usage in individuals with pelvic injuries, but also how the type of collision influenced those pelvic injuries. It was determined that 26% of individuals with pelvic injuries utilised seatbelts, 38% did not and in 8% of individuals the usage was unknown. In addition, 40% of these individuals were involved in front-impact collisions, 28% in side-impact collisions, and 18% in rollover collisions. Although front-impact collisions are thought to be generally less severe (Siegel *et al.*, 2001), they resulted in more severe pelvic fractures than side-impact or rollover collisions. The use of seatbelts however, greatly reduced the incidence of pelvic fractures (Adams *et al.*, 2003).

#### 2.3.3.7. Upper Extremity Injuries

Daffner *et al.* (1988) noted a vast difference in the patterns of upper limb injuries between drivers and front-seat passengers. Front-seat passengers sustained more clavicular and humeral fractures, whereas drivers suffered more elbow fracture-dislocations, radial and/or ulnar shaft fractures, and wrist fracture-dislocations. Drivers also incurred a substantial number of hand injuries which passengers did not. Daffner *et al.* (1988) postulated that the upper limb fractures were a result of various “reflex reactions” by individuals. For example, passenger clavicular and humeral fractures were attributed to individuals raising their arms in anticipation of impact. In drivers however, the same reflex reaction would more likely result in radial and ulnar shaft fractures or wrist and hand fractures/fracture-dislocations due to the close proximity of the steering wheel (Daffner *et al.*, 1988).

Another mechanism of elbow, forearm, wrist and hand injury, was due to the driver gripping the steering wheel and extending his/her arms in anticipation of

impact (Daffner *et al.*, 1988). This resulted in the driver's upper limbs being subjected to a substantial amount of impacting force.

The upper limb was also stated to have sustained injuries during airbag deployment. The most common of which were minor abrasions, erythema and in some cases even minor burns to the hands (Hendey & Votey, 1994).

#### 2.3.3.8. Lower Extremity Injuries

Törő *et al.* (2005) discerned that only 30% of individuals sustained severe soft tissue injuries and/or fractures of the lower limbs. However, Daffner *et al.* (1988) detailed a high incidence of femur fractures in drivers and front-seat passengers, with 64.8% and 41.2% respectively, presenting with these kinds of injuries. Femur fractures were noted to be a result of the individual's knees making contact with the dashboard during the forward motion of the body. Fractures of the distal shaft of the femur, knee and tibial plateau often result from attempts by the body to absorb the impacting forces.

Ankle and foot fractures/fracture-dislocations were stated to not only be a result of the feet getting entangled in the foot pedals during partial or complete ejection, but also as a result of the foot pedals being forced up against the feet during intrusion of the foot compartment at the time of impact (Daffner *et al.*, 1988).

The study by Ndiaye *et al.* (2009) displayed that lower limb injuries could be contributory to the demise of drivers involved in fatal MVCs. They noted that four individuals sustained severe lower limb injuries, two of whom suffered bilateral above-knee traumatic amputations and the other two, unilateral above-knee traumatic amputations.

#### 2.3.3.9. Genital Injuries in Males

Genital and scrotal injuries in males involved in MVCs are not commonly noted in the literature. However, Chirdan and Sutherland (2011) noted that blunt force trauma accounted for 98% of injuries to the urogenital tract in children in Africa, the most common cause of which was MVC related. However, the only injuries noted in MVC related incidents by Chirdan and Sutherland (2011) were those to the penis. They also found that the most common mechanism of scrotal injury was sport related.

Paparel *et al*. (2006) observed that testicular trauma in MVA victims occurred in 11% of individuals, scrotal trauma in 4% of individuals, and urethral trauma in 1% of individuals in France. The low incidence of external genital injury was due to the infrequent exposure of the genitals to direct contact with the vehicle. Motorcyclists, however, were more likely to sustain external genital injuries as a result of the crushing of the genitalia between the pelvis and the fuel tank of the motorcycle (Paparel *et al.*, 2006).

### 2.4. Vehicle Type

Much research has been done into injury patterns in MVCs involving sport utility vehicles (SUVs), minivans (MV), pick-up trucks (or “Bakkies”) (PU/Bakkie), and small passenger vehicles (small sedan or hatch back vehicles) (Bener *et al.*, 2006; Fredette *et al.*, 2008; Siegel *et al.*, 2001). These studies all determined that injury patterns differ markedly between the SUV-MV-PU/Bakkie category and the small passenger vehicle category (Mayrose & Jehle, 2002; Siegel *et al.*, 2001). These variable injury patterns have been attributed to many different factors, the most common of which was the discrepancy in size between the different vehicles. For example, Nygren (1983) and Siegel *et al*. (2001) noted that in two-vehicle

collisions involving a small passenger vehicle and an SUV, MV or PU/Bakkie, the individual/s in the small passenger vehicle were more likely to be severely or fatally injured than those in the SUV, MV or PU/Bakkie. Bener *et al.* (2006) observed in their study on the impact of four-wheel drive involved collisions that "four-wheel drive" vehicles caused more severe, serious, critical and moderate injuries to those individuals in the other vehicle involved in the collision, than small passenger vehicles did. Mayrose and Jehle (2002) performed a study based on the weight of SUVs and the subsequent risk that they pose in collisions with passenger vehicles. They found that in front-impact collisions, as the weight of the passenger vehicle approached that of the SUV, MV or PU/Bakkie, the number of small passenger vehicle deaths decreased and the number of SUV, MV, PU/Bakkie deaths increased. This detailed the impact the weight of the vehicle played in two-vehicle collision dynamics.

However, weight is not the only significant factor in determining the patterns and severities of injuries. For example, in one-vehicle collisions, in which a vehicle collides with another object such as a pole, tree or barrier, individuals in an SUV, MV or PU/Bakkie were more likely to be severely or fatally injured than those individuals in small passenger vehicles (Ulfarsson & Mannering, 2002). This was found to result from the greater rigidity of the SUV, MV or PU/Bakkie (Ulfarsson & Mannering, 2002). SUVs, MVs and PU/Bakkies are designed with increased self-protective and aggressive capabilities. This is to primarily protect the occupants of the SUV/MV/PU/Bakkie whilst deferring most of the impacting energy onto the other vehicle (Fredette *et al.*, 2008). This would result in a lower frequency of injuries to passengers in SUVs, MVs and PU/Bakkie involved in two-vehicle collisions but an increased incidence in one-vehicle collisions.

A study by Siegel *et al*. (2001) focused on the factors that influence injury patterns in SUV, MV, PU/Bakkie, and passenger vehicle collisions. They reported 1.85 times more small passenger vehicles registered than light trucks in the USA in 1997. However, 20.6% of fatal collisions involved a small passenger vehicle being struck by a light truck, whereras 18.7% of fatal collisions involved only small passenger vehicles. However, small passenger vehicle occupants were noted to have sustained fewer injuries in collisions with light trucks than with another small passenger vehicle.

Bener *et al.* (2006) recorded more head injuries in individuals in four-wheel drive vehicles than those in small passenger vehicles. The circumstances surrounding the MVCs however, were not stated in the article.

In South Africa, the most common means of public transport are taxis, which are minibus/minivan vehicles. Generally, these vehicles are overloaded during peak travelling times and drivers do not adhere to speed limits or road rules (Lotter, 2000). All of these factors influence the frequency and severity of taxi-involved collisions. According to Chang and Mannering (1999), whose study focused on truck- and non-truck involved collisions and the severity of the resulting injuries to the vehicle occupants, vehicles with an increased number of occupants had an increased probability of an occupant being injured during an MVC. This was noted to be due to intrusion of structural components of the vehicle into the passenger compartments during a collision. Overloading would increase the possibility of an occupant being injured by this intrusion (Chang & Mannering, 1999).

## 2.5. Collision Type

The direction and speed of impact is of great importance in determining the severity of the injuries caused in a collision, since it influences the ability with which a vehicle can provide protection to occupants. This will in turn influence the injury patterns and the severities of injuries sustained (Mayrose & Jehle, 2002; Siegel *et al.*, 2001).

### 2.5.1. Front-Impact versus Side-Impact Collisions

Front-impact collisions have been observed to result in less severe injuries than side-impact collisions (Siegel *et al.*, 2001). This is due to the decreased amount of side protection a vehicle possesses, as well as the decreased distance between the occupant and the impacting vehicle in side-impact collisions. For example, in a front-impact collision the engine would provide a barrier between the occupants and the impacting vehicle. In addition, the engine would absorb most of the force of the impact, in turn reducing the amount of impact transferred to occupants (Saukko & Knight, 2004; Siegel *et al.*, 2001). In side-impact collisions, the chassis of the vehicle would not be able to absorb all of the force and a considerable amount of it would be transferred to the occupant/s, resulting in more severe injuries (Siegel *et al.*, 2001).

Mayrose and Jehle (2002) determined that in front-impact collisions, as the weight of the small passenger vehicle approaches that of the SUV, fewer injuries were recorded in small passenger vehicle occupants than in SUV occupants. However, small passenger vehicle occupants were more severely injured even when the small passenger vehicle outweighed the SUV (Mayrose & Jehle, 2002).

Siegel *et al.* (2001), observed that individuals involved in front-impact collisions sustained considerably less cerebral injuries than those individuals involved in side-impact collisions, regardless of the incidence of seatbelt usage. This demonstrated the substantial design flaw in the protection of individuals in side-impact collisions. This has encouraged vehicle manufacturers to improve side-impact safety, which recently resulted in the introduction of side-impact strengthening devices and side curtain airbags (Siegel *et al.*, 2001).

### 2.5.2. Rear-Impact Collisions

Saukko and Knight (2004) reported that rear-impact collisions were the least fatal type of collision, since the front-seat occupants of the vehicles were protected by the rear portion of the vehicle. The increased distance between the impact site and the occupants allowed for increased absorption of the impacting energy. This in turn decreased the amount of energy transferred to the individuals' bodies which decreased the injuring capacity of the impact. However, in rear-impact collisions with stationary vehicles, "whiplash" injuries were common, due to the acceleration of the individual's head and subsequent hyperextension of the cervical spine (Saukko & Knight, 2004). Whiplash occurs as a result of sudden deceleration or acceleration forces acting on the body during a collision. The weight of the head will, due to inertia, attempt to withstand these forces and will either accelerate or decelerate accordingly. This violent motion would injure the neck (Saukko & Knight, 2004).

### 2.5.3. Left-Sided, Right-Sided, Near-Sided and Far-Sided Impact Collisions and the Influence on Injury Patterns

Yoganandan *et al.* (2000) discussed in detail other impact sites such as left and right-sided impacts as well as near and far-sided impacts and how the

different sites of impact influence abdominal injuries. The sites of impact were classified in relation to the face of an analogue clock such that front-impacts were those occurring between 11h00 and 01h00, left-sided impacts between 08h00 and 10h00, right-sided impacts between 02h00 and 04h00 and rear-impacts between 05h00 to 07h00. Their study was based on left-hand drive vehicles and therefore, near-sided impacts were classified as those occurring on the left side for drivers and the right for passengers and vice versa for far-side impacts. The differences in injury frequencies for each site of impact were documented and front-impact collisions were reported to result in more abdominal injuries than side-impact collisions. The different abdominal viscera had differing injury frequencies depending on the site of impact. For example, the spleen was more frequently injured in left and near-sided impacts, whereas the liver was more often injured in front, right and near-sided impacts (Yoganandan *et al.*, 2000). Consequently, the site of impact in a MVC is an important determinant in patterns of injuries sustained.

### 2.5.4. Rollover Collisions

SUVs, MVs and PU/Bakkies have been found to have low static abilities and therefore possess an increased tendency to roll over in MVCs, in comparison to small passenger vehicles (Trowbridge et al., 2007). According to both Góngora *et al.* (2001) and Trowbridge *et al.* (2007), whose studies concentrated on surviving ejection victims and the fatality rates of teenage drivers in the USA respectively, rollover incidents had more serious injuring capabilities than front and side-impact collisions and were consequently noted to result in far more fatalities. However, according to DiMaio and DiMaio (2001), rollover incidents were less lethal. They stated that partial or complete ejection would occur, resulting in

injuries isolated to the craniocerebral and cervical spine regions, although they noted no specific injury patterns. However, ejection incidents have been found to be severe in nature as are craniocervical injuries and therefore the finding of partial or complete ejection together with less severe isolated craniocervical injury is unusual (Góngora *et al.*, 2001).

### 2.5.5. Ejection Collisions

Góngora *et al.* (2001) executed a study focused on individuals ejected from vehicles during MVCs who survived and presented to trauma centers. They defined an ejection incident as one in which an individual is physically removed, either partially or completely, from the vehicle and subsequent contact with the ground made. Individuals that are ejected from vehicles during a collision suffer different injuries and injury patterns, due to the increased variety of objects and surfaces their bodies come into contact with (Góngora *et al.*, 2001).

Ejection incidents were found by Góngora *et al.* (2001) to be far more severe than any other type of incident, and were therefore noted to have much higher mortality rates (Góngora *et al.*, 2001). The most common injuries sustained by ejection victims were external in nature, followed by head/neck, extremity and thoracic injuries (Góngora *et al.*, 2001). Individuals ejected from vehicles were found to have a higher probability of sustaining injury to any body region than those individuals not ejected. They also sustained more frequent and severe injuries than those not ejected, whether belted or not.

A study by Malliaris *et al.* (1996) determined that the majority of ejection victims were not belted at the time of the incident and that most ejections occurred as a result of rollover incidents. Their study focused on ejection collisions involving

light vehicles. Ejected individuals were found to be ejected from a vehicle via six pathways:

1. Through closed, operable windows or fixed windows
2. Through operable windows, open prior to the incident
3. Through the windshield
4. Through doors or the “rear-gate” (boot) which opened during the collision
5. Through the sunroof
6. Through other less common pathways such as from trailers, pickup beds, or unknown paths

Góngora *et al.* (2001) noted that initially the most common ejection path followed by individuals was via doors that opened during the incident however, the introduction of antiburst door latches has decreased this occurrence. Most of the ejected individuals were noted to be male, outnumbering females by 3.2 to one, and were of a younger age (median = 26).

Góngora *et al.* (2001) reported a twofold increase in the number of belted passengers during the nine and a half year duration of their study (1990-1999), even though the number of ejected victims remained constant. South African MV/taxis have little or no seatbelt availability for rear-seated passengers. This increases the possibility of ejection incidents in addition to the possibility of more severe injuries being sustained to passengers.

Góngora *et al.* (2001) noted that some of the more common contributing factors to ejection incidents were speed, rollover status, blood alcohol levels and airbag deployment.

### 2.5.6. Intrusion of the Occupant Compartment

Although modern vehicles are designed to remain rigid and have specified crumple zones to absorb the impact without injuring the occupants, if the force of the impact is great enough, the engine, steering column, front wheel assembly and even the gearbox may intrude into the occupant compartment (Saukko & Knight, 2004). This possesses the potential to injure the occupants as there is decreased compartment space and consequently an increased probability of the occupant coming into contact with an intruding structure (Saukko & Knight, 2004).

Intrusion of some of the lower lying structures, such as the engine and gearbox, can result in the intrusion of the floor of the compartment which would injure the lower extremities of the occupants (Saukko & Knight, 2004).

In rollover incidents, the roof and/or A-frame could collapse and intrude into the occupant compartment, again increasing the probability of the occupant coming into contact with one of these structures and, resulting in a variety of axial structure injuries (Saukko & Knight, 2004).

## 2.6. Safety Features

Over the years, many safety features have been introduced into vehicles in an attempt to provide occupants with more protection against impacting forces as well as preventing ejection. This includes the introduction, and later stipulation of installation of seatbelts and airbags. In addition, modern vehicle designs have adjusted the protection with which both front-seat passengers and drivers are provided, which has been noted to influence the discrepancies noted between front and rear-seat passenger injury incidences (Bilston *et al.*, 2010).

### 2.6.1. Seatbelts

Research into the use of seatbelts and their safety has shown that although seatbelts may cause minor injuries to individuals utilising them, they tend to decrease injury severity in front-impact and side-impact collisions significantly (Hendey & Votey, 1994). Martin *et al.* (2000) determined that seatbelts have an 82% chance of reducing the rate of severe injuries. Their study concentrated on injury patterns in drivers of passenger vehicles involved in front-impact collisions. Although over-reporting of seatbelt use may have led to slightly inflated data, a significant increase in the protection afforded by seatbelts was evident (Martin *et al.*, 2000). However, Ndiaye *et al.* (2009) noted that of 383 French motor vehicle drivers, 27% utilised seatbelts, 22% did not and in 50% of cases the seatbelt usage was unknown. This is contrary to the over reporting found by Martin *et al.* (2000) and displayed that the frequency of seatbelt usage, despite being law-enforced, is relatively low in France.

A study by Hendey and Votey (1994) focused on the injuries that restrained of belted individuals incur in MVCs. According to Hendey and Votey (1994), seatbelts reduced the incidence of injuries in three ways: they limited contact between an individual's body and the interior of a vehicle, they prevented ejection of the individual from the vehicle, and they dispersed the force of deceleration over a wider area whilst increasing the amount of deceleration time, thereby allowing for slower deceleration of the individual.

Studies by both Hendey and Votey (1994) and Saukko and Knight (2004) noted that relatively severe injuries could be caused by seatbelts. Lapbelts were implicated in lumbar vertebrae fractures as well as liver and splenic injuries, and shoulder belts in cervical spinal and thoracic cage fractures. Byard (2002) also

observed occasional severe injuries in individuals utilising seatbelts involved in high-speed collions. Two individuals from the same vehicle, sustained fatal injuries as a direct result of seatbelt utilisation. One of whom was found to have sustained complete diagonal separation of the left and right portions of the thoracic rib cage as a result of multiple anterior comminuted rib, clavicular and sternal fractures, as well as fatal injuries to the thoracic aorta and heart. The other sustained a similar diagonal thoracic rib cage separation as well as fatal injuries to the thoracic aorta, right lung, liver and heart. Both individuals sustained these injuries in the area directly underlying the position the seatbelt traversed the body. This therefore, directly implicated the seatbelt in the causation of these injuries. Consequenty, seatbelt usage could be implicated in causing some severe and even fatal injuries in individuals, if not fitted correctly or if utilized at excessively high-speeds (Byard, 2002; Hendey & Votey, 1994).

### 2.6.2. Airbags

Airbags have also been implicated in saving lives and have become a standard safety feature in new motor vehicles world-wide (Sato *et al.*, 2002). According to Spitz and Fischer (2006), airbags situated in the steering wheel and dashboard deploy in response to the disruption of sensors found in the bumper of the vehicle and therefore, those airbags would not deploy during side impact collisions.

Airbags were designed to not only prevent impact between an individual's chest and the steering wheel or dashboard, but also to decrease the forward motion of the head during a collision thus minimizing the extent to which individuals experience hyperextension or whiplash (Spitz & Fischer, 2006).

Although some injuries could result from airbag deployment, the lifesaving capabilities outweighed the injuries caused by them (Hendey & Votey, 1994; Spitz & Fischer, 2006). The injuries caused by airbags were found to result from the instantaneous, explosive inflation of the airbag, which could injure individuals seated too close to the steering wheel or dashboard, as well as those who are unbelted or incorrectly belted (Spitz & Fischer, 2006). The most frequent injuries ranged from minor lacerations, contusions and abrasions of the face, neck and chest to more severe chemical and thermal burns and even fractures and avulsion injuries of the fingers and upper limbs (Antosia *et al.*, 1995; Hendey & Votey, 1994; Sato *et al.*, 2002; Smock & Nichols, 1995).

Fatal injuries to individuals as a result of airbags have been reported, such as cervical spinal injuries, basal skull fractures and injuries to the thoracic viscera (Spitz & Fischer, 2006).

Hendey and Votey (1994) stated that airbags aided in reducing the occurrence and severity of injuries sustained by individuals involved in MVCs. However, when utilised in isolation, airbags have been found to be far less effective than when used in combination with seatbelt restraining practices (Hendey & Votey, 1994). In isolation, airbags only reduce fatalities by 18%, whereas when used in combination with seatbelts there is a 45% reduction in fatalities (Hendey & Votey, 1994). Children have been noted to be specifically susceptible to injuries inflicted by airbags (Braver *et al.*, 1997). It was noted by Braver *et al.* (1997) that children under the age of ten have 34% higher chance if demising in an MVC as front-seat occupants in vehicles with dual front airbags. Most of the fatal injuries sustained by children are to the head and cervical spinal

region (Okamoto *et al.,* 2002) however, Mehlman *et al.* (2000) also noted relatively severe extremity fractures as well.

## 2.7. South African Data on Motor Vehicle Accidents

Limited research has been done in the field of motor vehicle collisions in South Africa (SA) and therefore not much data exists against which this study can be compared. A study by Govender and Allopi (2006), in which they endeavoured to gain more insight into taxi collisions, noted that not enough information was available from the Police Accident Reports (AR). The Police ARs were found not to have been conducive to scientific research. Instead they were found to have been designed specifically for law enforcement purposes and do not to aid in the determination of the cause of collisions or for the collation of collision trend data. They also noted that reporting mechanisms of the Police were flawed which resulted in inaccurate collision trend data (Govender & Allopi, 2006). One such flaw included the attending Police Officer stating that in single vehicle collisions the driver of the taxi “lost control” of the vehicle (Govender & Allopi, 2006). This was found to have resulted in the “underreporting of crashes by motorists who believe reporting will be to their disadvantage” (Govender & Allopi, 2006, pp. 102-103).

Lotter (2000) found that collisions involving MV/taxis were over-represented in SA due to “general unroadworthiness, unlawful driving and overloading” in the said vehicles (Lotter, 2000, p. 8). They also noted an increased number of collisions involving buses. These collisions were deduced to have been as a result of, among other reasons, excess speeding, reckless driving and defective vehicle parts.

Research into the causes and types of collisions as well as the number of fatalities, the position of occupancy of the decedents, and the injuries sustained by the decedents involved in the fatal collisions is therefore limited in a South African context. The lack of this kind of research identified the need for more South African research in the field and thus aided in the initiation of this research.

## 2.8. Injury Grading Scales

Many injury grading systems exist, specifically in the field of trauma surgery. Some such systems include the Injury Severity Score (ISS), the New Injury Severity Score (NISS), Trauma and Injury Severity Score (TRISS), the International Classification of Disease-9 (ninth revision) based Injury Severity Score (ICISS), the Revised Trauma Scale (RTS), the Abbreviated Injury Scale (AIS-90) system, the Glasgow Coma scale, and the Anatomic Profile Score (APS) (Association for the Advancement of Automotive Medicine, Committee on Injury Scaling, 1990; Baker *et al.,* 1974; Boyd *et al.*, 1987; Champion *et al.*, 1989; Copes *et al.*, 1990; Osler *et al.*, 1996; Osler *et al.*, 1997; Teasdale & Jennett 1974). Each injury scoring system is unique in the manner in which it scores the specific injuries. The primary focus of the scoring systems is to calculate the probable outcome of the individual with regard to their survival and recovery time (Adams & Carrubba, 1998; Baker *et al.,* 1974). These systems were put into place by physicians for use by other physicians in trauma settings. Some of the scoring systems have however, been applied in forensic settings in the interest of the completeness of trauma data among other reasons (Bilgin *et al.*, 2005; Riddick *et al.*, 1998).

The AIS, for example, uses a seven digit code based on the type, location, and severity of the injury in question (Association for the Advancement of

Automotive Medicine, Committee on Injury Scaling, 1990). Without medical knowledge (as physicians possess) the severity of injuries and the threat they pose to an individual's life or recovery cannot be calculated. The ISS, NISS, and TRISS use the AIS scale as a basis to calculate an individuals' injury score. This score then displays the extent of the injuries inflicted upon the individual and thus their estimated survival rate and/or their recovery time (Hannan *et al.* 2004).

The AIS takes into account the external and skeletal injuries sustained by individuals as well as the visceral injuries. However, the scoring of the severity of the injuries requires medical knowledge. In addition the AIS codes were noted by Adams and Carrubba (1998) to have been suitable for skin wounds and long bones fractures but were found to have been insufficient for wounds sustained by the muscles beneath intact skin which has been noted in individuals involved in MVCs.

The above mentioned injury scoring systems were designed primarily for use by physicians as medical knowledge is imperative in order to gauge the severity of a visceral injury. Consequently, the investigator could not utilise systems designed for use by physicians and instead derived an injury scoring system based on anatomical knowledge. As a result, the injuries in this study were scaled according to the extent of the damage caused by the injuries and not the severity of the injuries themselves. The depth of the injuries and structures involved in the injury were used in order to score the injuries' severities. The investigator was aided by medical professionals in order to ascertain the accuracy and relevance of the designed non-physician injury grading system.

In addition, in this study, the presence of visceral injuries could only be noted as being present or not and therefore, the severity of the visceral injuries could not be scored with any existing injury severity scoring system.

This literature review displays the many different avenues of research that have been investigated regarding motor vehicle collisions, including the vehicle safety, the injuries that occur, and the economic impact, and long term disability outcomes for those individuals having survived collisions. However, none of these studies has integrated the many complex aspects involved in a motor vehicle collision in one study. This study therefore aimed to integrate the many different variables of MVCs and focus on fatalities in MVCs and the patterns of injuries that result. These variables included the various types of collisions, types of vehicles, occupant positions and safety features utilised.

## 3. Methods and Materials

*This section describes the study design, the hypothesis tested, the sample population and the instrumentation used in addition to the statistical methodology performed to analyse the data.*

This study comprised a cross sectional study with literature, x-ray images and photographs of motor vehicle accident victims as well as the necessary information from the autopsy and Police reports.

This study was performed at the Johannesburg and Germiston Forensic Pathology Service (FPS) Medicolegal Mortuaries (Southern Cluster Mortuaries), and the Division of Forensic Medicine and Pathology, University of the Witwatersrand in Johannesburg. The sample included in this study comprised of any and all motor vehicle accident (MVA) victims that met the inclusion criteria of

this study, who presented at the Johannesburg FPS between 13 May 2011 and 30 June 2011 and the Germiston FPS between 1 July 2011 and 1 June 2012. The timing at the two mortuaries was dictated by the availability of a functioning x-ray machine. The research was originally planned to occur exclusively at the Johannesburg FPS facility but on 28 June 2011 the x-ray machine ceased to work and as a result the Germiston FPS facility was utilised.

In accordance with South African law, the performance of medicolegal autopsies in South Africa (SA) is governed primarily by the Inquests Act, 1959 (Act no. 58 of 1959), which states (inter alia) that when a person dies of "other than natural" (unnatural) causes, a medicolegal autopsy must be performed in order to establish the cause of death. The Forensic Pathology Services (FPS) are mandated to render these medicolegal autopsy duties and these Services are administrated through the various Provincial Departments of Health (DOH) in SA, with some of its main stakeholders being the South African Police Services (SAPS) and the Department of Justice. A total of 119 individuals met the inclusion criteria of this research and were therefore included in this study.

The Johannesburg FPS is situated in Hillbrow, Johannesburg. It is the second busiest mortuary in Gauteng with a jurisdiction including the northern suburbs and central Johannesburg. Many of the main highways fall into this jurisdiction as well as urban roads. Some untarred rural roads within Alexander informal settlement are also included in this catchment area. The Germiston FPS is situated in Germiston, Johannesburg and is the busiest mortuary in Gauteng. Its jurisdiction includes the eastern suburbs of Johannesburg and includes mainly urban roads, some highways and some untarred rural roads within the large informal settlement of Thembisa.

Appendix A, Figure 7.1 is a map of the Gauteng Province which includes Johannesburg and Pretoria. This provides a general overview of the layout of the areas in and around Johannesburg. Appendix A, Figure 7.2 displays the City of Johannesburg area; the red ring demarcates the jurisdiction of the Johannesburg FPS. Appendix A, Figure 7.3 displays the Ekurhuleni Municipality area and the red ring demarcates the Germiston FPS jurisdiction.

The Johannesburg and Germiston FPS Mortuary Jurisdictional Areas:

The Johannesburg FPS jurisdiction includes the suburbs of Alexandra, Booysens, Bramley, Brixton, Cleveland, Diepsloot, Douglasdale, Fairlands, Sophiatown, Hillbrow, Honeydew-East, Jeppe, Jhb Central, Langlaagte, Linden, Mondeor, Moffatview, Midrand, Norwood, Parkview, Randburg, Rosebank, Sandringham, Sandton, and Yeoville.

The Germiston FPS jurisdiction incudes the suburbs of Alberton, Bedfordview, Boksburg Central, Brackendowns, Downpark, Edenpark, Edenvale, Elsburg, Germiston, Isando, Ivory Park, Katlehong, Kempton Park, Norkem Park, Olifansfontein, OR Tambo, Primrose, Rabie Ridge, Reiger Park, Tembisa, Tokoza, and Vosloorus.

### 3.1. Inclusion and Exclusion Criteria

The inclusion criteria for the sample included:

- Motor vehicle accident victims admitted to the Johannesburg and Germiston Forensic Pathology Services during the course of this study (May 2011- June 2012).

- Individuals having not yet undergone medicolegal autopsy examinations, so as to ensure the x-ray images were clear and no alterations or disruptions of the body.
- Individuals older than 18. (Because individuals under the age of 18 have only partially ossified skeletons. A partially ossified skeleton is softer than a completely ossified skeleton and will therefore react differently in blunt force trauma incidents. In addition, children are generally smaller than adults and thus will encounter different surfaces during a collision to those an adult would encounter. Furthermore, children's bodies react differently to vehicle safety features such as airbags and seatbelts. This introduces many more variables for the biomechanics behind injury mechanisms and thus individuals under 18 are excluded.)

The exclusion criteria for the sample included:

- MVA victims having undergone any resuscitation attempts (at the scene of the incident) in order to revive the individual that may have caused autopsy artifacts, including fractures, dislocations or disruptions of any accident-related injuries.
- MVA victims who were first admitted to hospitals – since hospital interventions may alter the appearance of any accident-related injuries, including skeletal fractures.
- MVA victims autopsied on Saturdays, Sundays or Public Holidays (Due to religious, cultural or compassionate reasons, some medicolegal autopsies are expedited and are therefore performed over

weekends and on Public Holidays. Nonetheless, a very limited number of individuals are autopsied on weekends and/or public holidays and thus the sample size was not greatly affected). Any individual having undergone an autopsy performed on these days was not used, as the investigator was not present to collect the data. Data collection days included weekdays only.

- MVA victims that were severely burned during the collision, since many injuries are disrupted or obscured by the burning process.
- MVA victims younger than 18 years.
- Pedestrian MVA victims.

### 3.2. Estimation of Sample Size

An estimation of the sample size that would be expected in a year was calculated in order to determine if the sample would be large enough for statistical analyses. The sample size was estimated by examining the FPS Admission Registers (detailing each and every individual received at the FPS) for the period of one year. In order to calculate the number of MVA victims that would be collected directly from the scene of the collision, the number of MVA victims that were received from hospital each month was subtracted from the number of MVA victims received at the FPS each month. The number of MVA victims received each month directly from the scene (for the year) was then added up and divided by 12 in order to calculate the average number of MVA victims collected directly from the scene per month. This average was then multiplied by 12 to estimate the total sample collection size in a year. It was calculated that an average of 16.67 MVA victims were received directly from scenes per month and therefore an averaged total of 200 of such MVA victims would be received in a year. In the

current study 129 MVA victims were received during the time period allocated for the study.

The sample included in this study comprised any and all individuals involved in fatal MVCs that presented at the said Southern Cluster FPS Medicolegal Mortuaries during the course of the study. Individuals that were included in this study were required to have been no less than 18 years of age and were not to have received any medical intervention or hospitalization prior to their death. The said individuals were subject to full body anteroposterior (AP) x-rays prior to the autopsy using the C-arm compact Moonray GSE “Plus” – 13” – 12fps x-ray unit (Manufactured in Italy by Simad x-ray Medical Technology, a Sago Medica company) housed at the Johannesburg and Germiston FPS facilities. Tecmed Africa (Pty) Ltd. is the sole importer and provider of this equipment in South Africa. Appropriate training on this machines safe operation and handling procedures was provided by Tecmed (Pty) Ltd.

| FPS Facility | Product Code | Serial |
|---|---|---|
| Johannesburg | 0506-7001-04 | XR0849 |
| Germiston | 0602-7012-14 | 0602-7012-14 |

### 3.3. Data Collection

#### 3.3.1. Autopsy Processes

The autopsy procedure is standardized throughout the Southern Cluster Mortuaries. It begins with the Forensic Medical Practitioner examining the individual and the noting the clothes he/she is wearing. The clothes are then removed by an attending Forensic Officer. The Forensic Medical Practitioner then

examines the external surface of the individual and reports each and every injury and/or special identifying feature to the attending scribing Forensic Officer, to document. The scribing Forensic officer records all reported information pertaining to the individual onto the Autopsy Scribe Form. During the external evaluation of the individual, photographs were taken by the investigator documenting all the external injuries. Once this external examination of the individual was complete the individual was taken to the x-ray room for x-ray screening.

#### 3.3.1.1. X-Ray Protocol

The x-ray procedure involved placing the individuals on the x-ray table under the C-arm of the machine and the subsequent taking of sequential anteroposterior (AP) and occasional oblique x-rays, where needed. The head was manipulated so that clear left-to-right and right-to-left lateral shots as well as an anteroposterior shot of the cranium could be taken. The base of the skull could not accurately be observed under x-ray and as a result basal skull fractures were only noted after the removal of the cranial contents during the autopsy. Photographs were then taken as a means of recording any and all basal skull fractures.

The neck, left shoulder girdle region and right shoulder girdle region were then scanned under x-ray vision followed by the upper midline thoracic region. The sternum and anterior and anterolateral portions of the ribs could not be viewed under x-ray and therefore photographs were taken after deflection of the anterior chest skin and muscle prior to the removal of the chest plate (anterior portion of the thoracic cage) as well as after removal of the chest plate and lungs. Consequently, the upper midline thoracic x-ray scans included the cervical and upper thoracic spine as well as the posterior portion of the ribs.

AP x-ray shots were then taken of the left side of the thoracic cage (two to three scans), right side of the thoracic cage (two to three scans), thoracic spine (two to three scans), lumbar spine and sacrum (two to three scans).

The pelvis was x-ray scanned in four parts: the left ilium (iliac alae), ischium and pubis; the distal portion of the pelvis, the left and right inferior and superior pubic rami and pubic symphysis; right ilium, ischium and pubis; and the pelvic inlet/pelvic brim.

The lower limbs were x-ray scanned sequentially down the left leg from the femoral head to the left foot (left hip joint and femoral head, the left femur, left knee, left tibia and fibula, left ankle left foot, left toes). The scanning of the right leg proceeded in the same sequential pattern.

The left and right upper limbs were x-ray scanned sequentially from shoulder joint and humeral head to fingers (shoulder joint, humerus, elbow joint, radius and ulna, wrist, hand, fingers).

The resulting x-rays were sequential radiographic shots of the individuals' entire body noting any and all fractures, both complete and incomplete, dislocations and any irregularities of the bones.

Observation of the autopsy then followed.

**3.3.1.2. Autopsy Procedure**

Once the Forensic Medical Practitioner has completed the external examination of the body, the Forensic Officer reflects the scalp to expose the calvarium; the calvarium is then removed to expose the underlying brain. The underlying meningeal tissues are then reflected by the Forensic Medical

Practitioner and the brain is dissected away from the brainstem for further forensic examination. Additional dissection of the meningeal layers is required to expose the underlying cranial fossae, which is essential in the assessment possible skull fractures as a result of MVC related deaths.

In addition a median thoraco-abdominal midline incision is made from the mental protuberance superiorly to the pubic symphysis inferiorly. All soft tissues are reflected bilaterally to fully expose the underlying internal organs and vessels. All pertinent soft tissues are then removed in a sequential process from their associated body cavities for further forensic examination.

Any and all free and clotted blood and fluid collections noted within the individual's thoracic cage, abdomen and pelvic area are removed and measured prior to removal of the soft tissues and viscera within those cavities. The Forensic Medical Practitioner then examines and dissects each organ and large blood vessels, noting any and all abnormalities, acute and/or chronic diseases present and any injuries that may have been sustained. These are all reported to and documented by the Scribing Forensic Officer in the scribe notes. In addition, any necessary ancillary forensic samples for further analysis e.g. histological or toxicological investigations will be collected by the Forensic Medical Practitioner and documented in the scribe notes. The autopsy findings and, where relevant, ancillary investigative findings are then assimilated into an autopsy report by the Forensic Medical Practitioner, where the cause of death will be stated. This report is then collected from the FPS by the SAPS Investigating Officer of each case.

Any and all visceral, external, and skeletal injuries noted on the autopsy reports, photographs, and x-rays were documented on the appropriate data collection sheets, compiled by the investigator (Refer to Appendix D, Figure 7.5).

### 3.3.2. Police Data Collection

Data regarding the circumstances of the motor vehicle collisions was then collected from the Johannesburg Metropolitan Police Department (JMPD) for those cases received at the Johannesburg Forensic Pathology Services, and South African Police Services (SAPS) for those cases received at the Germiston Forensic Pathology Services, due to the various Police jurisdictions. The SAPS data was collected from affidavits provided by the SAPS Officer who attended the scene of the incident and included, where possible, the make and model of the vehicle, the site of impact, the occupancy of the said individual(s) in the vehicle and the object or other vehicle that was involved in the collision. The JMPD collision reports were those compiled by the Metropolitan Police officer attending the scene and included statements of the officer regarding the scene, witness statements where possible, sketches of the scene and photographs of the vehicles and deceased occupants as the attending officer found them. The information collected also comprised the make and model of the vehicle, the site of impact, the occupancy of the said individual(s) in the vehicle and the object or other vehicle that was involved in the collision. This information was recorded on the appropriate data collection sheet, compiled by the investigator (Refer to Appendix D, Figure 7.6).

## 3.4. Data Analysis

The data collected from the autopsy reports, x-rays and photographs taken during the autopsy, were analyzed and the injuries were plotted onto figures

denoting the different types of injuries observed (graze-abrasions, lacerations, contusions, traumatic amputations). Each individual's body was divided up into twelve regions consisting of the head, neck, thorax, abdomen, pelvis, shoulder girdle, upper limb, forearm, hand, thigh, leg and foot (Refer to Appendix B, Figure 7.4). Each external injury was ranked according to the investigator's own external injury grading system (Refer to Appendix C, Table 7.1) as no external injury grading system for non-physicians exists. The injury grades for each body region were tabulated for each individual in a Microsoft Excel Spread Sheet.

The visceral injuries were recorded in a separate Microsoft Excel Spread Sheet as were the skeletal fractures.

Descriptive statistical techniques were used to describe the various injuries noted for each body region as well as each individual. These statistical methods were also used to compare the patterns of injuries noted in various individuals as well as the patterns of injuries noted in specific body regions. Central tendencies and distributions (mean, median, and quartiles) were used to describe the demographics of the sample. Graphical representations of the trends in the time of day, day of the week, and most common month for the collisions were plotted.

In all statistical analyses of the injuries the external, visceral, and skeletal data was compared separately. This provided individual comparisons between the external injuries, the visceral injuries, and the skeletal fractures for the various vehicles and positions of occupancy.

In order to compare the external, visceral, and skeletal injury patterns in individuals in different vehicles (SUVs, PU/Bakkies, MVs, passenger vehicles and large trucks) a two-factor analysis of variances (ANOVA) without repetition was

run with a statistical significance of 0.05. A two-factor ANOVA without repetition was chosen for this analysis as an ANOVA is utilized to evaluate the variances of more than two categories to determine if any differences exist. In addition, the type of vehicle as well as the region of injury was being tested for variability. This study was also run only once (it was not repeated with different samples) and therefore no repetition of the data collection occurred and so the two-factor ANOVA was tested without repetition. This was performed by sorting the external, visceral, and skeletal injury data according to the type of vehicle the individual occupied at the time of the collision, in Microsoft Excel. The mean frequencies for the external, visceral, and skeletal injuries were calculated separately for each type of vehicle and the means were tested by the two-factor ANOVA, with a statistical significance of 0.05, in Microsoft Excel.

A single-factor ANOVA, with a statistical significance of 0.05, was also run in Microsoft Excel for the mean frequencies of external, visceral, and skeletal injuries for individuals occupying different types of vehicles, to determine if any differences in the number of injuries sustained by the said individuals existed. This was done in the same manner as the two-factor ANOVA with the exception of the single-factor ANOVA being run.

Driver and passenger patterns of injury were compared to one another using a student's two-sample unpaired t-test, with a statistical significance of 0.05, to note if the injury frequencies differed between all drivers and passengers. This was performed by sorting the injury data according to the individuals' occupancy in the vehicle in Microsoft Excel. The mean injury frequencies for the external, visceral, and skeletal data for the drivers and passengers were then calculated

and placed into Past (Paleontological Statistics Version 2.02) where an unpaired t-test was then performed.

In order to observe if any differences existed between drivers and passengers in the same vehicle, a student's two-sample paired t-test, with a statistical significance of 0.05, was performed. The student's two-sample paired t-test was chosen for this comparison as it is utilized to determine if two data sets that have a link (such as the individuals being in the same vehicle) are significantly different from one another. The data was first sorted according to the individuals' occupancy in the vehicle. Drivers and passengers that were known to have occupied the same vehicle were then isolated. All of the drivers and all of the passengers were then combined into one table and the mean frequencies for the injuries were documented. A paired t-test was then performed in Past (Paleontological Statistics Version 2.02).

### 3.5. Ethical and Radiological Clearance and Permission

Application to the Human Research Ethics Committee (Medical) for clearance of research was performed on 6 April 2011 and was approved unconditionally on 29 April 2011 (Refer to Appendix E, Figure 7.7).

Bioethical application for the use of biohazardous material in a research project was submitted on 4 April 2011 and was granted on 8 April 2011.

Permission from The head of the Department of Forensic Medicine and Pathology was granted in January 2011 (Refer to Appendix E, Figure 7.8).

## 4. Results

*This section is comprised of the results gathered from the data collection. The results are displayed in the form of various explanations as well as graphs and accompanying illustrations where necessary.*

### 4.1. Data Exclusions

The exclusion of five individuals was due to a variety of factors. One individual was deduced to have demised as a result of a myocardial infarction, which was classified as a “natural death”. In addition, the said individual sustained no external, visceral, or skeletal injuries and was consequently excluded from the sample. Another individual did not undergo a complete autopsy owing to the extensively mutilating nature of the injuries sustained. This individual incurred multiple traumatic amputations of the extremities, transection of the torso and complete destruction of all the body parts. The viscera had become exposed and traumatically mutilated as a result of the collision and could not be easily discerned. Therefore, the attending Forensic Medical Practitioner did not perform a complete autopsy and consequently no specific visceral or external injures were documented. The third excluded individual was noted in the Police report, to have been the driver of a motorized scooter and therefore did not fit the criteria of having been a vehicle occupant at the time of the collision and was as a result, excluded from the sample. Two other individuals were determined, from the Police reports, to have been pedestrians and not occupants of a vehicle at the time of the collision and were therefore also excluded from the sample.

### 4.2. Overview and Demographic Trends

The sample consisted of 124 individuals involved in fatal motor vehicle collisions collected over a period of one year. There were five exclusions from the

data set included the following cases: one individual who was found to have sustained a myocardial infarction, another who did not undergo a complete autopsy, another who was found to have been the driver of a motorcycle and two who were later found to have been pedestrians. Therefore, 119 individuals were found to fit the inclusion criteria of this study. Of these individuals, 85.1% (n=102) were male and 14.9% (n=17) were female (Figure 4.1). The racial distribution of the sample was as follows: 76.5% (n=91) were black, 16.8% (n=20) were white, 5% (n=6) were coloured and 1.7 % (n=2) were Asian (Figure 4.2). The individuals' ages ranged from 18 to 75 with an average age of 35.5 years (Q1 = 27, Median (Q2) = 35, Q3 = 44). Figure 4.3 displays the prevalence of the different age ranges for this sample. The majority of the individuals in this study were between 35 and 39 years of age.

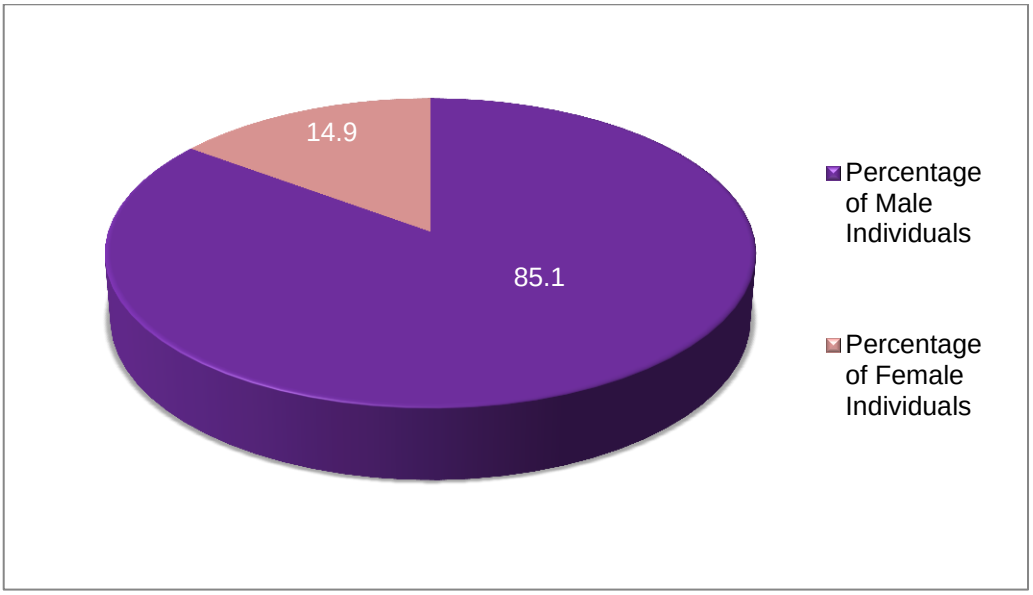



Figure 4.1: Pie chart demonstrating the sex (%) distribution for individuals involved in fatal motor vehicle collisions (n=119)

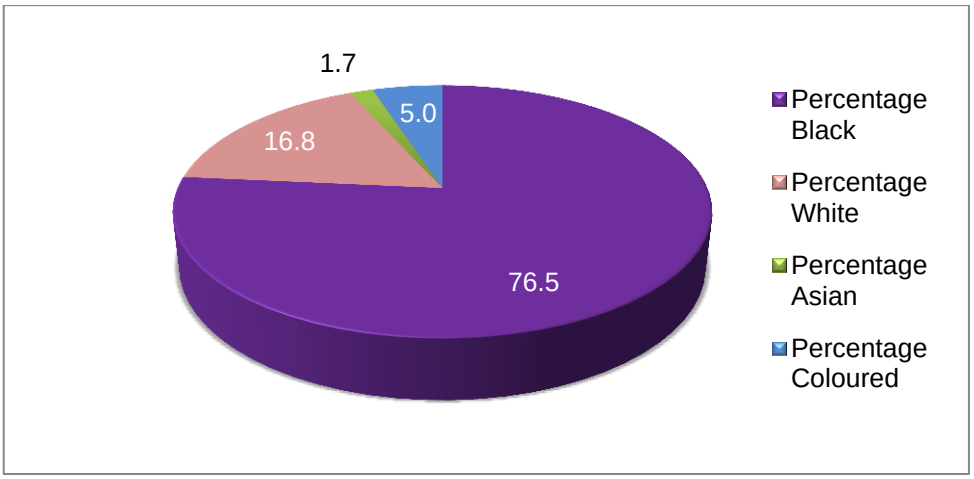



Figure 4.2: Pie chart demonstrating the percentage race distribution for individuals involved in fatal motor vehicle collisions (n=119)

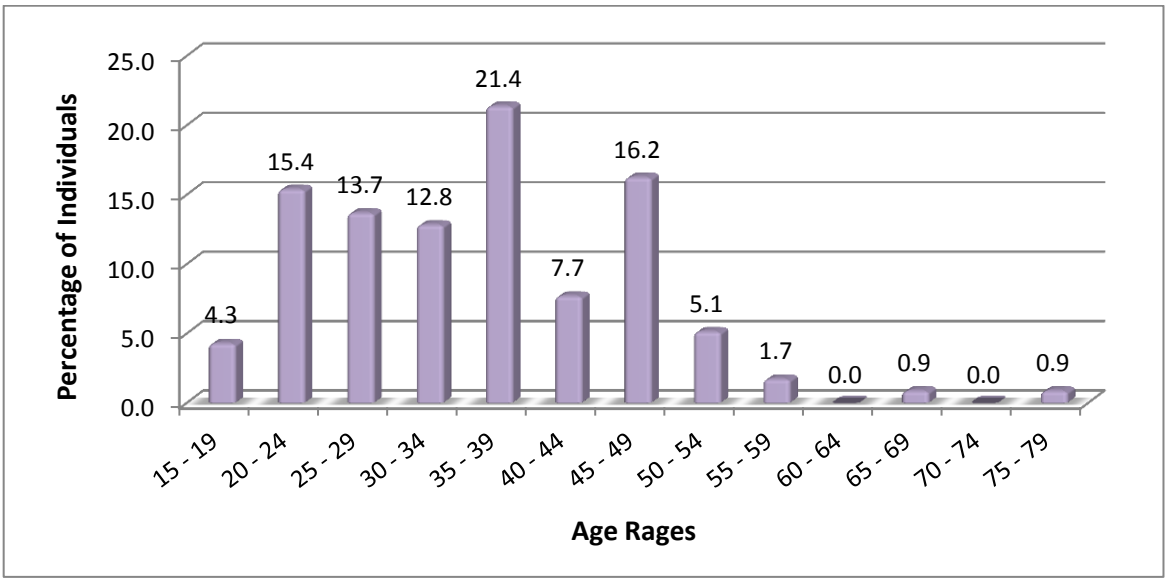



Figure 4.3: Bar graph displaying the age group distribution, by percentage of individuals, for individuals involved in fatal motor vehicle collisions (n=119)

## 4.3. Seasonal Trends

It was determined that fatal motor vehicle collisions tended to occur more frequently between 19h01 and 20h00 (8.4%) and 22h01and 23h00 (8.4%), as well as between 05h01 and 06h00 (7.4%) and 06h01 and 07h00 (7.4%) (Figure 4.4). It was also determined that most fatal MVCs occurred on a Sunday (20.6%),

followed by a Saturday (18.6%) and a Friday (17.5%) as is seen in Figure 4.5. It was also noted that the most common times for fatal MVCs to have occurred on Sundays was between 05h01 and 06h00, and 18h01 and 19h00; on Saturdays between 03h01 and 04h00, and 19h01 and 20h00; and on Fridays between 22h01 and 23h00, and 23h01 and 00h00. These time of day trends for Fridays, Saturdays and Sundays is depicted in Figure 4.6.

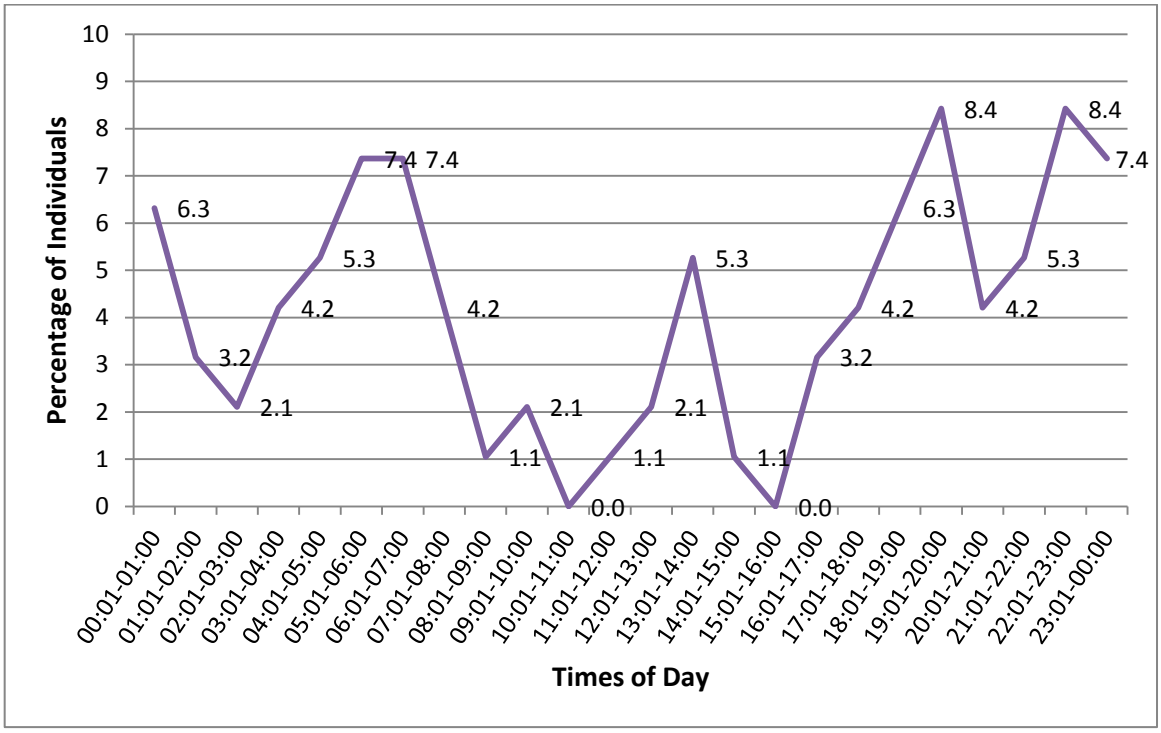



Figure 4.4: Lie graph displaying the distribution (in percentage) of the time of day for fatal motor vehicle collisions (n=119)

October (21.6%) was found to be the most common month of the year by a substantial margin in this study, as is displayed in Figure 4.7.

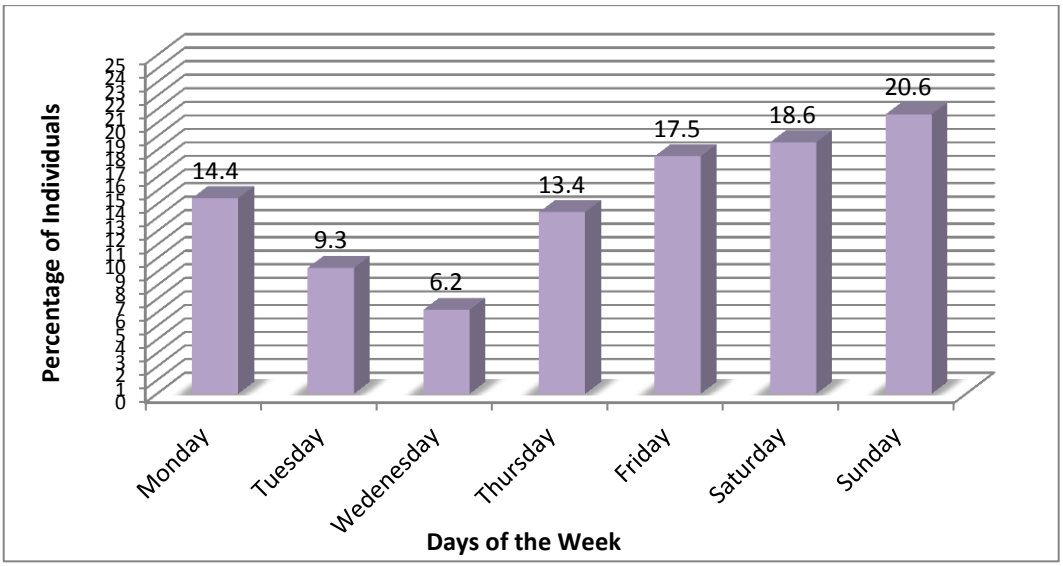



Figure 4.5: Bar graph displaying the day of the week distribution (by percentage of individuals) for fatal motor vehicle collisions (n=119)

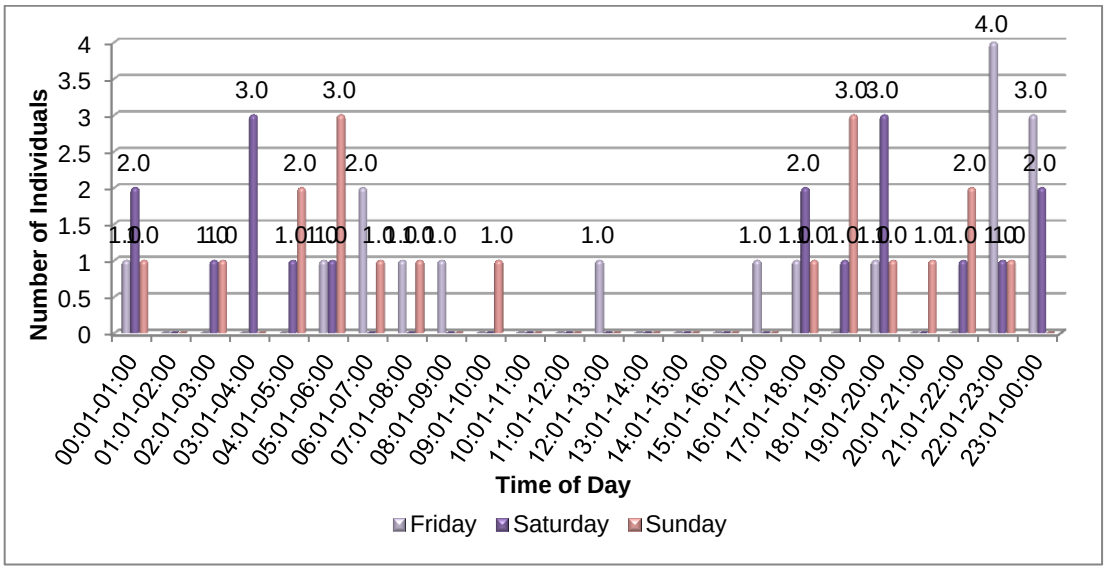



Figure 4.6: Bar graph displaying the distribution (frequency of individuals) of the time of day for the three most common days of the week on which fatal motor vehicle collisions occurred (n=119)

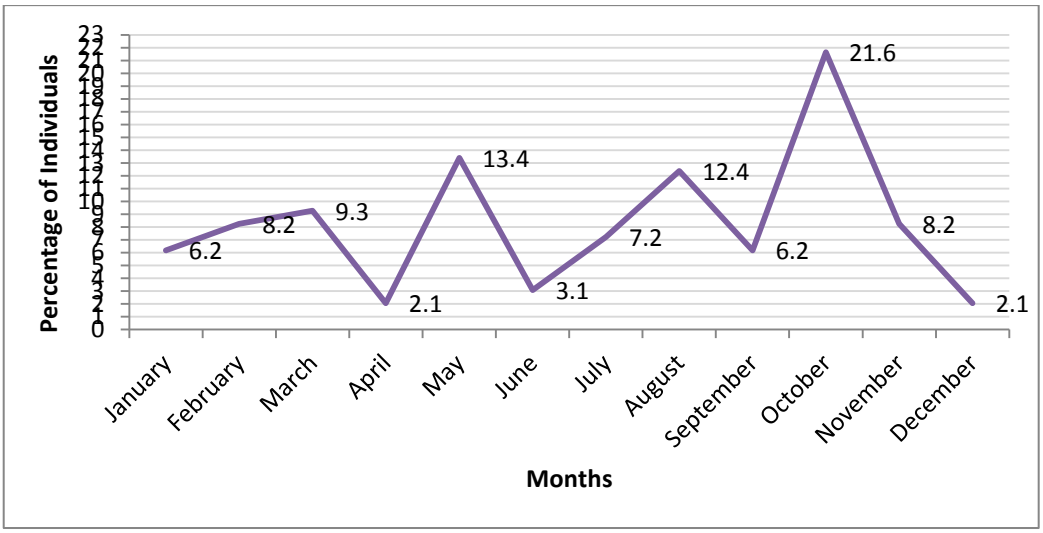



Figure 4.7: Bar graph displaying the monthly distribution (by percentage of individuals) for fatal motor vehicle collisions (n=119)

*Due to the nature and quality of the JMPD and SAPS reports, information was only available for 77 individuals included in this study and because some of these individuals were in the same vehicle at the time of the collision, only 62 collisions/circumstances will be discussed under the following headings.*

## 4.4. Vehicle Type Trends

The most common type of vehicle involved in a fatal MVC in this study was a passenger vehicle, accounting for 45.2% of all cases. Only one individual was noted to have been the occupant of an SUV involved in a fatal MVC. The distributions of the different types of vehicles are noted in Figure 4.8.

The most common make of vehicle to be involved in fatal MVCs in this study was Toyota (24.2%), followed by Volkswagen (11.3%). The distribution of the different vehicle makes are displayed in Figure 4.9. Of the Toyota vehicles, the most common model was the Corolla however; the most common vehicle type was the Minivan/Taxi (MV/Taxi), which included Toyota Quantums and Toyota

Siyayas. The distribution of the models of Toyota vehicles involved in fatal MVCs is displayed in Figure 4.10.

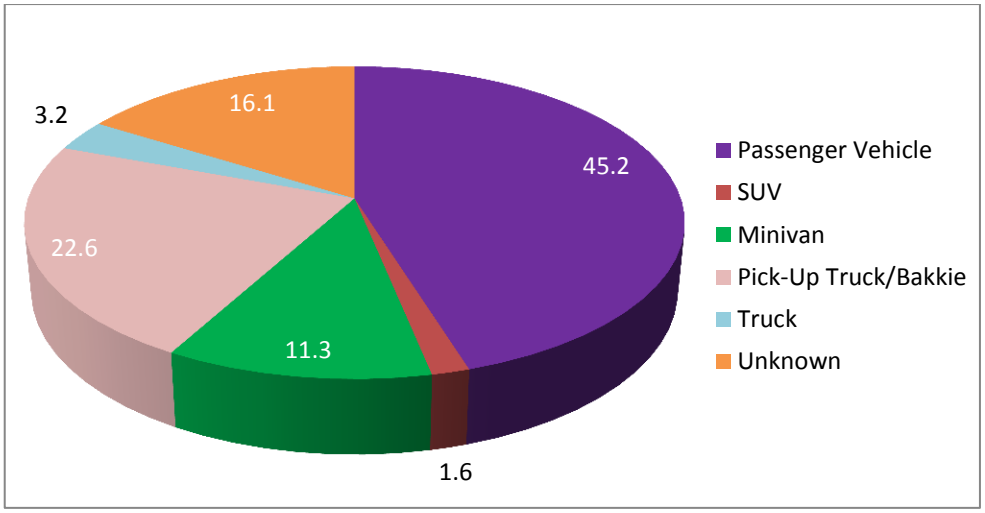



Figure 4.8: Pie chart displaying the distribution of the percentages of vehicle types involved in fatal motor vehicle collisions (n=62)

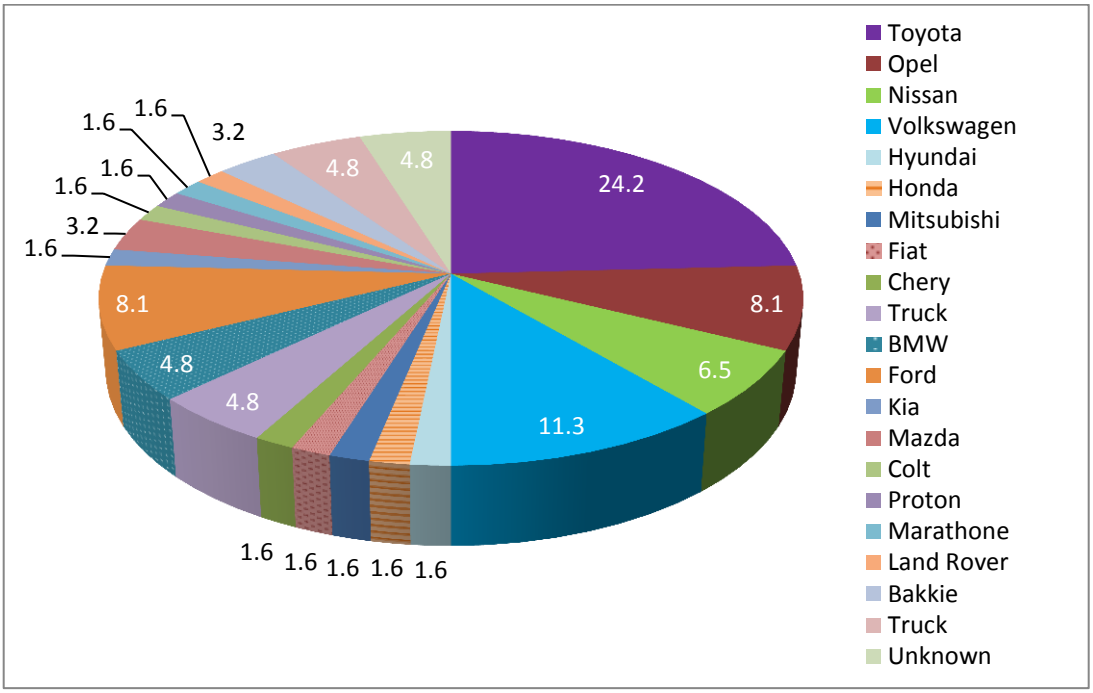



Figure 4.9: Pie chart displaying the distribution of the vehicle makes, in percentages, involved in fatal motor vehicle collisions (n=62)

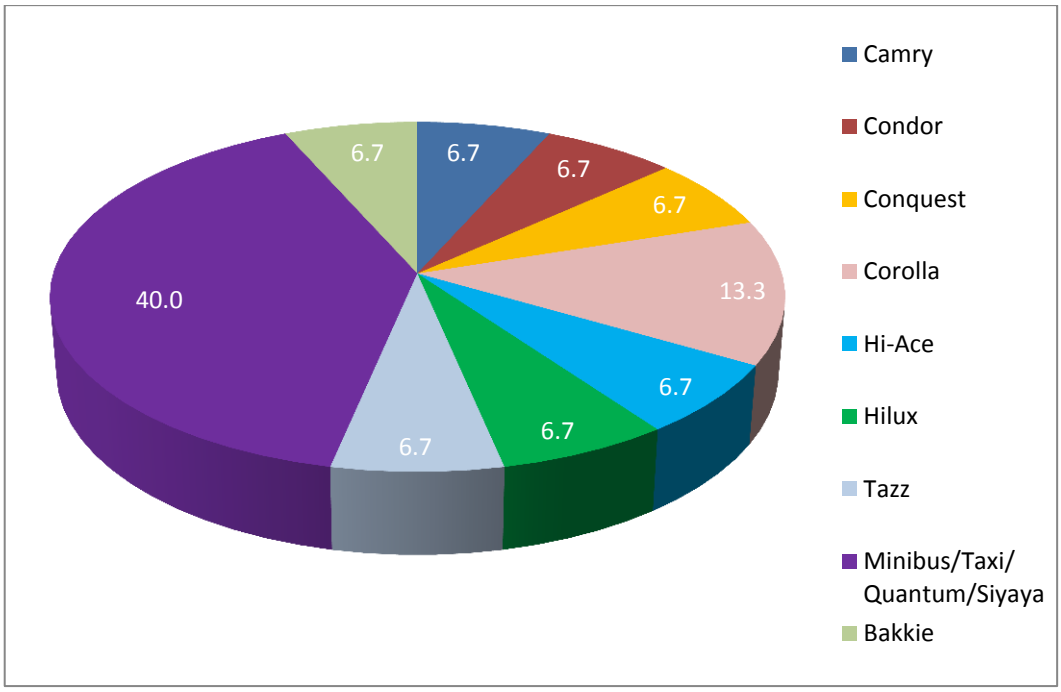



Figure 4.10: Pie chart demonstrating the distributions by percentage of the Toyota vehicles involved in fatal motor vehicles collisions (n=15)

## 4.5. Collision Type Trends

The direction of impact was rarely noted in the Police reports and for this reason cannot be tested for statistical significance with respect to the injury patterns noted in the individuals included in this study. Of the 62 collisions, 16.1% (n=10) were reported as being front-impact collisions, 1.6% (n=1) were rear-impact collisions and 3.2% (n=2) were right lateral impact collisions. No left lateral impact collisions were reported in this study. In 22.6% (n=14) of cases the vehicle was noted as having 'overturned' or 'rolled'. In one case this was described to have occurred as a result of the right rear tyre bursting and the driver not maintaining control of the vehicle. For the remaining 56.5% (n=35) of collisions no direction of impact was noted.

With respect to the object or other vehicle involved in the collision, 54.8% (n=34) of collisions involved another vehicle, 12.9% (n=8) involved an object, 1.6% (n=1) involved both another vehicle and an object, and in 14.5% (n=9) it was not documented whether another vehicle or object was involved in the collision.

Of the 35 collisions involving other vehicles, 37.1% (n=13) involved passenger vehicles, 17.1% (n=6) involved PU/Bakkies, 8.6% (n=3) involved MVs, 17.1% (n=6) involved Larger Trucks, 5.7% (n=2) involved SUVs, 2.9% (n=1) involved a bus, and 11.4% (n=4) involved multiple vehicles. In one (2.9%) incident a pedestrian was involved in addition to two other vehicles, a steel barricade and a lamp pole.

Of those 9 collisions involving stationary objects, the most common were walls, bridges, and lamp poles. Each of these were noted to have been involved in 22.2% (n=2) of cases respectively. Other objects included trees, bushes, a steel barricade, and palisade fencing.

### 4.4.1. Trends in the Different Vehicle Type Pairings during Collisions

In a two vehicle collisions the vehicles involved are referred to as “paired” in a collision. The different kinds of “pairings” include the vehicle that the individuals included in the study were travelling in and the other vehicle involved in the collision. Of the 35 collisions involving more two (or more) vehicles, the type of both the vehicle in which the decedent was occupying as well as that collided with was known in 29 circumstances. The most common pairing was between two passenger vehicles in 24.1% (n=7) of collisions. This was followed by PU/Bakkie and passenger vehicles in 10.3% (n=3) of circumstances.

### 4.6. Trends in the Position of Occupancy during a Collision

The position of occupancy was easily noted in the majority of the SAPS and JMPD reports but, in circumstances where more than one individual demised in a single collision, the position of occupancy was not easily discernible for each individual. For example, four individuals were received by the Germiston FPS from one collision and, the position of occupancy was not noted in the SAPS report for any of the individuals. Of the 77 individuals involved in fatal MVCs where collision information was collected, 46.8% (n=36) were noted to have been the driver of the vehicle, 10.4% (n=8) were front-seat passengers, 11.7% (n=9) were rear-seat passengers and in 31.2% (n= 24) of cases, the position of occupancy was not noted.

### 4.7. Safety Feature Trends

The safety features utilised by individuals involved in fatal MVCs included in this sample, were not documented by the attending Police officers and therefore no information was available.

### 4.8. Injuries

(Please refer to Appendix C for Grading)

#### 4.8.1. External and/or Soft Tissue Injuries

External and/or soft tissue injuries were most frequently noted on the left side of the forehead (41.2%; n=49), followed by the left frontal region of the scalp (38.7%; n=46) and the anterior thoracic region (37 %; n=44). The most frequent external and/or soft tissue injuries, in all regions, were Grade 1 (Mild, superficial epidermal injuries including contusions, abrasions and superficial Lacerations. Involving only the superficial skin)

#### 4.8.1.1. External Injuries of the Craniocerebral Region

The scalp was assessed separately from the face. The left frontoparietal region was observed to be the most frequently injured region of the scalp. Although Grade 1 injuries were the most common, Grade 2 – 4 injuries were also observed. It was found that of those individuals who sustained external injuries to the left frontoparietal region (n=49) 75.5% sustained Grade 1 injuries, 14.3% Grade 2 injuries, 6.1% Grade 3 injuries, and 4.1% Grade 4 injuries. The Grade 4 injuries noted, presented with complete mutilation of the cranium and extrusion of the brain matter though gaping lacerations.

Grade 4 injuries were only noted in two individuals in this study (Individuals A and B), who presented with complete destruction of the cranium and extrusion of the brain matter though skull fractures and gaping scalp lacerations. Individuals A, the driver of a vehicle involved in a rollover collision, sustained Grade 4 injuries to the entire left side of the head and face including the left frontal, parietal and temporal regions, the left cheek, the left mental region, the submental region, the left eye, the left ear, the nose, and both the upper and lower lips. Individual B, a front-seat passenger in a separate collision, sustained Grade 4 injuries to the frontal and parietal regions. The driver of the vehicle in which individual B was travelling (Driver B), was noted to have sustained Grade 1 injuries to the face and left temporal regions and a Grade 3 injury to the right parietal region of the scalp. Although Driver B sustained head trauma, the incurred external injuries were much less severe than those of individual B. Figure 4.11 depicts the injuries sustained by Individual B and the driver of the vehicle.

The cheeks and both sides of the forehead were noted to have been injured in approximately a quarter of individuals included in this study. The remainder of

the face (ears, eyes, nose, mouth, chin and the submental region) was not frequently injured, with less than 13% of individuals presenting with injuries to any of these regions. The frequencies of external and/or soft tissue injuries to the various regions of the head are displayed in Figure 4.12.

(a)  (b) 

Figure 4.11 Photographs of the driver (a) and front seat passenger (b) involved in a collision in the same vehicle, demonstrating the variance in facial injury severity

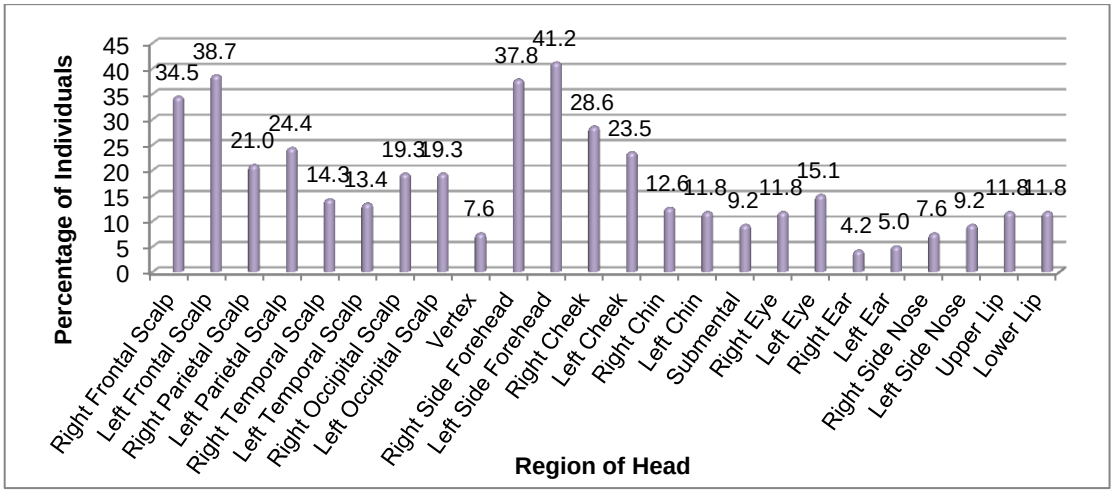



Figure 4.12: Bar graph displaying the percentages of individuals having sustained external injuries to the head while involved in fatal motor vehicle collisions (n=119)

### 4.8.1.2. External Injuries of the Neck Region

Few individuals presented with external and/or soft tissue injuries to the anterior and left lateral regions of the neck (10.1%; n=12), and even less so to the

right lateral (9.2%; n=11) and posterior regions of the neck (5%, n=6). Only Grade 1 and 2 injuries were noted, with 31.9% (n=38) and 2.5% (n=3) of individuals respectively. The Grade 2 injuries noted in the neck region were all isolated to the left lateral side of the neck.

#### 4.8.1.3. External Injuries of the Thoracic Region

When the thoracic region was considered as a whole, 52.1% (n=61) of individuals were found to have sustained external injuries to this region. However, a high frequency of external and/or soft tissue injuries was noted in this region. The anterior portion of the thoracic region was noted to have sustained one of the highest frequency of external and/or soft tissue injuries, where 37% (n=44) of individuals sustained injuries to this region. The lateral and posterior regions displayed injuries in less than 17% of individuals. Of those individuals that sustained external injuries to the anterior thorax (n=44) the most common were Grade 1 (90.9%, n=40) however, 6.8% (n=3) of individuals sustained Grade 2 injuries and 2.3% (n=1) sustained Grade 3 injuries to the anterior thoracic region.

#### 4.8.1.4. External Injuries of the Abdominal Region

The abdomen presented with external and/or soft tissue injuries less frequently than the thorax, with only 28.6% (n=34) of individuals noted to have sustained external and/or soft tissue injuries in this region. The most common region of the abdomen to be externally injured was the posterior aspect, followed by the anterior, left lateral and right lateral regions respectively.

#### 4.8.1.5. External Injuries of the Pelvic Region

Pelvic injuries were noted in 27.7% (n=33) of individuals. The most common external injuries were Grade 1 injuries however; some Grade 2 and 3 injuries were

also noted. The injury features of the pelvis were much like the abdomen, in that the posterior portion more commonly sustained external injuries. The anterior region however, was noted to have sustained the fewest external injuries in the pelvic region.

#### 4.8.1.6. External Injuries of the Upper Extremities

The left and right shoulder girdles displayed similar patterns with respect to external injury occurrences in the sample included in this study. Less than 11% of individuals sustained injuries to these regions. The anterior portion of both shoulder girdles was frequently injured externally (10.9% (n=13) = Left; 7.6% (n=9) = Right) whilst the posterior region was noted to have been the least frequently injured region. The superolateral surface of the right shoulder was more frequently injured than the anterior, posterior, and lateral regions of the shoulder girdle whereas the superolateral surface of the left shoulder was preceded only by the frequency of external injuries to the anterior region of the shoulder girdle.

The left and right arms displayed different injury frequency results. The left arm presented with the most frequently injured region being the posterior and lateral portions, whilst the right arm presented with the anterior and lateral portions being more frequently injured. The left arm displayed severe injuries, with one individual (0.8%) having sustained Grade 4 injuries, whilst the right upper arm displayed less severe, Grade 1, 2 and 3 injuries.

Although the elbows were not frequently injured in the individuals included in this sample, the left elbow was more frequently injured than the right elbow. Both elbows presented mainly with Grade 1 type injuries but Grade 2 and 3 injuries were noted in a few individuals.

The study revealed that the posterior region was the most commonly injured region of the forearm. The right posterior forearm was injured in 15.1% (n=18) of individuals which was slightly higher than that of the posterior left forearm, which presented in 13.4% (n=16) of individuals. Low incidences of injury to the anterior, lateral and medial portions of the forearms were observed.

The wrists were rarely injured and presented with injuries in 10.9% (n=13) to the right, 12.6% (n=15) to the left, and 0.8% (n=1) to both wrists.

The dorsum of the right hand (27.7%, n=27) was more frequently injured than the palmer surface (3.4%, n=4); the same was seen for the left hand (22.7% (n=27) and 2.5% (n=3) respectively). The right hand was observed to have more frequent external injuries than the left.

#### 4.8.1.7. External Injuries of the Lower Extremities

The right and left thighs displayed similar injury frequencies to the various regions of the thighs; however, the right thigh was more frequently injured than the left in almost all individuals. Both thighs indicated that the anterior portion of the thigh was the most commonly injured region (Left: 15.1% (n=18), Right: 17.6% (n=21)), followed by the lateral (Left: 12.6% (n=15), Right: 17.6% (n=21)), medial (Left: 10.1% (n=12), Right: 10.1% (n=12)), and posterior (Left: 3.4% (n=4), Right: 5.9% (n=7)) regions.

The left and right leg regions of the lower extremities displayed similar patterns and similar injury frequencies to one another. The anterior portion of the leg was more commonly injured than any other region of the leg (Left: 21.8% (n=26), Right: 18.5% (n=22)) and the posterior region was the least injured region (Left: 3.4% (n=4), Right: 3.4% (n=4)).

The posterior region of both knees did not present with any external injuries in any individuals. Again the anterior region of the knee was more frequently injured (Left: 11.8% (n=14), Right: 13.4% (n=16)) and in the right knee the medial region (Left: 12.6% (n=15), Right: 7.6% (n=9)) was less frequently injured than the lateral (Left: 8.4% (n=10), Right: 8.4% (n=10)). However, for the left knee the medial region was more commonly injured followed by the anterior and then lateral regions.

The ankles were not frequently injured externally. The left and right ankles displayed similar injury frequencies with the lateral region of the ankles being more commonly injured than any other region (Left: 6.7% (n=8), Right: 3.4% (n=4)). The left ankle was slightly more commonly injured than the right (Left: 13.4% (n=16), Right: 9.2% (n=11)).

The dorsal surfaces of the feet were more commonly injured than the plantar surfaces (Left Dorsal 8.4% (n=10), Left Plantar: 1.7% (n=2), Right Dorsal: 10.9% (n=13), Right Plantar: 0% (n=0)). The right foot presented more frequently with external injuries than the left foot (Left: 10.1% (n=12), Right: 10.9% (n=13)). The dorsum of the right foot presented with Grade 2 and 3 injuries whilst the dorsum of the left foot only presented with Grade 1 type injuries.

#### 4.8.1.8. External Injuries of the Genital region in Males

The males in this study were not noted to have sustained any internal damage to the external genitalia and were rarely noted to have presented with external injuries (6.7%, n=8), however the finding is still noteworthy. As with all other regions most of the external and/or soft tissue injuries were Grade 1 injuries

however, Grade 2 and 3 injuries were also noted. Figure 4.13 displays some of the different injuries noted to the external genitalia in this sample.

a)  b)  c) 

Figure 4.13: Examples of the three different grades of external injuries noted in individuals Included in this sample. a) Grade 1 - Mild external injury, b) Grade 2 – Moderate soft tissue injury involving skin and underlying structures c) Grade 3 - Severe soft tissue injury exposing viscera

### 4.7.1. Visceral Injuries

The most frequently injured viscus was the brain (66.4%, n=79), followed by the lungs (Left = 54.6% (n=65), Right = 56.3% (n=67)). The gall bladder was not noted to have been injured in any individuals. Although the lungs were the most frequently injured thoracic viscera, the heart was also noted to have been injured in 40.3% (n=48) of individuals.

The most frequently injured abdominal viscus was the liver (47.1%, n=56), followed by the spleen (27.7%, n=33).

The great blood vessels were divided into the ascending, arch, and descending portions of the thoracic aorta, the inferior vena cava, the abdominal aorta and other. The “other” category included the subclavian, femoral, iliac and renal vessels. In this study 20.5% (n=24) of individuals sustained injuries to the great blood vessels. The ascending aorta was not injured in any individual in this

sample. The descending thoracic aorta was noted to be most commonly injured vessel (11.8%, n=14). The percentage of individuals who presented with injuries to each viscus is demonstrated in Figure 4.14.

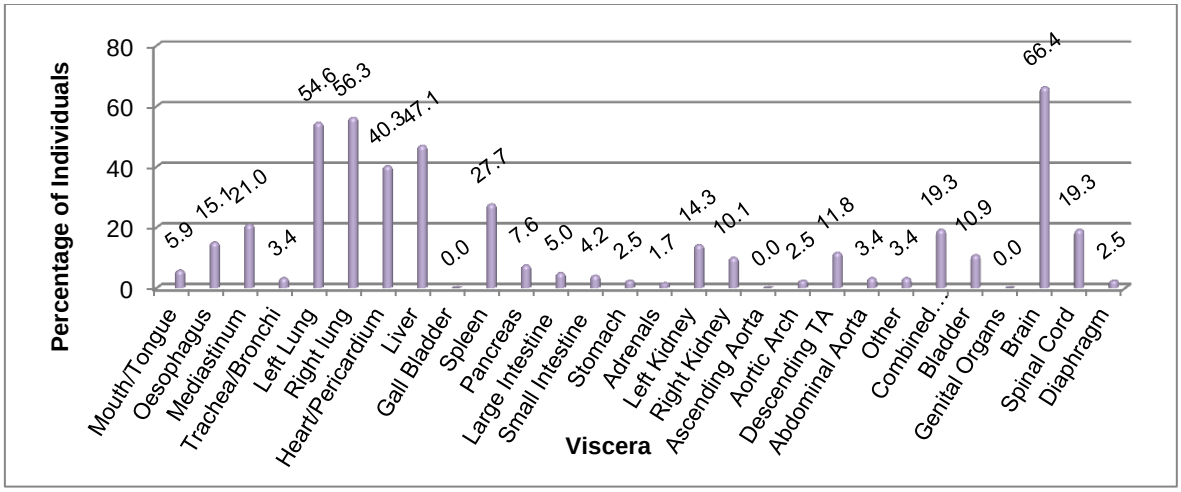



Figure 4.14: Bar graph displaying the percentages of individuals involved in fatal motor vehicle collisions who sustained visceral injuries (n=119)

### 4.7.2. Skeletal Fractures

The most frequently fractured bony elements were the base of the skull (39.5%, n=47) and the posterior portion of the left thoracic rib cage (39.5%, n=47), followed by the posterior portion of the right thoracic rib cage (37.8%, n=45).

The calvarium was noted to have been fractured in 35.3% (n=42) of individuals, the facial bones in 12.6% (n=15), the maxilla in 10.1% (n=12), and the mandible in 17.6% (n=21). Therefore, when all the components of the skull are considered in combination with the basal skull, the skull was deduced to be one of the most frequently fractured bony structure (51.3%, n=68) in MVCs overall. The percentage distribution of skull fractures is demonstrated in Figure 4.15.

Figure 4.16 displays the incidence of fractures to the various elements of the skull in drivers and passengers. It displays the difference between the

incidence of fractures to these different skull elements in all drivers and passengers regardless of whether or not they occupied the same vehicle or not.

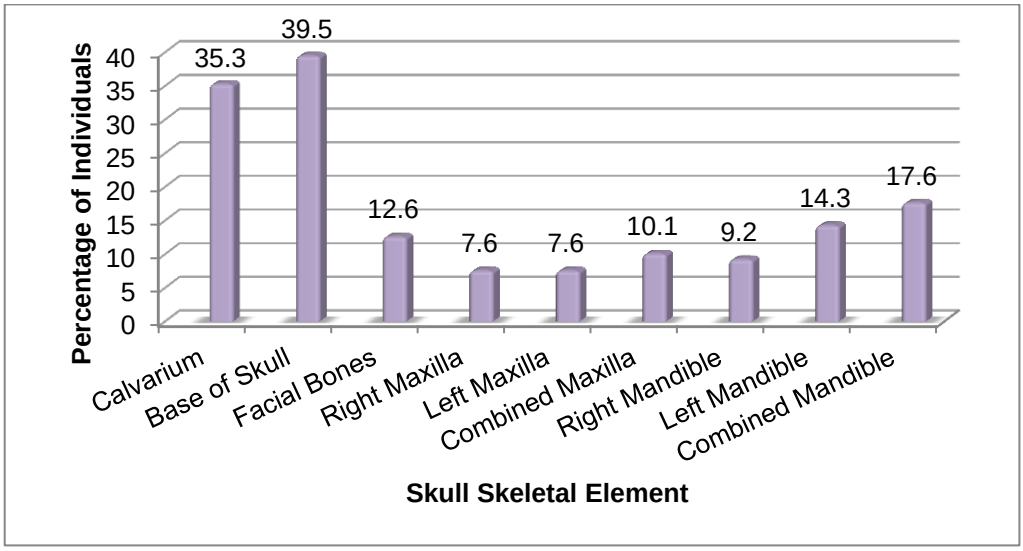



Figure 4.15: Bar graph displaying the percentages of individuals who sustained skull fractures while involved in fatal motor vehicle collisions (n=119)

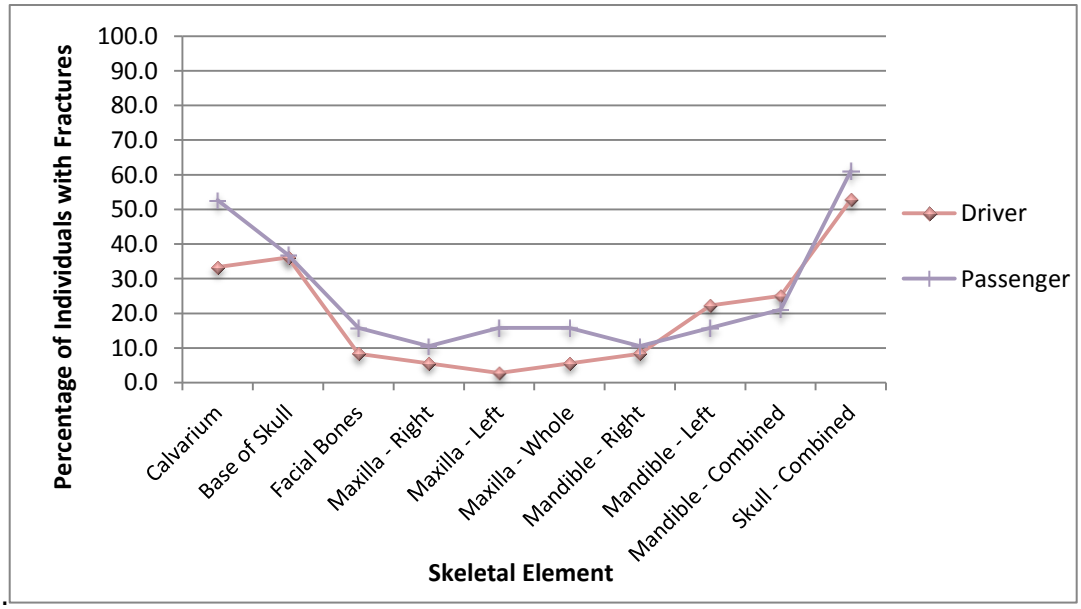



Figure 4.16: Line graph depicting the percentage of drivers and passengers having sustained skull fractures in fatal MVCs in this study.

Figure 4.17 displays the percentage of individuals who presented with fractures to the thoracic cage. Approximately a quarter or more of individuals presented with fractures to each region (anterior, left and right lateral and posterior) of the thoracic cage and 13.4% (n=16) to the sternum. When the thoracic cage is considered as a whole, 70.6% (n=84) of individuals were noted to have sustained fractures to one or more elements of the thoracic cage and/or sternum.

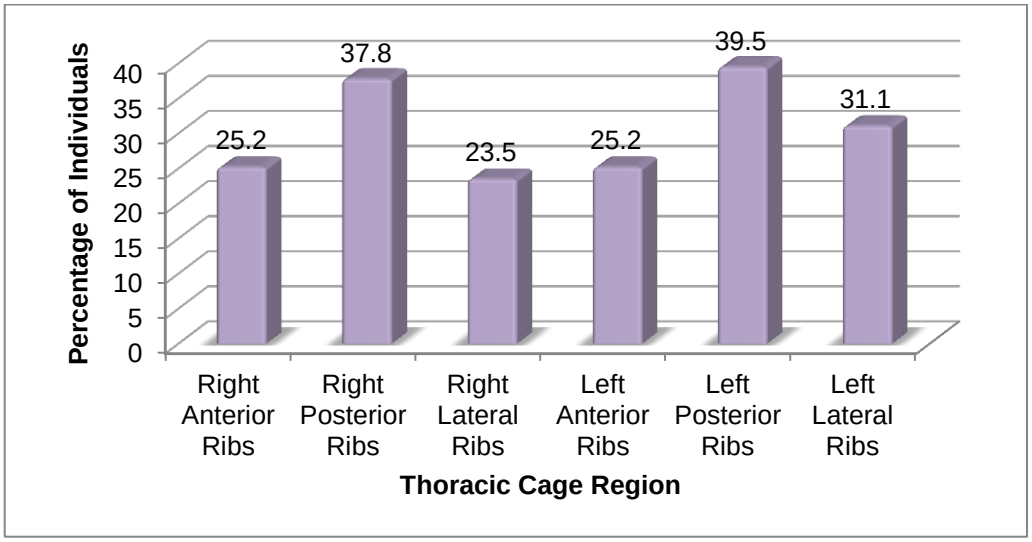



Figure 4.17: Bar graph displaying the percentages of individuals who sustained thoracic cage fractures to the different regions (n=119)

The spine was considered in three separate parts, namely the cervical, thoracic and lumbar regions. This study indicated that 7.6% (n=9) of individuals sustained cervical spinal fractures, 18.5% (n=23) thoracic spinal fractures and 0.8% (n=1) lumbar spinal fractures. Atlanto-occipital (AO) fractures were considered separately due to the specific nature of the mechanisms behind these fractures and 7.6% (n=9) of individuals were noted to have sustained AO fractures.

Of the 32.8% (n=39) of individuals that presented with pelvic factures the most frequently fractured regions were the right and left pubic bones having been noted in 14.3% (n=17) and 11.8% (n=14) of individuals respectively.

With regard to the limbs, it was noted that the right upper arm (from the shoulder to the elbow) was more frequently fractured than the left, and but the left distal arm (from the wrist to the fingertips) was more frequently injured than the right. In the forearm it was noted that more fractures occurred medially in the right forearm than the left forearm. It was observed that slightly more passengers than drivers sustained fractures of the humerus, radius, and ulna.

In the lower limbs, the femora and tibiae did not display and left- or right-sided trends; however the fibulae, patellae, and feet were more commonly fractured on the right side of the body. It was also noted that passengers more frequently sustained fractures to the femora and fibulae than drivers but drivers more frequently sustained fractures to the patellae, tibiae and feet.

### 4.8. Comparisons of the Injury Patterns in Specific Types of Vehicles

The injury patterns of individuals occupying different types of vehicles at the time of the collision were compared for the 77 individuals where the appropriate information was available from the SAPS and JMPD reports. In this study 35 individuals were noted to have been occupants of passenger vehicles at the time of the collision, 17 were in pick-up trucks/Bakkies, 10 individuals were in minivans, one individual was in an SUV, and three individuals were in larger trucks and for 11 individuals the type of vehicle occupied was unknown.

A single-factor ANOVA was run at this point to determine if any statistical differences could be noted between all of the injury patterns (external, visceral,

and skeletal) for individuals occupying different types of vehicles. The single-factor ANOVA result was calculated to be P=0.48 including the SUV occupant, and P=0.23 excluding the SUV occupant. Therefore, it was deduced that the external, visceral, and skeletal injury patterns were not statistically significant in individuals occupying different vehicle types.

### 4.8.1. Comparisons of the External Injury Patterns in Specific Types of Vehicles

A comparison of the external injury frequencies between passenger vehicle, PU/Bakkie, MV, SUV, and larger truck occupants was performed using a two-factor ANOVA without replication (95% confidence interval). The result of the two-factor ANOVA without replication was significant (p=0.04) for the external injury patterns of individuals utilizing different types of vehicles.

Due to the fact that there was only one SUV occupant in this study, which may have altered the ANOVA, another two-factor ANOVA without replication was performed for the passenger vehicle, PU/Bakkie, MV and larger truck occupants, excluding the SUV occupant. A statistically significant difference was again noted for the external injury patterns of the occupants of these vehicles ($p=2.45x10^{-15}$).

A single-factor ANOVA was also run to note if the number of injuries varied in individuals occupying different vehicles and it was determined that the difference was significant (p=0.02). In addition when the SUV occupant was excluded and another single-factor ANOVA run, the result was also significant (p=0.0004). Consequently, it was concluded that the number of external injuries sustained by individuals in this study in different vehicles was significantly different.

### 4.8.2. Comparisons of the Visceral Injury Patterns in Specific Types of Vehicles

A two-factor ANOVA without replication (95% confidence interval) for the visceral injury frequencies for the passenger vehicle, PU/Bakkie, MV, SUV and larger truck occupants was performed and was found to have been significant ($p=2.8x10^{-08}$). Therefore, a significant difference in the visceral injury patterns of individuals in different vehicles was noted.

The SUV occupant was again excluded and a second two-factor ANOVA without replication was run. The result was noted to have been significant ($p=8.63x10^{-10}$) and as a result the visceral injury patterns were noted to have varied for occupants of passenger vehicles, PU/Bakkies, MVs, and larger trucks.

The single-factor ANOVA run was used to determine if the number of visceral injuries varied in individuals occupying different vehicles. It was found that the results were not significant both including ($p=0.81$) and excluding ($p=0.52$) the SUV occupant. Therefore, the number of visceral injuries sustained by individuals in different vehicles was similar in this study.

### 4.8.3. Comparisons of the Skeletal Fracture Patterns in Specific Types of Vehicles

The skeletal fracture pattern two-factor ANOVA without replication for passenger vehicle, PU/Bakkie, MV, SUV and larger truck occupants displayed a significant difference ($p=7.58x10^{-11}$). With the exclusion of the single SUV occupant the two-factor ANOVA without replication for the passenger vehicle, PU/Bakkie, MV and larger truck occupants was also significant ($p=1.43x10^{-18}$).

Consequently, skeletal fracture patterns differed between individuals occupying different types of vehicles both including and excluding the SUV occupant.

A single-factor ANOVA was run to conclude whether the number of skeletal fractures in individuals occupying different vehicles was similar. The result calculated was not significant ($p=0.52$) and therefore it was found that the number of skeletal fractures in individuals in different vehicles in this study sustained similar numbers of fractures. The result was unchanged with the exclusion of the SUV occupant ($p=0.76$).

## 4.9. Comparisons of the Injury Patterns of Individuals with Regard to their Position of Occupancy

Injury patterns of all the drivers and passengers, regardless of whether they occupied the same vehicle or not, were compared for the 77 individuals where appropriate information was available. Thirty-six individuals were stated to have been the driver of the vehicle at the time of the collision and 19 individuals were known to be passengers at the time of the collision. Eight of those passengers were noted to have been front-seat passengers, nine were rear-seat passengers, and two were unspecified passengers. For the remaining 22 individuals the position of occupancy was not known.

### 4.9.1. Comparisons of the External Injury Patterns of Individuals with Regard to their Position of Occupancy

For the external injury pattern comparison between all drivers and passengers the unpaired t-test was found to have been significant ($p=0.02$). This therefore, demonstrated that a statistically significant difference in the external injury patterns in drivers and passengers existed. Drivers were found to have

sustained more external injuries (Grade 1 and 2) to the thoracic and abdominal regions than passengers, whereas passengers more frequently sustained injuries to the head (Grade 1 to 4) than drivers. In addition, drivers were noted to have sustained more severe external injuries (Grade 3 and 4) than passengers (Grade 1 and 2).

### 4.9.2. Comparisons of the Visceral Injury Patterns of Individuals with Regard to their Position of Occupancy

The unpaired t-test for the visceral injury patterns of drivers and passengers was not significant (p=0.5). This therefore, demonstrated that the visceral injury patterns in drivers and passengers, irrespective of whether they occupied the same vehicle at the time of the collision or not, were statistically similar.

Drivers were noted to have sustained more mouth/tongue, mediastinum, right lung, heart/pericardium, liver, spleen, stomach, and diaphragm injuries than passengers, but passengers were found to have sustained more oesophageal, tracheal, left lung, pancreatic, intestinal, kidney, aortic, bladder, brain, and spinal injuries than drivers.

### 4.9.3. Comparisons of the Skeletal Fracture Patterns of Individuals with Regard to their Position of Occupancy

The skeletal fracture patterns were compared between all drivers and passengers and the unpaired t-test was found not to have been significant (p=0.30). For that reason, the skeletal fracture patterns were not statistically different in drivers and passengers of vehicles involved in fatal MVCs.

## 4.10. Comparisons of the Injury Patterns of Drivers and Passengers in the same Vehicle

The injury patterns of those drivers and passengers who occupied the same vehicle at the time of the collision were compared using paired t-tests. Of the 77 individuals where appropriate information was available, only four pairs of individuals were determined to have been the driver and passenger from the same vehicle. Another triplet of the sample was excluded, as, although they all demised in the same collision in the same vehicle, they were all rear-seat passengers. All four of the driver-passenger pairs were found to have been the driver and front-seat passenger from the same vehicle at the time of the collision.

### 4.10.1. Comparisons of the External Injury Patterns of Drivers and Passengers in the same Vehicle

The results obtained from the paired t-test performed for the external injuries was $P=0.2$ ($P>0.05$) and therefore the external injury patterns, of drivers and passengers occupying the same vehicle, were found to have been statistically similar.

### 4.10.2. Comparisons of the Visceral Injury Patterns of Drivers and Passengers in the same Vehicle

The paired t-test run for the visceral data of the driver-passenger pairs provided a P value of 0.4, and consequently the visceral injury incidences were found to have been statistically similar for drivers and passengers occupying the same vehicle.

### 4.10.3. Comparisons of the Skeletal Fracture Patterns of Drivers and Passengers in the same Vehicle

The paired t-tests performed for the skeletal fracture data produced a P value of 0.4. This result then displayed that the skeletal injury patterns for the drivers and passengers occupying the same vehicle was not statistically different from one another.

It is important to note that a sample size of four is extremely small and as a result the statistical results may have been influenced. A larger sample size may produce different findings to the above paired t-test results and in turn the statistical similarity or difference of the external, visceral and skeletal injury patterns in drivers and passengers occupying the same vehicle as well. However, from the results presented above, it was noted that the findings tend to both correspond and conflict with those noted in other studies. The significance of these similarities and dissimilarities will be further discussed.

## 5. Discussion

*This section is utilised to expand, explain, and discuss the results found in this study, and to compare the results with those found in other studies. The discussion is broken down in a similar format to the results section and will explain and analyse each sub-section in detail. It also includes a sub-section on the limitations experienced in this study and the investigator's recommendations regarding overcoming these limitations.*

*The following sub-sections are included in this discussion: a brief summary of the main findings, a general overview of the demographics of the individuals in this study, seasonal trends, vehicle type trends, collision type trends (including*

*vehicle pairing trends), and positions of occupancy trends, injuries (subdivided into external, internal and skeletal), comparisons of the injury patterns of individuals occupying different types of vehicles, comparisons of driver and passenger injury patterns, comparisons of injury patterns sustained by drivers and passengers in the same vehicle and the study's limitations, recommendations and proposed further research.*

The sample in this study comprised 119 individuals, 85.1% of whom were male and 14.9% of whom were female. Their ages ranged between 18 and 75 with an average age of 35.6 years. The sample consisted mostly of black individuals, followed by white, coloured and asian individuals respectively, which is aligned with the population demographics in Gauteng from 2011 (Statistics South Africa, 2012).

The seasonal trends displayed that higher frequencies of fatal MVCs occurred in October, mostly on Sundays followed by Saturdays, and more commonly in the evenings between 19h01 and 20h00, and 22h01and 23h00 and in the mornings between 05h01 and 06h00, and 06h01 and 07h00.

The most common vehicle type was found to have been passenger vehicles, and the most common vehicle make was Toyota.

Most of the collisions were noted to have been rollover collisions followed by front-impact collisions. The majority of the collisions involved a second vehicle however, 14.5% (including the collision in which a stationary object as well as another vehicle were involved) involved a stationary object. Most of the two-vehicle collisions involved two passenger vehicles. Of the collisions involving stationary objects, most involved a wall, a bridge, or a lamp pole. Most of the

individuals for whom collision data was collected were found to have been the driver, followed by unknown occupants, rear-seat and front-seat passengers respectively.

External and/or soft tissue injuries were noted to have occurred most frequently to the left side of the forehead, followed by the left frontal region of the scalp and the anterior thoracic region. Most of the external injuries were found to have been Grade 1. The brain and lungs were determined to have been the most commonly injured viscera; and the basal skull and the posterior portion of the left side of the thoracic rib cage the most commonly fractured skeletal elements.

Comparisons of the external, visceral, and skeletal injuries of occupants of passenger vehicles, PU/Bakkie, MV, SUV, and large trucks generally displayed significant differences. Therefore, this indicated that occupants of different vehicle types normally sustained different injury patterns.

Comparisons of the external, visceral and skeletal injuries sustained by drivers and passengers (irrespective of whether they occupied the same vehicle at the time of the collision or not) displayed only significant differences in the external injury patterns. The visceral and skeletal injury patterns were found not to have been significantly different.

Comparisons of the external, visceral and skeletal injuries sustained by drivers and passengers who occupied the same vehicle at the time of the collision, displayed no significant differences and therefore the injury patterns in drivers and passengers from the same vehicle were determined to have been similar.

## 5.1. Overview and Demographic Trends

As was noted five individuals were excluded for various reasons, of the 119 remaining individuals included in the sample, the majority were noted to have been black males, between the ages of 35 and 39. According to Statistics South Africa's Midyear Population Estimates of 2011, approximately 79.5% of the South African population was black and 48.5% were male. Of the black male population, approximately 15.5% were between the ages of 30 and 39 (Statistics South Africa, 2011). Therefore, the high number of black individuals between 35 and 39 years of age included in this study is in keeping with the population demographics of South Africa. The Medical Research Council/UNISA's National Injury Mortality Surveillance System (NIMSS) data in both 2009 and 2010 indicated that approximately four times more male individuals demised in transport-related incidents than females (Donson, 2010; 2012). This study displays a similar statistic where six times more male individuals were noted to have demised in MVCs than female individuals however; this study's sample is a subsample of the NIMSS 2009 and 2010 reports' sample (Donson, 2010; 2012). This study excludes individuals under the age of 18, those autopsied on weekends and public holidays as well as those received from hospitals, which the NIMSS studies do not. This may explain the slight discrepancy in the ratio of males to females in this study, versus those in the NIMSS reports. (Donson, 2010; 2012).

According to the 2009 NIMSS data, the most prevalent age range for fatal motor vehicle deaths (unspecified) was 35-39 years, for drivers it was 30-34 years and for passengers 25-29 years (Donson, 2010). The 2010 NIMSS data indicated that the most common age range for motor vehicle deaths (unspecified) to occur was 30-34 years, for drivers it was 30-34 years and for passengers it was 25-29

years (Donson, 2012). Tolonen *et al.* (1986) observed the most common age range in Finland between 1972 and 1982, to have been between 31 and 40 years of age (16.1%). Ndiaye *et al.* (2009), on the other hand, noted the most frequent age range in France between 1996 and 2004 to have been 20 - 29 years of age (30%), followed by 30 - 39 years of age (18.9%). This study however, determined the most prevalent age range to be between 35 and 39 years of age (Unspecified: 20-24 years; Driver: 35-39/45-49 years; Passenger: 45-49 years). Therefore, the most prevalent age range for individuals to demise in an MVC according to this study, varies slightly to that documented by the 2010 NIMSS data, as well as in France but is somewhat in keeping with the 2009 NIMSS data and the Finnish study. Again, this studies sample is a subset of the NIMSS sample and thus direct inference cannot be drawn between the two. These differences and similarities could be due to the diversities in the inclusion criteria in the various studies. For example, only individuals having demised directly as a result of cervical spinal injuries were included by Tolonen *et al.* (1986)., both surviving and deceased individuals were included by Ndiaye *et al.* (2009), and individuals of all ages, having demised at the scene of the collision, as well as in hospitals were included in the 2009 and 2010 NIMSS studies. In this study however, only individuals having demised at the scene of the collision were included.

### 5.2. Seasonal Trends

Figure 4.4 does not display any specific trends with regard to the prevalence of fatal MVCs and peak traffic times, as one would assume. The most frequent time of day for individuals to have demised in MVCs, in this study, was between 19h01 and 20h00 (8.4%), and 22h01 and 23h00 (8.4%) as well as between 05h01 and 06h00 (7.4%) and 06h01 and 07h00 (7.4%). Peak travelling

times in Johannesburg are generally between 06h30 and 08h30, and 16h00 and 18h00 (Bomikazi, 2012) and therefore, no overlap between the peak travelling times and the peak evening times of day for fatal MVCs, in this study, exists. On the other hand there is an overlap between the peak travelling times and the morning peak times for fatal MVCs to have occurred in this study. It is thought that during peak travelling times drivers would not be able to speed due to the heavy traffic loads and as a result MVCs occurring outside of the peak travelling times would be expected. This is thought to describe why the evening peak times for fatal MVCs to have occurred in this study were outside of Johannesburg peak travelling times. The morning overlap is thought to have occurred due to individuals driving home after a night out in which alcohol may have been consumed thus lowering their driving abilities. This would increase the chance of a collision occurring. On the other hand, the traffic in Johannesburg is beginning to get busier at about 06h30/07h00 (and may not yet be at peak travelling time capacity). Therefore, individuals may still speed even though there is a heavier presence of other vehicles. This increased speed in the presence of heavier traffic (due to peak morning travelling times) may have resulted in the increase in the number of fatal collisions between 05h01 and 07h00 in this study.

The 2009 NIMSS report (Donson, 2010) displayed the most common time of day for fatal transport-related incidents to have occurred, as being between 18h00 and 00h00, and in 2010 between 17h00 and 21h00. This study's finding regarding the most common time of day for fatal MVCs to have occurred corresponds to both the 2009 and 2010 NIMSS data (Donson, 2010; 2012). Therefore, little variance is evident between this study and the 2009 and 2010 NIMMS data in the time of day for fatal MVCs to have occurred, in South Africa.

Sunday was found to be the most common day of the week for fatal MVCs to have occurred (20.6%). This was followed by Saturday (18.6%) and then Friday (17.5%). According to the 2009 and 2010 NIMSS data, the most common day of the week for fatal transport-related incidents to have occurred was Saturday, followed by Sunday and then Friday (Donson, 2010; 2012). Therefore the NIMMS data, while being slightly different from that obtained in this study, shows that fatal MVCs are more likely to have occurred at the weekend as opposed to during the week (Donson, 2010; 2012). As was noted, the most common time on Sundays for fatal MVCs to have occurred was between 05h01 and 06h00, and 18h01 and 19h00. On Saturdays it was between 03h01 and 04h00, and 19h01 and 20h00, and on Fridays it was between 22h01 and 23h00, and 23h01 and 00h00. These trends showed that fatal MVCs in this study were more likely to occur late on a Friday night, in the early hours of a Saturday morning, on a Saturday evening, in the early hours of a Sunday morning and on a Sunday evening. These times display a distinct trend of occurring in the later evenings and early mornings on weekends. It is thought that these trends follow those of driving post weekend social gatherings where alcoholic drinks would in all likelihood have been consumed. This could not be confirmed in this study, because of the extreme delays in obtaining post mortem blood alcohol results from the Forensic Chemistry Laboratory in Gauteng.

In this study, October was noted to be the most frequent month of the year for fatal MVCs to have occurred by a substantial margin. In 2009, the NIMSS data revealed August as the most common month of the year for transport-related deaths to have occurred, followed closely by October (Donson, 2010). However, the 2010 NIMSS data displayed different monthly frequencies with March being

the most common month of the year for transport-related deaths to occur and October being the sixth most common month (Donson, 2012). This variation in the 2009 and 2010 NIMSS data as well as that obtained from this research emphasises the lack of a trend regarding the most common month of the year for MVCs to occur in South Africa (Donson, 2010; 2012).

### 5.3. Vehicle Type Trends

Passenger vehicles were found to have been the most common type of vehicle to be involved in fatal MVC's in this study. Siegel *et al.* (2001) observed a similar trend where of the 224 collisions involving two vehicles, 94.2% were passenger vehicles (sedan), and 9.8% (n=22) were SUV, MV or PU/Bakkie vehicles. Fredette *et al.* (2008) also noted a larger number of passenger vehicles involved in MVCs, stating that 67.3% of individuals occupied passenger vehicles, while 13.8% occupied PU/Bakkies, 9.3% MV's, 4.6% SUV's and 4.1% heavy trucks. In addition, Bener *et al.* (2006) found that 57.6% (n=656) of individuals occupied passenger vehicles and 42.4% (n=482) occupied four-wheel drive vehicles in their study. Therefore, the high incidence of passenger vehicle occupants being involved in fatal MVCs, in this study, is in keeping with international collision statistics. It is also in keeping with the high frequency of the use of passenger vehicles compared to other types of vehicles on the roads in South Africa (National Association of Automobile Manufacturers of South Africa, 2013).

Seventeen point one percent (17.1%) of individuals in this study were noted to have been occupants of PU/Bakkies, which was the second most common vehicle type category. This was found to have been higher than the 9.8% recorded by Siegel *et al.* (2001) and the 13.8% recorded by Fredette *et al.* (2008).

Therefore, the incidence of PU/Bakkie occupants involved in fatal MVCs in this study is higher than international studies. This was thought to be due to an increased percentage of PU/Bakkies that are unroadworthy in Gauteng, SA, than occur in other countries (National Association of Automobile Manufacturers of South Africa, 2013). Therefore, individuals would more easily be fatal injured and thus an increased frequency would be expected.

The incidence of fatal collisions involving SUV occupants in this study (1.6%) is far lower than the 9.8% documented by Siegel *et al.* (2001) and the 4.6% by Fredette *et al.* (2008). However, these studies were performed in the United States of America and Canada where the prevalence of SUVs in operation in 2008 was reported at 11.42% and 12% respectively (AftermarketNews.com, 2008; Office of Energy Efficiency and Natural Resources Canada, 2010). According to the Online WSJ Autosales, 94 498 new SUVs were purchased in the USA between January 2012 and January 2013, further increasing the proportion of SUVs on the road by another 9% (WSJ, 2013). In South Africa however, SUV usage is slightly lower at a recorded 8.9% of the total vehicles on the road (National Association of Automobile Manufacturers of South Africa, 2013). Therefore, the increased proportion of SUVs on the roads in the USA and Canada would account for the higher fatality statistics, as an increased proportion of SUVs would mean an increased likelihood of those SUVs being involved in fatal collisions.

In addition, the low incidence of SUV related fatalities could be due to the safety features SUVs possess, which prevent the deaths of their occupants. As was noted, SUVs have high self-protective and aggressive capabilities which may

have resulted in SUV occupants being injured, but not fatally, and consequently not being suitable for the inclusion criteria of this study (Fredette *et al.,* 2001).

The high incidence of Toyota vehicles involved in fatal collisions in this study was thought to have been due to the fact that Toyota manufactures many different minivan-taxi vehicles, which are renowned for being involved in collisions in South Africa (Govender & Allopi, 2006). Of the 24.2% (n=15) of Toyota vehicles involved in collisions in this study, 42.9% (n=6) were minivan-taxi type vehicles. The finding that the minivan-taxi type vehicles constituted the largest portion of the Toyota vehicles accounted for the high number of Toyota vehicles involved in fatal MVCs in this study.

### 5.4. Collision Type Trends

This study found the most frequent type of collision to be one in which the vehicle 'overturned' or 'rolled-over' (22.6%, n=14), followed by front-impact collisions (16.1%; n=10). The high incidence of rollover collisions was thought to have been due to a lack of reliable information surrounding the collisions. Inaccurate Police and/or witness statements may have altered the collision type categories and it is thought that if more accurate data could have been obtained then the overturned/rolled-over category may have been decreased in size and other categories increased.

Siegel *et al.* (2001) noted that of the collisions included in their sample, 75% (n=309) were front-impact collisions and 25% (n=103) were lateral-impact collisions. Fredette *et al.* (2008) found that 4.6% of collisions were front-impact (head-on) collisions and 33.7% were rear-impact collisions. Therefore, the prevalence of rollover and front-impact collisions in this study was not in keeping

with the international literature. This could be due to the misreporting or non-reporting of the type of collision and site of impact on the Police accident scene reports: in 73.4% of collisions in this study, no direction of impact was noted. However, the findings of Fredette *et al.* (2008) and Siegel *et al.* (2001) not only vary from this study's findings but also from one another's findings. This may have been due to variable inclusion criteria of the studies. Siegel *et al.* (2001) only included those individuals involved in front-impact and lateral-impact collisions while Fredette *et al.* (2008), included individuals involved in front, lateral, and rear-impact collisions as well as side-swipe, left and right turn conflict, right angle and other collisions. This study included individuals involved in front-, rear- and lateral-impact collisions and was the only study of the three to consider rollover collisions as well. It was thought that the inclusion of other direction-of-impact collisions accounted for the variance in this study's findings to those of the international studies. Further research and investigation on the type of collision in MVCs is required both in South Africa and abroad to shed light on these statistics and provide clarity on whether there are comparable trends between South Africa and other countries.

In this study 1.6% (n =1) of individuals were found to have been involved in rear-impact collisions. This low incidence was thought to have been distorted due to the inaccuracy of the provided accident scene reports. It was noted however, that rear-impact collisions are generally less severe and less common than front or lateral-impact collisions and therefore occur less frequently (O'Donnell & Connor, 1996; Zhang *et al.*, 1998). Fredette *et al.* (2008) noted that rear-impact collision incidences far exceeded front-impact collisions which is unusual, but it was noted that their study was not isolated to decedents but also included injured (ranging

from mildly to severely) surviving individuals. Since rear-impact collisions have been noted to be less severe, the likelihood of individuals surviving the collision is greater. Consequently, studies comprising surviving individuals may include more rear-impact collisions than those focusing on decedents and therefore the study by Fredette *et al.* (2008) may have included a larger number of rear-impact collisions than this study (Saukko & Knight, 2004).

It was noted in two-vehicle, collisions in this study, that the most common vehicle to have collided with was a passenger vehicle (34.3%, n=12) followed by a PU/Bakkie (17.1%, n=6). These findings were found not to have been similar to Siegel *et al.* (2001) where 54.5% (n=122) of collisions were found to have involved two passenger vehicles and 9.8% (n=22) involved an SUV, MV, or PU/Bakkie colliding with a passenger vehicle. The large number of collisions involving passenger vehicles, both the vehicle in which the decedent was travelling as well as the vehicle with which the decedent's vehicle collided, may be due to the large proportion of passenger vehicles on South African roads.

In collisions involving stationary objects, the most common were walls, bridges, or lamp poles. Ndiaye *et al.* (2009) noted that 23% of fatal collisions involved a vehicle colliding with a fixed object. The incidence of collisions with fixed objects in this study (14.5%, n=9) was lower than that of Ndiaye *et al.* (2009) but may have been underreported in the Police Accident Reports. In this study, only 9 cases documented the occurrence of a collision with an object other than another vehicle, whereas in 8.1% (n=5) of cases no documentation of the occurrence of a collision with any other vehicle or object was noted and in 22.6% (n=14) the vehicle was stated as having "overturned" or "rolled". Therefore, the

14.5% of collisions with fixed objects in this study was postulated to have been inaccurate due to incomplete Police accident scene reporting.

### 5.4.1. Trends in the Different Vehicle Type Pairings during Collisions

The majority of the 29 two-vehicle collisions, where the type of vehicle was known for both (or more) vehicles, involved two passenger vehicles (24.1%, n=7). This finding is in agreement with the finding of Siegel *et al.* (2001) where 54.5% of collisions involved two passenger vehicles. The second most common vehicle pairing in fatal collisions in this study involved PU/Bakkies being struck by passenger vehicles in 10.3% (n=3) of instances. Siegel *et al.* (2001) noted that 9.8% (n=22) of collisions involved an SUV, MV, PU/Bakkie vehicle being stuck by a passenger vehicle. Consequently, the incidence in this study is slightly higher than that of Siegel *et al.* (2001). This could be due to the inaccuracy of the Police data accounting for inaccurate statistics of vehicle pairings, or the proportion of roadworthy and unroadworthy PU/Bakkies in South Africa may exceed that of the USA. This discrepancy could also be due to the PUs/Bakkies themselves; the South African PU/Bakkies may have been smaller than those in the USA, therefore decreasing the weight difference between the passenger vehicles and the PU/Bakkie. This would allow for more damage to be inflicted on the PU/Bakkie by the passenger vehicle.

## 5.5. Trends in the Position of Occupancy during a Collision

In this study, it was noted that most of the individuals were drivers (46.8%). Of the 22.1% of individuals who were found to have been passengers, 10.4% were front-seat passengers and 11.7% were rear-seat passengers. For the remaining 31.2% of individuals, the position of occupancy was not noted. Törő *et al*. (2005) noted that of the 200 motor vehicle occupants, 59% (n=118) were drivers and 41%

(n=82) were passengers. Adams *et al.* (2003) noted that of the 50 individuals included in their study who sustained pelvic trauma, 48% (n=24) were drivers and 24% (n=12) were passengers (the remaining 28% (n=14) were pedestrians and motorcyclists). Pintar *et al.* (2007) noted that of their sample 71.7% were drivers and 28.3% were passengers. Therefore, this study is in keeping with international studies in that more drivers were seriously or fatally injured than passengers.

In addition the increased number of drivers involved in collisions was thought to have been due to the fact that in a collision, a driver is always present whereas a passenger is not. Consequently, there is a greater chance of a driver being injured or demising in a collision than a passenger and therefore it is expected that more drivers will demise in collisions than passengers.

## 5.6. Injuries

### 5.6.1. External and/or Soft Tissue Injuries

The most common external and/or soft tissue injuries noted in individuals included in this study were Grade 1 injuries. Few studies discuss the external injuries sustained by MVA victims, as they focus primarily on the severe or life threatening visceral and skeletal injuries that occur. Consequently, limited comparisons to other studies could be done.

Studies focusing on the injuries caused by airbags and/or their covers do note the different types of external injuries inflicted by these apparatus (Antosia *et al.*, 1995; Sato *et al.*, 2002; Smock & Nichols, 1995). These studies however, are not suitable for comparisons to this study as no airbag information was provided for the collisions included in this study.

In order to ascertain the frequency of external injuries in MVA victims in this study, all external injuries were grouped together for each body region, regardless of the injury grade. Consequently, the percentages represented the incidence of external injuries but did not detail the various grades of injuries. For example, the left side of the forehead was the most commonly injured region (41.2%, n=49), followed by the left frontal region of the scalp (38.7%, n=46) and the anterior thoracic region (36.9%, n=44). Even though the anterior thoracic region more frequently sustained Grade 1 injuries, the left side of the forehead sustained external injuries of all Grades. Of those individuals who sustained external injuries to the left side of the forehead (n=49), 75.5% of individuals sustained Grade 1 injuries, 14.3% sustained Grade 2 injuries, 6.1% sustained Grade 3 injuries, and 4.1% sustained Grade 4 injuries. However, for the anterior thoracic region (n=44), 90.9% of individuals sustained Grade 1 injuries, 6.8% sustained Grade 2 injuries, and 2.3% sustained Grade 3 injuries and none sustained Grade 4 injuries to this region.

The most common region noted to have sustained Grade 1 external injuries was the anterior portion of the thoracic region in 33.6% (n=40) of individuals, followed by the left side of the forehead in 31.1% (n=37) of individuals. These will be further discussed below.

Santamariña-Rubio *et al.* (2007) noted various external injuries in different regions of the body in drivers and passengers involved in MVCs. They noted the most common region to have sustained open wounds in both drivers and passengers was the head/neck, followed by the extremities. In drivers, they note the most common region to have sustained contusions as being the other/unspecified region followed by the head/neck, extremities, and then the

torso. In passengers, they note the most common region to have sustained contusions as being the head/neck, followed by the others/unspecified region, the extremities, and then the torso. No contusions were noted to the back/spine region in either drivers or passengers in their study. In this study however, most of the superficial injuries (Grade 1) occurred to the lumbar region (47.2%, n=17) followed by the anterior thoracic region (44.4%, n=16) in drivers, and the left frontal scalp region, the left side of the forehead, and the right cheek in passengers (29.4%, n=5 for each region). As a result, the external injury patterns sustained by MVC occupants in this study are fairly consistent with Santamariña-Rubio *et al.* (2007). The high incidence of external injuries to the head in passengers is similar in both studies. The external injuries in drivers in this study were noted to have been to the lumbar and anterior thorax, both of which are included in the torso region of Santamariña-Rubio *et al.* (2007). Therefore, the external injury patterns in drivers in this study and that of Santamariña-Rubio *et al.* (2007) are somewhat in keeping with one another.

The fact that the results in this study are similar to international studies results lends credence to the statement by Daffner *et al*. (1988) who indicated that since certain mechanisms of injury produce specific injuries, these injuries should be predictable and even reproducible. Therefore, the pattern of superficial external injuries to the anterior thoracic region of the body could be due to the drivers' thoracic region making contact with the steering wheel or even from the seatbelt itself (Daffner *et al.*, 1988; Saukko & Knight, 2004). The mild external injuries to the driver's lumbar region could be due to ejection incidents and consequent graze abrasions inflicted by the road surface or from the driver's body twisting slightly and the seatbelt clasp coming into contact with the drivers lower back.

Byard's (2002) case study documented the presence of external contusions in the two individuals however; the external injuries were not discussed in detail, whereas the skeletal and visceral injuries were.

#### 5.6.1.1. External Injuries of the Craniocerebral Region

The scalp and face were assessed separately in this study. The results displayed that the most commonly injured external region of the scalp was the left frontoparietal region, and of the face was the left side of the forehead. The injuries to these regions were primarily Grade 1 injuries. As was noted, only two individuals sustained Grade 4 injuries (Individuals A and B). Individual B, a front seat passenger, was noted to have sustained much more severe head injuries than the driver of the vehicle in which Individual A demised. Daffner *et al.* (1988) observed that passengers were likely to sustain more severe craniofacial injuries than drivers. This was noted to have been as a result of the passengers' head making direct contact with the windscreen, whilst the steering wheel as the first contact point (as occurs in drivers) would decelerate the driver thereby decreasing the force of impact between the drivers' head and the windscreen. The steering wheel could also prevent the drivers' head from making contact with the windscreen altogether. In Figure 4.11 the comparison of the injury severities for the above noted driver and the passenger can be observed.

The cheeks and forehead were noted to have been injured in more than a quarter of individuals in this study. The remainder of the face was less frequently injured with fewer than 16% of individuals presenting with injuries to any of the regions. According to Saukko and Knight (2004), the face frequently incurred obvious external damage in MVCs. They noted that this was due to contact between the face and the windscreen. In some instances, an individual's head

could breach the windscreen and the glass could cause incisions and/or lacerations. If the head did not penetrate the windscreen, the impact could result in tearing of the skin over the bony facial structures causing lacerations to the face (Saukko & Knight, 2004). Consequently, the relatively high incidence of facial injuries in individuals in this study is unsurprising.

#### 5.6.1.2. External Injuries of the Thoracic Region

The anterior region of the thorax was found to have sustained more Grade 1 injuries than any other region of the body. When the thoracic region was considered as a whole it was found that 52.9% of individuals sustained external injuries to this region. Santamariña-Rubio *et al.* (2007) noted that 2% of drivers and no passengers sustained open wounds to the torso, and 7% of drivers and 4% of passengers sustained contusions to the torso region. Therefore, this study noted far more external injuries to the thoracic region than Santamariña-Rubio *et al.* (2007). Although this study's Grade 1 injury category included contusions and mild, superficial abrasions and lacerations, the classification of the external open wounds by Santamariña-Rubio *et al.* (2007) did not specify the severity of their noted wounds. Their open wound category may have included more serious injuries, which would have been equivalent to the Grade 2 or 3 categories of this study. The number of individuals who sustained Grade 2 and 3 external injuries to the thoracic region in this study was 4.2% (n=5), which is similar to the low occurrence found by Santamariña-Rubio *et al.* (2007). It was therefore thought that the Santamariña-Rubio *et al.* (2007) study did not take into account superficial grazing of the skin but rather more severe external injuries only. Consequently, if the incidence of Grade 1 injuries in this study is excluded and only the more severe Grade 2 and 3 injuries are considered similar results can be noted.

This demonstrates the deficiency in studies noting the presence of mild external injuries in MVA victims. Although these injuries may not be a threat to the individual's life or prolong their recovery period, they do add to the injury patterns of MVA victims and are thus important to note. The injuries could be attributed to certain internal structures within the vehicle with injuring capabilities or specific injury mechanisms and therefore, if the collision information was available it may have aided in the understanding of external injury mechanics in MVCs.

#### 5.6.1.3. External Injuries of the Genital region in Males

Urogenital injuries have been noted in various transport injury related studies. However, a trend not reported before was noted in this study where 6.7% of occupants sustained injuries to the external genitalia (scrotum, penis, and testicles). Even though Grade 1 injuries were the most frequently noted, Grade 2 and 3 injuries were also sustained by the individuals included in this study. Paparel *et al.* (2005) noted that in traffic related accidents, 24% of individual's sustained testicular injuries, 8% scrotal injuries, and 11% penile injuries. However, their sample included not only motor vehicle accident victims, but victims of all traffic related accidents including "motorists, users of two-wheeled motorized vehicles, cyclists, pedestrians, van drivers, bus passengers and skateboarders" (Paparel *et al.*, 2006, p. 338). They noted that individuals in accidents involving two-wheeled motorized vehicles and bicycles were more likely to sustain injuries to the external genitalia than those individuals in motor vehicles. It was stated that these injuries resulted from upward crushing mechanisms where the external genitalia were compressed between the petrol tank or handlebars and the bony pelvis. Paparel *et al.* (2005) and Gimbergues *et al*. (1999) both stated that the driver compartment of a motor vehicle provided sufficient protection to the external genitalia and

therefore injuries were not often noted in motorists. However, rear seat passengers and individuals in multi-passenger vehicles such as minivan/taxis, do not have the same level of protection that the driver and front passengers have and as a result the external genitalia can be more readily injured. This is thought to have accounted for the incidence of external genital injuries in individuals in this study.

### 5.6.2. Visceral Injuries

The most frequently injured viscus in individuals in this study was determined to have been the brain (66.4%, n=79). The high incidence of cerebral injuries in MVCs has been noted in various studies throughout the world, as has the high incidence of lung injuries (Daffner *et al.*, 1988; Hendey & Votey, 1994; King & Yang, 1995; Ndiaye *et al.*, 2009; Nygren, 1983). The lungs were noted to have been the second most frequently injured viscera with 54.6% (n=65) of individuals sustaining injuries to the left lung and 56.3% (n=67) to the right lung.

In this study some of the viscera were noted to have sustained very few injuries, such as the stomach, adrenal glands, trachea and bronchi. Other viscera, such as the gall bladder, were noted to have suffered no injuries at all.

The cephalothoracic viscera were more frequently injured than the abdominocaudal viscera. For example, the brain (66.4%), lungs (left = 54.6%; right = 56.3%), and heart (40.3%, n=48) were frequently injured, but the abdominal and peritoneal viscera such as the spleen (27.7%, n=33) and kidneys (left = 14.3%, n=17; right = 10.1%, n=12) were less frequently injured.

#### 5.6.2.1. Injuries of the Cerebral Region

The brain was the most frequently injured viscus. A total of 66.4% of individuals sustained some form of cerebral injury, ranging from subdural, subarachnoid and extradural haemorrhages to lacerations, cortical contusions and even complete destruction of the brain matter in some circumstances. All cerebral injuries noted were considered to have contributed to the demise of the individual in some manner and the cause of death was determined to have been as a result of either “blunt force injury to the head” or “multiple blunt force injuries”.

The finding that brain was the most frequently injured viscus is comparable to international studies which noted that craniocerebral injuries were the most frequent injuries, along with thoracic injuries. Hendey and Votey (1994) noted one of the most commonly injured regions of the body in unbelted individuals to be the head. They also noted that the incidence of head injuries decreased in belted individuals.

Although Nygren *et al.* (1983) did not observe the head to be the most frequently injured region in their study; they determined that the majority of individuals involved in fatal MVCs demised as a result of the head trauma sustained.

Santamariña-Rubio *et al.* (2007) found that traumatic brain injuries (TBI) were the most commonly sustained injury with 78% of their sample presenting with TBI. However, the “head/neck” was only noted to be the second most commonly injured region with 44% of drivers and 59% of passengers sustaining injuries to this region. Other injuries to the head, face and neck were noted in only 45% of their sample.

Törő *et al.* (2005) described the different types of cerebral injuries and their incidences in 248 fatal motor vehicle collisions in Budapest. Their “motor vehicle occupant” category however, included motorcycle and moped (*pronounced as two syllables;* a type of low-powered motorcycle) scooter users in addition to motor vehicle users. They found that 40% of “motor vehicle occupants” sustained cerebral contusions, 22% subarachnoid haemorrhages, 11% subdural haemorrhages, and 1% epidural haemorrhages.

Daffner *et al.* (1988) noted that 16% of unrestrained drivers and 24.4% of unrestrained front seat passengers sustained skull and brain injuries, although they did not define the types of cerebral injuries observed. They detailed how the body of an unrestrained front seat occupant involved in a non-fatal MVC could incur various injuries. The head was noted to have been the second region of the body to make contact with the interior surface of the car, after the knees. Therefore the incidence of knee injuries was considered in combination with head injuries. The incidence of anterior external knee injuries in individuals in this study was 26.4% (for both knees) and the skeletal fracture incidence to the knee region was 3.3% (for both knees). Therefore, the high incidence of front-seat passenger and driver head injuries and the low incidence of knee injuries may indicate that a large number of the individuals in this study did not make initial contact with their knees, but rather with their head. Fifty percent (n=18) of the 36 known drivers and 54.5% (n=6) of the 11 known front seat passengers were found to have cerebral injuries. Unfortunately no comparison can be made between this study and the one conducted by Daffner *et al*. (1988), as their study’s findings included data on safety feature usage.

#### 5.6.2.2. Injuries of the Thoracic Region

The thoracic viscera were frequently injured in the individuals in this study. The left lung was noted to have been injured in 54.6% of individuals, the right lung in 56.3% of individuals, and the heart in 40.3% of individuals. When the lungs were considered together 65.5% (n=78) of individuals were noted to have sustained lung injuries. When the heart and lungs were considered together, 72.2% (n=86) of individuals were found to have sustained injuries to the thoracic viscera. Therefore, the thoracic viscera as a whole were injured more frequently than the head. This is in keeping with various studies such as Daffner *et al. (*1988), Ndiaye *et al.* (2009), Törő *et al.* (2005), and Santamariña-Rubio *et al.* (2007).

Daffner *et al. (*1988) noted that 46.4% of unrestrained drivers and 33.2% of unrestrained front-seat passengers sustained blunt force injuries to the thoracic region (again, this data includes the use of safety features). Ndiaye *et al*. (2009) noted that blunt force trauma to the thoracic region, in isolation or in combination with blunt force trauma to the head, accounted for over 70% of fatalities. Törő *et al.* (2005) did not note the incidence of lung injuries in their sample, but found that 20% of their sample presented with contusions to the heart.

Santamariña-Rubio *et al.* (2007) observed that, in their sample of 719 individuals in Barcelona, the torso viscera were most frequently injured. Sixty-one percent of drivers and 55 % of passengers presented with torso visceral trauma. Their body region classification was performed according to the Barell Matrix (a matrix of ICD-9-CM codes used to classify injuries by type and anatomic region, which enables one to explain how ‘‘injury profiles’’ may be associated with different mechanisms and consequences of injuries) and therefore the torso included the thorax, abdomen, pelvis and urogenital tract, trunk and back, and buttocks (Barell

*et al.*, 2002). As a result, their torso region is inclusive of many regions which are considered separately for this particular study. If the Barell Matrix torso classification is applied to this study's data, then the torso is noted to have been the most frequently injured region in this study which is in keeping with the results from Santamariña-Rubio *et al.* (2007). This details the similarity between this study's visceral injury data and that of Santamariña-Rubio *et al.* (2007).

#### 5.6.2.2.1. Injuries of the Thoracic Aortic Region

The aorta is often injured in MVCs and for this reason the frequency of injury to the aorta was calculated. It was found that the ascending aorta was not injured in any individuals in this study, however the arch was injured in 2.5% (n=3) of individuals and the descending portion of the thoracic aorta was injured in 11.8% (n=14) of individuals.

The statistics of aortic injury vary between studies. In this study fewer individuals were noted to have sustained aortic injuries than the Törő *et al.* (2005) study, but more individuals were noted to have sustained aortic injuries than in the Ndiaye *et al.* (2009) study. The descending thoracic aorta (11.8%, n=14) was noted to have been injured more frequently than the abdominal aorta (3.4%, n=4), which could be due to the high frequency of thoracic injuries in this study as well as the inertia of the heart during a fatal MVC which results in tears in the aorta (Saukko & Knight, 2004). Therefore, although the incidence of aortic injuries is varied between studies and was found to have been low in this study, Prahlow (2010) describes lacerations of the aorta as a "classic" injury in individuals involved in fatal MVCs.

#### 5.6.2.3. Injuries of the Abdominal Viscera

The abdominal viscera (liver, gallbladder, spleen, pancreas, kidneys, stomach, intestines and mesentery) were (as a whole) injured frequently (56.2%, n=67). The liver was the most frequently injured viscus with 47.1% (n=56) of individuals presenting with injuries to this organ. This was followed by the spleen in 27.7% (n=33) of individuals. The remainder of the abdominal viscera was injured in less than 15% of individuals each.

The incidence of liver injuries in this study is slightly higher than that noted by Törő *et al.* (2005), who documented a 31% occurrence of injury to the liver. Yoganandan *et al*. (2000) noted that the liver was the second most commonly injured viscus following the spleen. They noted that of the 129269 abdominal injuries observed in vehicle collision victims between 1993 and 1998, 31% were splenic injuries and 30% were liver injuries. Therefore, the incidence of abdominal visceral injury was much higher in this particular study than that of Yoganandan *et al.* (2000). In addition, the incidence of splenic and liver injuries was reversed in this study with the liver having been more frequently injured than the spleen. This may be due to the types and severities of collisions and the characteristics of the roads and road users which may differ between Gauteng (South Africa) and the United States of America, thereby providing differing injury patterns in fatal MVCs.

### 5.6.3. Skeletal Fractures

The most frequently fractured bony elements were ascertained to have been the base of the skull in 39.5% (n=47) of individuals and the posterior portion of the thoracic rib cage (70.6%; n=84).

#### 5.6.3.1. Fractures of the Cranial Region

The base of the skull was one of the most commonly fractured skeletal elements (along with the rib cage) in addition to being the most commonly fractured cranial element. The calvarium was the second most commonly fractured area of the cranium with fractures being noted in 35.3% (n=42) of individuals. Various studies also noted the high incidence of skull fractures in MVA victims. For example, Santamariña-Rubio *et al.* (2007) noted skull fractures in 37% of drivers and 50% of passengers involved in MVCs.

Ndiaye *et al.* (2009) noted that skull fractures formed part of one of the top three most severe injury scores in the head region. They documented 32 individuals (11.1%) as having sustained complex basal skull fractures and one individual, a massive skull depression as a result of skull vault fracture (0.3%). Consequently, skull fractures were found to have occurred in 11.5% of the individuals in their study, which is substantially lower than that found in this study. However, this may due to the fact that the injuries documented in this study were isolated to decedents, which were assumed to have been more severe. Therefore skull fractures having occurred in individuals that survived MVCs (*i.e.* resuscitated at the scene or admitted to hospitals) were not included in this data set. In addition, the sample included by Ndiaye *et al.* (2009) was isolated to drivers whereas this study included both drivers and passengers. In this study more passengers were noted to have sustained skull fractures than drivers as is depicted in Figure 4.15. It is thought that the inclusion of passengers may account for the greater incidence of skull fractures in this study than that noted by Ndiaye *et al.* (2009).

Törő *et al.* (2005) recorded the incidence of skull fractures at 46% in their motor vehicle category. This result again, may have been distorted by the inclusion of motorcycle and moped scooter users and as a result is higher than the finding of this study.

The higher incidence of skull fractures in passengers than drivers is thought to have been due to the passengers head making initial contact with the windscreen or A-frame. Drivers' heads, on the other hand, would not make initial contact as first; the thoracic region would collide with the steering wheel. Therefore the higher incidence of passenger skull fractures is not unexpected.

#### 5.6.3.2. Fractures of the Thoracic Cage Region

When the thoracic cage is considered as a whole, as opposed to anterior, posterior and lateral regions as well as the sternum, the thoracic cage then becomes the most commonly fractured region of the body by a substantial margin (70.6%, n=84 of individuals).

Ndiaye *et al.* (2009) noted that thoracic injuries were the most frequently incurred injuries in fatal MVCs, and of these, flail chest injuries were the most common. Therefore, the finding of this study that thoracic cage fractures are extremely common in fatal MVCs is not surprising.

Many studies noted the presence of thoracic injuries as a result of seatbelt usage but the seatbelt usage in this study was only determined in one case. This individual was noted to have been wearing a seatbelt at the time of the collision, and even though the individual sustained fractures to the entire posterior and left lateral portions of the thoracic cage, this single finding is not statistically significant

and consequently it cannot be assumed that these fractures occurred as result of the usage of the seatbelt.

#### 5.6.3.3. Fractures of the Spinal Column

The spine was considered in three parts *i.e.* the cervical, thoracic and lumbar regions. Cervical spinal fractures were noted in 7.6% (n=9) of individuals, thoracic spinal fractures in 18.5% (n= 22) of individuals and lumbar spinal fractures in 0.8% (n=1) of individuals.

##### 5.6.3.3.1. Fractures of the Cervical Spinal Colum Region

Many studies have focused solely on cervical spine injuries in MVA victims due to the unique injury mechanisms in this region. For example, Tolonen *et al.* (1986) focused on fatal cervical spine injuries in road traffic accidents. They found that cervical spine injuries were fatal in approximately 10.5 % of individuals which this study was in agreement with. However, they did not detail the extent or type of injuries that occurred.

Hendey and Votey (1994) observed the patterns of injuries which presented as a result of the use a variety of seatbelts. They noted that cervical spinal fractures occurred in individuals utilising two-point “sash-like’ seatbelts. The individuals’ thorax would slide beneath the seatbelt and the seatbelt would then catch their neck. However, the incidence of cervical spinal fractures was not noted by Hendey and Votey (1994) and therefore an accurate comparison to this study’s findings could not be performed.

Góngora *et al.* (2000) grouped the head and neck regions together and found that the overall incidence of injury to this region in MVC ejection incidents was 64.7%, with 47.3% occurring in non-ejected, unbelted individuals and 31.8%

occurring in non-ejected, belted individuals. As a result, one can deduce that perhaps seatbelts reduce the incidence of cervical spinal injuries. However, due to the lack of exclusive cervical spinal injury data in the Góngora *et al.* (2000) study, and the lack of seatbelt usage data in this study, the statistics between the two studies cannot be compared.

#### 5.6.3.3.2. Fractures of the Thoracic and Lumbar Spinal Regions

The spine and back were considered together in a study by Santamariña-Rubio *et al.* (2007) and 15 % of individuals were noted to have incurred fractures to this region. According to the Barell Matrix that was used, the spine/back region included the cervical, thoracic and lumbar portions of the spine as well as the spinal cord and unspecified regions of the back (Barell *et al.*, 2002). When the spine is considered as a whole in this study, as was done by Santamariña-Rubio *et al.* (2007), 26.9% of individuals are noted to have sustained spinal injuries. This statistic was much larger than that stated by Santamariña-Rubio *et al.* (2007). Their study was conducted in Barcelona, Spain (population ± 1.5 million), which according to Pérez *et al.* (2005) recorded 10695 road collisions in 2004. In those collisions, 12939 occupants were injured. Johannesburg, on the other hand, (population ± 11.2 million people in 2010) had a reported 3 138 road traffic collisions (of which 31% were occupants at the time of the collision) (Donson, 2012; Statistics South Africa, 2010). The much larger population and dangerous driving behavior in South Africa, such as those described by Matzopoulos *et al.* (2008) (substance abuse, aggressive driving, fatigue, distractions, and inadequate safety practices) were all thought to have contributed to the disparity in the incidence of spinal injuries between Santamariña-Rubio *et al.* (2007) and this study.

Daffner *et al*. (1988) found that the thoracic spine was noted to have been fractured/injured in 3.2% of unbelted drivers however; no unbelted front-seat passengers sustained these injuries. This finding is lower than that of this study where 18.5% of drivers and passengers were noted to have sustained thoracic spinal fractures. Of these individuals five of the 36 drivers (13.9%), four of the nine rear-seat passengers (44.4%) and no front-seat passengers were noted to have sustained thoracic spinal fractures. Therefore, the absence of front seat passenger thoracic spinal injury is in line with that noted by Daffner *et al*. (1988). However, a higher proportion of drivers sustained thoracic spinal injuries than the Daffner *et al*. (1988) study. The incidence of rear-seat passenger thoracic spinal fractures however, could not be compared to Daffner *et al*. (1988) as their study did not include rear seat passengers.

King and Yang (1995), as previously noted, observed that thoracic spinal injuries occur as a result of three point or two-point "sash-like" seatbelts. They noted that the natural kyphotic curvature of the thoracic spine becomes straightened out due to the seatbelt restraining the thorax against the seat. This straightening out of the thoracic spine then puts pressure on the vertebrae, especially the anterior portions of the bodies of the vertebrae, and can result in anterior wedge fractures (King & Yang, 1995). From this hypothesis it is thought that perhaps both the rear-seat passengers and drivers could have incurred thoracic spinal fractures from the usage of seatbelts. In addition the injury mechanism proposed by Daffner *et al*. (1988) in drivers (flexion of the spine around the steering wheel) may also have accounted for the higher incidence of driver thoracic spinal fractures in this study. However, further investigation is required as no seatbelt usage was recorded in this study.

According to Hendey and Votey (1994), the lumbar spine was often injured in individuals utilising two point lap belts. However, Daffner *et al.* (1994) noted that 7.2% of unbelted drivers and 1.2% of unbelted front seat passengers incurred lumbar spinal injuries/fractures, which is contrary to the finding of Hendey and Votey (1994). In this study, no drivers or front-seat passengers, and only one rear-seat passenger was noted to have sustained lumbar spinal fractures. The rear-seated individual who sustained a lumbar spinal fracture incurred a fracture to L1 as well as T12, and a dislocation of the T12-L1 intervertebral joint. King and Yang (1995) described how rear-seat passengers sustain lumbar spinal fractures as a result of "submarining" under the lap portion of the seatbelt whilst undergoing rapid deceleration. Hendey and Votey (1994) on the other hand, noted that two-point "sash-like" seatbelts produced "Chance" fractures (violent flexion injuries of the spine resulting most commonly in transverse lumbar vertebral fractures involving the posterior portions of the vertebral bodies). Therefore, the theory that the individual in this study who sustained a lumbar spinal fracture may have utilized a lapbelt cannot be discounted as seatbelt data was not available for confirmation. The injury mechanism put forward by Daffner *et al.* (1988) whereby drivers and passengers incur lumbar spinal fractures as a result of flexion of the spine around the steering wheel or dashboard is thought not to have played a role in the individuals included in this study as so few individuals sustained lumbar fractures.

#### 5.6.3.3.3. Fracture-Dislocations of the Atlantooccipital Joint

As was noted before, AO fracture dislocations were considered separately to the remainder of the cervical spine due to the unique injury mechanism that often occurs in this region. Of the 7.6% (n=9) of individuals in this study noted to have sustained AO fracture-dislocations 44.4% (n=4) sustained skull fractures,

66.7% (n=6) sustained external injuries to the head (Grade 1 and 2 injuries to frontal, temporal, parietal, and occipital regions), and 33.3% (n=3) sustained both skeletal and external injuries to the head. Tolonen *et al.* (1986) noted that 40% of unbelted individuals sustained AO fracture-dislocations as a result of hyperflexion, whilst no belted individuals sustained these fracture-dislocations. However, they also noted that belted individuals sustained significantly more injuries caused by deceleration than unbelted individuals (Tolonen *et al.*, 1986). In addition, equal proportions of belted and unbelted individuals demised as a result of cervical spinal injuries (Tolonen *et al.*, 1986). Therefore, seatbelt usage was thought not to influence cervical spinal injury mechanisms but is thought to influence AO fracture-dislocation mechanisms by preventing hyperflexion of the AO joint. Consequently, it cannot be discounted that the individuals in this study who sustained AO fracture-dislocations may have incurred them as a result of non-usage of seatbelts. This would result in the head making contact with the roof or other structures forcing the head into an awkward position thereby placing the AO joint in an awkward position, and with additional force, fracturing/dislocating the said joint. In order for these AO fracture-dislocations to occur one would expect significant force to be applied to the head thus resulting in head injuries and/or skull fractures. However, as was noted, not all individuals who sustained AO fracture-dislocations were noted to have skull fractures and therefore it was assumed that the applied force to the head may not have resulted in a direct head injury but still exerted enough force on the AO joint to cause a fracture-dislocation of it. In addition hyperflexion or hyperextension of the AO joint (whiplash) may also have caused these fracture-dislocation injuries in the absence of head injury or skull fracture.

#### 5.6.3.4. Fractures of the Pelvic Region

It was observed in this study that 32.8% (n=39) of individuals sustained pelvic fractures. This is higher than the findings of Adams *et al*. (2003) and Törő *et al.* (2005) who noted that approximately 25% of individuals involved in MVCs sustained pelvic injuries. However, in this study it was noted that 20.8% (n=16) of drivers and 13% (n=10) of passengers sustained pelvic fractures, which is consistent with the finding that more drivers than passengers sustained pelvic fractures by Adams *et al*. (2003).

Of the 32.8% of individuals (drivers and passengers) in this study that presented with pelvic factures, the most frequently fractured regions were the right and left pubic bones which was noted in 14.3% (n=17) and 11.8% (n=14) of individuals respectively. Only 2.5% (n=3) of individuals were noted to have sustained sacral fractures, all of whom also sustained fractures to other bones of the pelvis. This supports the finding of Daffner *et al.* (1988) in which individuals having sustained sacral fractures also incurred fractures to other regions of the pelvis. However, the incidence of sacral fractures noted in this study is lower than that found by Daffner *et al.* (1988) where 14% of drivers and 4% of passengers were found to have sustained sacral fractures.

The left and right acetabula were fractured in 3.4% (n=4) and 5.9% (n=7) of individuals respectively, therefore displaying the low occurrence of acetabula fractures in individuals in this study. Daffner *et al*. (1988) discussed the occurrence of acetabula fractures; they proposed that acetabula fractures occur as a result of the femoral head being forced into the acetabula fossa as a result of the knees making contact with the dashboard. Daffner *et al*. (1988) established that of the individuals, who sustained acetabula fractures, four were drivers and two were

passengers. Of the passengers one was a front-seat passenger and the other a rear-seat passenger. Consequently, the hypothesis that the acetabula fractures are caused by the knee(s) making contact with the dash board or the surface of the front-seat (in cases of rear seat passengers) has validity.

#### 5.6.3.5. Fractures of the Upper Extremities

The right humerus, elbow and radius were noted to have been fractured more frequently than the left. The left and right ulnae were equally commonly fractured however, the left wrist, and hand were noted to have been more frequently injured than the right. Therefore the right upper arm from the shoulder to the elbow was more frequently fractured, but the left distal arm from the wrist to the finger tips was more frequently injured. With regard to the forearm, medially it was fractured more frequently in the right arm but laterally it was fractured equally in both arms. Therefore, impact to the right upper arm occurred more often, as did impact to the left wrist and hand.

Daffner *et al.* (1988) noted that various fracture patterns occurred in the upper limbs of drivers and passengers. They noted that passengers incur more clavicular and humeral fractures than drivers, and drivers incur more elbow, radial, ulna, wrist and hand fractures than passengers. In this study however, the results indicated that drivers and passengers did not display distinct trends with regard to the fracture incidences of the upper limbs. Drivers sustained more left clavicular, humerus, radius, hand and finger fractures, as well as right ulna and wrist fractures than passengers, but passengers sustained more right clavicular, humerus, elbow, radius, hand and finger fractures as well as left scapula, ulna and wrist fractures than drivers. Therefore, with the exception of the hand and humeral fractures, this study's findings were different to that of Daffner *et al.* (1988).

Daffner *et al*. (1988) state that upper limb injuries in drivers occur as a result of drivers raising their arms in anticipation of impact. Their arms then make contact with the steering wheel which may result in fractures. However, it is thought that if passengers raised their arms in anticipation of impact, their arms would make contact with the dashboard, if seated in the front seat, or the rear surfaces of the seat in front or other surfaces such as the windows, if seated in the rear seats. According to Nygren (1983) the limbs experience inertia during a collision and may come into contact with various surfaces which have the capacity to injure them. As a result, it was thought that those individuals who did not injure their upper limbs by the mechanism described by Daffner *et al.* (1988), may have incurred upper limb fractures as a result of their limbs succumbing to inertia and colliding with the internal surfaces of the vehicle.

King and Yang (1995) discerned that upper limb injuries occur as a result of drivers bracing themself for the impact with the steering wheel. In addition, intrusion of the occupant compartment during a collision was noted to have the capacity to injure the upper limbs as a result of contact between the upper limbs and the internal surface of the vehicle (King & Yang, 1995).

Santamariña-Rubio *et al.* (2007) grouped the upper and lower limbs together and noted that in drivers 8% sustained open wounds, 9% sustained contusions, 15% sustained fractures, and 6% sustained “Others” whilst in passengers 7% sustained open wounds, 8% sustained contusions, 17% sustained fractures, and 1% sustained “Others”. The “Others” category included dislocations, sprains and strains, amputations, blood vessels, crush burns, nerves or unspecified (Barell *et al.*, 2002; Santamariña-Rubio *et al.*, 2007). Therefore, from their study it can be deduced that more passengers sustained extremity fractures

than drivers. In this study a similar trend was noted, in that more passengers sustained upper limb fractures than drivers.

#### 5.6.3.6. Fractures of the Lower Extremities

In this study, the left and right femora and tibiae were fractured in an equal number of individuals. However, the right fibula, patella and foot were fractured more frequently than the left. Consequently, impacts to the femurs and tibiae were equivalent in individuals but impacts to the fibula, ankle, and foot were more frequent in the right leg than the left.

This study noted that passengers incurred more femoral fractures than drivers, but drivers sustained more patella, tibial, fibular and foot fractures than passengers. Therefore this study's findings were contrary to those of Daffner *et al.* (1988) with regard to femur fracture incidences however; they were similar with regard to the incidences of foot fractures. Daffner *et al.* (1988) noted that drivers more often present with femur fractures than passengers but this study found that approximately twice the number of passengers incurred femur fractures. Passengers would experience the same forces as drivers in front-impact collisions and would therefore be expected to make contact with the dashboard as unbelted drivers would. In passenger side impact collisions the passengers would be expected to have sustained more femur fractures than drivers as the passenger would experience the majority of the impacting force. In driver side impacts the drivers would be expected to have sustained more femur fractures and as a result it was thought that more front-impact and passenger side (left lateral) impact collisions occurred in this study thus accounting for the increased passenger femur fracture incidence.

However, Daffner *et al.* (1988) determined that foot fractures are common driver injuries as a result of the feet becoming entangled in the foot pedals during the collision. This study found that 2.8% of drivers incurred fractures of the feet but no passengers presented with the same kind of fractures. Therefore, it was deduced that the foot fractures noted in the individuals in this study were in accordance with the mechanism described by Daffner *et al.* (1988).

### 5.7. Comparisons of the Injury Patterns in Specific Types of Vehicles

Police (SAPS and JMPD) accident scene data was available for 77 of the 119 individuals in this study. Of these, 35 were noted to have been passenger vehicle occupants, 17 were pick-up truck/Bakkie occupants, 10 were minivan occupants, three were larger truck occupants and one was a sport utility vehicle occupant and for 11 the vehicle type was unknown. The external and visceral injury and skeletal fracture patterns were assessed individually to provide more comprehensive, vehicle specific injury pattern results.

The two-factor ANOVAs (without repetition) performed, to compare the external, visceral, and skeletal injury patterns in individuals occupying different vehicle types, all produced statistically significant results. Therefore, it was deduced that occupants of different types of vehicles incurred different external, visceral, and skeletal injury patterns to one another. When the sole SUV occupant was excluded, the results remained unchanged and the two-factor ANOVAs were still significant. Consequently, it was deduced that the single SUV occupant did not influence the ANOVA tests, and the injury patterns of occupants of different vehicles were significantly diverse.

This finding is in keeping with the literature and was therefore somewhat anticipated. Studies by Fredette *et al.* (2008), Siegel *et al.* (2001) and Bener *et al.* (2006) noted that different types of vehicles protect occupants in different manners therefore producing varied injury patterns. Fredette *et al*. (2008) stated that the alteration of the US vehicle fleet was noted to have influenced passenger safety. They found that light trucks and vans had decreased fatality rates in MVCs when compared to passenger vehicles. They noted that these fatality rate differences were due to the self-protective capabilities of the said vehicles which ensured that a vehicle primarily protected its own occupants. They also noted that the aggressive driving styles of the light trucks and vans influenced the fatality rates of occupants in the other vehicle in the collision. This was a result of different vehicles being able to inflict varying degrees of damage to other vehicles during a collision (Fredette *et al.*, 2008). Therefore, different types of vehicles will experience different magnitudes of force during a collision and will transfer varying forces to the occupants thereby resulting in varying injuries.

Bener *et al.* (2006) found that small passenger vehicle occupants more frequently sustained injuries than four-wheel drive vehicle occupants. They noted that the head was the only region to have been injured more frequently in four-wheel drive occupants. The remainder of the body however, was more frequently injured in small passenger vehicle occupants therefore, displaying that occupants of smaller vehicles more frequently sustained injuries and consequently diverse injury patterns to occupants of larger, more robust vehicles.

This study's results were in accordance with these international studies. It was also noted that the majority of vehicles included in this study that were involved in two-vehicle collisions, collided with vehicles of equal or heavier

weights. This also concurs with international studies which noted that vehicle weight played an important role in two-vehicle collisions (Bener *et al.*, 2006; Fredette *et al.*, 2008; Nygren, 1983; Siegel *et al.*, 2001). The size and weight discrepancies of the two colliding vehicles in this study influenced the injuries sustained by the occupants. Due to the fact that the collisions generally involved vehicles of equal or heavier weights, the injuries would have been expected to be more severe, which this study demonstrated (Fredette *et al.*, 2008; Nygren, 1983; Siegel *et al.*, 2001).

### 5.8. Comparisons of the Injury Patterns of Individuals with Regard to their Position of Occupancy

The position of occupancy plays an important role in injury patterns as occupants in different positions in a vehicle will encounter different surfaces in the vehicle and will, as a result, sustain different injury patterns (Daffner *et al.*, 1988; King & Yang, 1995). Therefore, the external, visceral, and skeletal injury patterns were compared between the drivers and passengers to note whether the difference in the injury patterns was statistically significant. This was performed by comparing the external, visceral, and skeletal injury frequencies between the 35 known drivers and 17 known passengers.

To compare the driver and passenger external injury frequencies, whether they occupied the same vehicle or not, unpaired t-tests were utilized. They were determined to have been the most appropriate statistical analysis as two unlinked categories were being tested. The calculated unpaired t-test result for the external injury patterns was statistically significant ($p<0.05$) and therefore the external injury patterns were significantly different. This supports the hypothesis that drivers and passengers incur different external injury patterns (Daffner *et al.*, 1988). In this

study drivers were found to have sustained external injuries primarily to the thoracic and abdominal regions, whereas passengers more frequently sustained injuries to the head region. In addition, drivers were noted to have sustained more severe external injuries (Grade 3 and 4) than passengers (Grade 1 and 2). Both of these factors could account for the differences found by the unpaired t-tests in external injury patterns in drivers and passengers.

The unpaired t-tests performed on the visceral and skeletal injury data however, were not statistically significant ($p>0.05$) and as a result, the visceral injury patterns and skeletal fracture patterns in drivers and passengers were determined to have been similar in individuals in this study. The most frequently injured viscera in drivers and passengers were noted to have been the brain and lungs. Passengers were noted to have incurred more oesophageal and tracheal injuries than drivers, whereas drivers sustained more liver, spleen, and diaphragmatic injuries than passengers. These differences however, were found to have been negligible. In addition, drivers were noted to have incurred more fractures to the skull and facial bones than passengers but passengers were noted to have incurred more upper limb fractures than drivers. Although some visceral injury and skeletal fracture differences existed, the patterns were notably similar.

Daffner *et al.* (1988), King and Yang (1995), Ndiaye *et al.* (2009), and Saukko and Knight (2004) detailed the different mechanisms of injury that drivers and passengers experienced during a collision. All of these were found to have influenced the patterns of injuries sustained by individuals involved in MVCs. Ndiaye *et al.* (2009), Daffner *et al.* (1988) and Saukko and Knight (2004) found that drivers and front seat passengers sustained different injury patterns to one

another, which they attributed to the different surfaces that the drivers and passengers encountered during collisions.

In addition, the use of seatbelts was noted by Hendey and Votey (1994) to alter skeletal fracture patterns, as belted and unbelted individuals would encounter different surfaces in the vehicle and would experience different forces to one another.

King and Yang (1995) noted the difference in protection a vehicle provides a driver and a passenger with. They also noted that the interior structure of a vehicle influenced the injury patterns due to the difference between the driver compartment and the front-seat passenger compartment, as well as the front- and rear-seat passenger compartments. Therefore, these studies all offer explanations for the differences in external injury patterns noted in the individuals in this study. These consist of frequent external injuries in passenger vehicle occupants to the frontal scalp, forehead and cheek regions, in MV occupants to the forehead, right wrist and right hand, in PU/Bakkie occupants to the head, face, thoracic and abdomen, in SUV occupants to the shoulder, right elbow and lower limbs, and large truck occupants to the abdominal, pelvic, and right thigh regions.

The finding that drivers and passengers in this study sustained similar visceral and skeletal injury patterns was therefore, unexpected. It is thought that the drivers and passengers in this study were involved in extremely high impact collisions, which subjected the occupants to extensive forces. The magnitude of these forces resulted in multiple injuries being incurred by the vehicle occupants. The occurrence of these multiple visceral injuries and skeletal fractures would then have resulted in similar injury patterns, consequently offering an explanation to the

finding that drivers and passengers sustained similar visceral injury and skeletal fracture patterns.

### 5.9. Comparisons of the Injury Patterns of Drivers and Passengers in the Same Vehicle

The drivers and passengers that occupied the same vehicle at the time of the collision should, in theory, have distinctive injury patterns as the impact force would be transferred to the individuals in different manners and magnitudes and as a result the individuals will encounter different objects and surfaces during a collision. Therefore, paired t-tests were performed in order to compare the external, visceral, and skeletal injury patterns in drivers and passengers occupying the same vehicle at the time of the collision. Paired t-tests were chosen to statistically evaluate these injury patterns as not only were two categories being compared, but the data was also linked due to the fact that the drivers and passengers occupied the same vehicle at the time of the collision.

Of the 77 individuals for whom Police accident information was available, four driver-passenger pairs were determined to have occupied the same vehicle at the time of the collision.

The paired t-tests for the external and visceral injury, and skeletal fracture pattern data produced results that were not statistically significant. It was consequently determined that the four driver-passenger pairs' injury patterns were similar to one another. This was not expected, as it has been documented that drivers and passengers generally sustain varying injury patterns (Daffner *et al.*, 1988; King & Yang, 1995; Saukko & Knight, 2004). The non-significant result was therefore deduced to have been due to the small sample size, which influenced

the statistical analysis. Further studies with larger sample sizes may be able to detail the injury patterns in drivers and passengers occupying the same vehicle and whether a significant difference exists between the injury patterns of the two.

## 5.10. Study Limitations, Recommendations, and Further Research

*This section is comprised of three subsections, including one on the various limitations experienced during the course of this study, one on the investigator's recommendations in order to overcome these limitations for future research, and one on the investigator's ideas for further research on this topic, including expansion on areas that this research could not elaborate upon due to limitations of the study.*

### 5.10.1 Study Limitations

This study was limited by various factors which prevented a study of this nature from reaching its full potential. In order to improve upon studies like this in the future, the limitations will be further elaborated upon.

One of the main limitations was the time available for the investigator to properly x-ray and assess the individuals included in this study. This was due to the fact that during the data collection individuals were x-rayed prior to autopsy *i.e.* prior to the initial external examination by the attending Forensic Medical Practitioner. Some of the attending Forensic Medical Practitioners preferred the external evaluation of the body to be performed (by themselves) prior to the x-raying done by the investigator. This was requested in order for the Forensic Medical Practitioner to examine the individuals with as little movement of- and (possible) interference with the decedents possible. This would prevent any artifactual post mortem injuries during the x-ray processes from compromising the

autopsy examination findings. This limited the amount of time the investigator could spend performing the x-rays which often resulted in rushed, poorer quality x-ray examination.

The investigator performed the data collection at two different Forensic Pathology Service (FPS) facilities. This occurred as a result of malfunctioning x-ray facilities at the Johannesburg FPS facility. The x-ray machine housed there ceased to work at the end of June 2011, and therefore the investigator moved the data collection to the Germiston FPS in order to utilize the functioning x-ray machine. This move altered the individuals included in the study as the catchment areas of the FPS facilities are different. The Johannesburg FPS jurisdiction is comprised of more highways and urban roads, while the Germiston FPS jurisdiction contains more urban and rural roads, and fewer highways. Therefore, the individuals received at the Germiston FPS may have been involved in different types of collisions to those that would have been received at the Johannesburg FPS. However, since the Johannesburg and Germiston FPS facilities are the two busiest facilities in the Gauteng Southern Cluster, a large enough sample size for the purposes of this study would be ensured and the move was performed. The demographics of the individuals in the two catchment areas is similar and would therefore not affect the demographic assessment portion of the study.

The South African Police Services and Johannesburg Metro Police Department Accident Reports were exceedingly difficult to obtain as permission to access “open case” files was not sanctioned, despite all efforts to do so. Numerous individuals were contacted and multiple avenues explored to gain access to the said accident scene reports. This process, however, took over 12 months in some circumstances. Other Accident Reports were never received due

to incorrect Police case (CAS) numbers being provided to the Forensic Pathology Services by the attending Police officers. Some of the CAS numbers were never provided by the attending officers and attempts to contact the relevant Police Stations directly were unsuccessful. In addition the Police reports and the information required to complete them was not suitable for this study, because much of the information regarding the collisions as well as the vehicles and individuals involved in the collisions was absent. Therefore, accident information was available for only 77 of the 119 individuals included in this study. This sample size, of 77, limited the methodologies of this study as approximately 21% of the available sample was not utilised. This may have influenced some of the statistics by either reinforcing or weakening them. In addition some of the statistics, such as those of the driver passenger pairs, may have been possible to complete with a reasonable sample size, which may have been available if the remainder of the sample could have been included.

There was a distinct lack of safety feature information available for the individuals included in this study. This resulted as no information regarding safety feature usage was documented in the SAPS accident scene reports. The JMPD accident scene reports however, included photographs of the collisions and the decedents in the vehicle (or as they were found by the attending Police Officer), thereby allowing for documented evidence of safety feature usage. In one JMPD case, the decedent could clearly be seen to be wearing a seatbelt. This case however, was the only one from which any safety feature information could have been recorded. As a result, no injury pattern comparisons could be made between individuals utilising and not utilising safety features. This prevented an important portion of the research from being completed. Although the JMPD reports provided

much more accident scene information, very few of the individuals included in this study demised in collisions in the JMPD jurisdiction and consequently few accident scene reports were obtained from them.

Incorrect recording of individuals' external causes of death resulted in the exclusion of some individuals post data collection. Three such cases had to be excluded from the sample. It was discerned from the Police scene reports that the individuals were pedestrians or motorized scooter drivers and not occupants of a vehicle at the time of the collision. Therefore, the individuals did not fit the inclusion criteria of this study and were consequently excluded. The Forensic Officers from the Forensic Pathology Services however, had documented these individuals as MVA occupants and for this reason they were initially included in the sample.

A "large truck" category had to be added to the vehicle type categories during the data collection as a result of several large truck occupants demising during the course of this study and presenting at the FPS facilities. The large truck occupants who fit the inclusion criteria of the study were required to be included in the sample regardless of their mode of transport and therefore an additional vehicle type category was added to accommodate them, which was not anticipated prior to the data collection.

The substantial lack of comparative South African data was noted during the course of this study, and comparisons between the findings of this study and other South African studies could therefore not be performed. This necessitated the comparisons to be made with international studies, which comprised different demographics, vehicle types, roads, road rules, and road users. Therefore, if more

South African data was available additional comparisons could have been made between the findings of this study and those of other South African studies.

It was found that few studies on MVAs included information or data on external injuries. This lack of MVA victim studies documenting external injuries limited the study as not many comparisons could be made to this studies data. In addition a distinct lack of grading systems including external injuries was noted, with most including only visceral and skeletal injuries. Therefore, an injury grading system solely for external injuries was required, especially one for non-clinicians. The presence, severity and type of external injuries noted in this study could not accurately be compared to other studies as no other study included sufficient data on external injuries. Consequently, the external injury comparisons in this research are particularly limited.

### 5.10.2. Study Recommendations

With regard to the limitations experienced as a result of subpar Police accident scene reports, it is in the investigators opinion that the attending SAPS Officers need to provide more accurate information regarding the collisions. This would include the correct make and model of the vehicle, the object or other vehicle (make and model) collided with, direction of impact, the position of occupancy of the different individuals, as well as the safety feature(s) used. This would provide more detailed information which would be required for further MVC research. The investigator understands that in some situations information regarding the circumstances of the collisions was gathered from witnesses who may not have provided accurate information to the attending Police officer. However, in other situations when Police were called to collisions where no

witnesses were present, the vehicle was often deduced to have ‘overturned’ or ‘rolled-over’. This inaccuracy of reporting is detrimental to research and in the investigators opinion better training and the implementation of simpler documentation methods for the attending SAPS Officers would vastly improve the information that can be obtained from motor vehicle accident scene investigations.

With regard to the investigator having to exclude certain decedents from the study after the completion of the data collection, the investigator believes that the Forensic Pathology Officers require more training in accurately determining the circumstances surrounding the decedents’ deaths as well as documenting this at a death scene. This would ensure that the information provided to investigators is more comprehensive and accurate. This would also aid in preventing confusion in the records as well as the data, which will potentially be used to assess trends in the circumstance of death.

### 5.10.3. Further research

Further research with accurate information from accident scene reports and the circumstances surrounding the collisions would be immensely advantageous. This would allow for comparisons with international studies in multiple areas of this research including but not limited to cerebral injuries and the influence of safety feature usage. More extensive research on MVCs with the inclusion of safety feature usage would be enormously beneficial as it may aid Emergency and Forensic Medical Practitioners in future to retrospectively recognize the use or non-use of seatbelts in cases where no seatbelt usage data was available. It would also provide more insight into the injuries caused by safety feature usage as

well as the comparisons of injury patterns in individuals utilizing and not utilizing safety features.

More research into the patterns of injuries sustained by drivers and passengers who demised in the same vehicle would also be advantageous, as it would not only provide better statistical results than those provided by this study but would also aid in producing more conclusive results. A larger sample size may provide varied results from this study and in turn more accurate inferences could be drawn.

Further research into the risks different types of collision in MVCs pose to occupants would be beneficial to provide accurate data in South Africa as well as abroad. The inferences drawn in this study were based on the limited data available and thus further research would be preferential.

## 6. Conclusion

This study found that the population of Johannesburg involved in fatal MVCs is both similar and vastly different from international populations. Some of the demographics and injury patterns in this study are similar to international studies while some of them are not. The injury patterns noted in individuals occupying different vehicles as well as those of drivers and passengers were found to be different from those determined by international studies. The injury patterns noted in drivers and passengers were not found to be altogether different with only the external injuries being significantly different, which was contrary to that documented internationally. The similarities with international studies included the finding that isolated injuries to the head, thoracic region, or a combination of the two were the most commonly sustained injuries in fatal MVCs. The injury

patterns noted in the individuals in this study varied to international studies with regard to the region of the body involved and the study in question. This is thought to have been due to the exclusivity of South African road conditions, the attitudes, and proficiency of South Africans, and the standards/types of vehicles commonly utilized in this country, which all contributed to the varied findings of this study.

This research is of great significance not only in clinical trauma management settings but also in forensic pathology and investigative settings as well. It displays that many initially non-apparent (occult) injuries are sustained in MVCs, some of which can be severe or fatal. It reveals that in clinical settings concealed injuries should be anticipated when examining MVA victims, so as not to overlook or completely misdiagnose potentially fatal injuries. It also shows the importance of relevant radiologic examinations of patients so as to gain an overview of the patient's skeletal injuries before treatment begins. In the Gauteng Forensic Pathology Services setting, routine radiologic examinations of all individuals admitted to the Medicolegal Mortuaries are not performed, due to (inter alia) the limitations of radiologic equipment provided, lack of appropriately trained staff as well as the high numbers of unnatural death cases dealt with on a daily basis at these FPS facilities. Full radiological skeletal surveys prior to the performance of medicolegal autopsies could be of significant assistance to the attending Forensic Medical Practitioners, as it was noted that some of the skeletal fractures noted radiologically by the investigator were not all obvious to the Forensic Medical Practitioners during the autopsy examinations. This confirms the necessity of the ideal standard to introduce radiological examinations of all MVC fatality victims as a standard operating procedure in Medicolegal Mortuaries, to ensure accurate documentation of the full extent of skeletal injuries sustained.

The quality of the South African Police accident scene reports is of great concern for further research as the circumstantial information required is currently not being adequately gathered or documented by the attending Investigating Police Officers. More information regarding the circumstances surrounding collisions (both fatal and non-fatal) such as the direction of impact, the full makes and models of the vehicles involved, the individual positions of occupants in the vehicle, and the vehicular safety features utilised/present, is vital for further comparative research to be conducted successfully. In addition, the accuracy of the FPS Forensic Officer scene attendants whereby they classify the circumstances surrounding an individual's death requires interrogation and corrective measures (such as training) in order to ensure accurate documentation of scene information. This will prevent further confusion in research as well as in the Forensic Pathology Services themselves. However, despite the limitations and obstacles experienced during this study, the data presented by this study which focuses on the injury patterns in forensic MVC fatalities is unique and the first of its kind in a South African context.

## 7. References


1. Adams, V.I., and Carrubba, C. (1998). The abbreviated injury scale: application to autopsy data. *Am J Forensic Med Pathol* **19**(3): 246-251.
2. Adams, J.E., Davis, G.G., Alexander, C.B., and Alonso, J.E. (2003). Pelvic trauma in rapidly fatal motor vehicle accidents. *J Orthop Trauma* **17**(6): 406-410.
3. AftermarketNews.com (2008). *Number of SUVs, Pickup Trucks on the Roads Holds Strong, According to Experian Automotive.* http://www.aftermarketnews.com/Item/37214/number_of_suvs_pickup_trucks_on_the_roads_holds_strong_according_to_experian_automotive.aspx (26 February 2013).
4. Anderson, P.A., Rivara, F.P., Maier, R.V., and Drake, C. (1991). The epidemiology of seatbelt-associated injuries. *J Trauma* **31**(1): 60-67.
5. Antosia, R.E., Partridge, R.A., and Virk, A.S. (1995). Air bag safety. *Ann Emerg Med* **25**(6): 794-798.
6. Arrive Alive (2011). *Arrive Alive South Africa - Festive Season Road Safety Report 16 January.* http://www.arrivealive.co.za/documents/Festive%20Season%20Road%20SafSaf%20Report%20-%2016%20January%202011.pdf (8 March 2012).
7. Association for the Advancement of Automotive Medicine, Committee on Injury Scaling. (1990). The abbreviated injury scale – 1991 revision (AIS-90). Des Plains, IL: Association for the advancement of automotive Medicine.

8. Baker, S.P., O'Neill, B., Haddon Jr, W, Long, W.B. (1974) The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. *J Trauma* **14**: 187-196.
9. Barell, V., Aharonson-Daniel, L., Fingerhut, L.A., Mackenzie, E.J., Ziv, A., Boyko, V., Abargel, A., Avitzour, M., and Heruti, R. (2002). An introduction to the Barell body region by nature of injury diagnosis matrix. *Inj Prev* **8**: 91-96.
10. Bener, A., Ghaffar, A., Azab, A., Sankaran-Kutty, M., Toth, F., and Lovasz, G. (2006). The impact of four-wheel drives on road traffic disability and deaths compared to passenger cars. *J Col Physicians Surg Pak* **16**(4): 257-260.
11. Berryman, H.E., and Symes, S.A. (1998). Chapter 16: Recognizing gunshot and blunt cranial trauma through fracture patterns. In: *Forensic Osteology: Advances in the identification of human remains* (ed. K.J. Reichs), pp. 333-352. Charles C Thomas, Springfield.
12. Bilgin, N.G., Mert, E., and Camdeviren, H. (2005). The usefulness of trauma scores in determining the life threatening condition of trauma victims for writing medical reports. *Emerg Med J* **22**: 783-787.
13. Bilston, L.E., Du, W., and Brown, J. (2010). A matched-cohort analysis of belted front and rear seat occupants in newer and older model vehicles shows that gains in front occupant safety have outpaced gains for rear seat occupants. *Accid Anal Prev* **42**: 1974-1977.
14. Bomikazi, N. (2012). *Joburg: a world class African city.* (Online) Johannesburg: City of Johannesburg

http://www.joburg.org.za/index.php?option=com_content&task=view&id=406&Itemid=52 (22 November 2012).

15. Boyd C.R., Tolson, M.A., and Copes, W.S. (1987). Evaluating trauma care: the TRISS method trauma score and the Injury Severity score. *J Trauma* **27**: 370-378.
16. Braver, E.R., Ferguson, S.A., Greene, M.A., and Lund, A.K. (1997). Reductions in deaths in frontal crashes among right front passengers in vehicles equipped with passenger air bags. *J Am Med Assn* **278**: 1437-1439.
17. Byard, R.W. (2002). Shoulder-lap seat belts and thoracic transection. *J Clin Forensic Med* **9**: 92-95.
18. Champion, H.R., Sacco, W.J., Copes, W.S., Gann, D.S., Gennarelli, T.A., and Flanagan, M.E. (1989). A revision of the Trauma score. *J Trauma* **29**: 623-629.
19. Chang, L.Y., and Mannering, F. (1999). Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents. *Accid Anal Prev* **31:** 579-592.
20. Chirdan, L.B., and Sutherland, R.S. (2011). Chapter 31: Urogenital and Perineal Trauma. In: *Paediatric Surgery: A Comprehensive Text for Africa.* (Ed. E.A. Ameh, S.W. Bickler, K. Lakhoo, B.C. Nwomeh, and D. Poenaru), pp. 201-207. Global HELP Organisation, Seattle.
21. Connolly, F.J. (1995). *Fractures and Dislocations: Closed Managements, Volume 1.* W B Saunders Company, Philadelphia.

22. Copes, W.S., Champion, H.R., Sacco, W.J., Lawnick, M.M., Gann, D.S., Gennarelli, T., Mackenzie, E., and Schwaitzberg, S. (1990). Progress in characterising anatomic injury. *J Trauma* **30**: 1200-1207.
23. Daffner, R.H., Deeb, Z.L., Lupetin, A.R., and Rothfus, W.E. (1988). Patterns of high-speed impact injuries in motor vehicle occupants. *J Trauma* **28**(4): 498-501.
24. Dembovsky, H. (2011). *"Festive season" road fatality statistics released.* http://www.aartofacts.co.za/news/post/2011/01/11/Festive-season-road-fatality-statistics-released.aspx (8 March 2012).
25. DiMaio, V.J., and DiMaio, D. (2001). *Forensic Pathology.* 2nd ed. CRC Press, Boca Raton.
26. Donson, H., editor. (2010). *A profile of fatal injuries in Gauteng 2009: Annual report for Gauteng based on the national injury mortality surveillance system (NIMSS).* (Online) South Africa: MRC-UNISA Safety and Peace promotion Research Unit Available at:http://www.mrc.ac.za/crime/nimss2009_gauteng.pdf (23 January 2011)
27. Donson, H., editor. (2012). *A profile of fatal injuries in Gauteng 2010: Annual report for Gauteng based on the national injury mortality surveillance system (NIMSS).* (Online) South Africa: MRC-UNISA Safety and Peace promotion Research Unit Available at: http://www.mrc.ac.za/crime/NIMSSGauteng2010.pdf (3 August 2012)
28. Drake, R.L., Vogl, W., Mitchell, A.W.M., and Gray, H. (2010). *Gray's Anatomy for Students.* 2nd ed. Churchill Livingstone/Elsevier, Philadelphia.
29. Evans, F.G. (1973). *Mechanical properties of bone.* Charles C Thomas, Illinois.

30. Fredette, M., Mambu, L.S., Chouinard, A., and Bellavance, F. (2008). Safety impacts due to the incompatibility of SUVs, minivans, and pickup trucks in two-vehicle collisions. *Accid Anal Prev* **40:** 1987-1995.
31. Giancoli, D.C. (1995). *Physics: Principles with applications*. 4th ed. Prentice Hall, New Jersey.
32. Gimbergues, P., Guy, L., Boyer, L., and Boiteux, J.P. (1999). Traumatic dislocation of the testes. Report of three cases. *Prog Urol* **9**(2): 322-326.
33. Góngora, E., Acosta, J.A., Wang, D.S.Y., Brandenburg, K, Jablonski, K., and Jordan, M.H. (2001). Analysis of Motor Vehicle Ejection Victims Admitted to a Level I Trauma Centre. *J Trauma* **51**(5): 854-859.
34. Govender, R., and Allopi, D. (2006). *Towards a Safer Minibus Taxi Industry in South Africa.* In: 25th Annual Southern African Transport Conference (2006), pp 100-108, Pretoria, South Africa.
35. Gustilo, R. B., Kyle, R.F., and Templeman, D. (1993). *Fractures and dislocations,* vols 1 and 2. Mosby - Year Book, Inc., Missouri.
36. Hannan, E.L., Waller, C.H., Farrell, L.S. and Cayten, G. (2004). A comparison among the abilities of various injury severity measures to predict mortality with and without accompanying physiologic information. *J Trauma* **58**(2): 244-251.
37. Heght, E. (1996). *Physics: Calculus.* Brooks/Cole Publishing Company, Pacific Grove.
38. Hendey, G.W., and Votey, S.R. (1994). Injuries in restrained motor vehicle accident victims. *Ann Emerg Med* **24**(1): 77-84.
39. King, A.I., and Yang, K.H. (1995). Research in biomechanics of occupant protection. *J Trauma* **38**(4): 570-576.

40. Kumar, V., Cotran, R., and Robbins, S. (1992). *Basic Pathology.* 5th ed. W.B. Saunders, Philadelphia.
41. Lotter, H.J.S. (2000). *Road safety performance measurement in South Africa.* Proceedings of the South African Transport Conference (2010), Pretoria, South Africa.
42. Malliaris, A.C., DeBlois, J.H., and Digges, K.H. (1996). Light vehicle occupant ejections-a comprehensive investigation. *Accid Anal Prev* **28**(1): 1-14.
43. Martin, P.G., Crandall, J.R., and Pilkey, W.D. (2000). Injury trends of passenger car drivers in frontal crashes in the USA. *Accid Anal Prev* **32**: 541-557.
44. Matzopoulos, R., Myers, J.E., and Jobanputra, R. (2008). Road traffic injury: Prioritising interventions. *S Afr Med J* **98**(9): 692-696.
45. Mayrose, J., and Jehle, D.V.K. (2002). Vehicle weight and fatality risk for sport utility vehicle-versus-passenger car crashes. *J Trauma* **53**(4): 751-753.
46. McElhany, J.H., Hopper, R.H., Nightingale, R.W., and Myres, B.S. (1995). Mechanisms of basilar skull fracture. *J Neurotrauma* **12**(4): 669-679.
47. Mehlman, C.T., Scott, K.A., Koch, B.L., and Garcia, V.F. (2000). Briefly noted: orthopaedic injuries in children secondary to airbag deployment. *Orth Forum* **82**(6): 895-898.
48. National Association of Automobile Manufacturers of South Africa (2013). *Heavy Commercial Market - February 2013*. http://www.naamsa.co.za/flash/hcv.html (03 March 2013)

49. Ndiaye, A., Chambost, M., and Chiron, M. (2009). The fatal injuries of car drivers. *Forensic Sci Int* **184**: 21-27.
50. Nygren, A. (1983). Injuries to car occupants – some aspect of the interior safety of cars. A study of a five-year material from an insurance company. *Acta Otolaryngol (Stockh)* **95**(395): 1-135.
51. O'Donnell, C.J., and Connor, D.H. (1996). Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice. *Accid Anal Prev* **28**(6): 739-753.
52. Office of Energy Efficiency and Natural Resources Canada (2010). *2008 Canadian Vehicle Survey: Update Report.* Energy Publications, Ottawa.
53. Okamoto, K., Takemoto, M, and Okada, Y. (2002). Airbag-mediated craniocervical injury in a child restrained with safety device. *J Trauma* **52**(3): 587-590.
54. Osler, T., Baker, S.P., and Long, W. (1997). A modification of the injury severity score that both improves accuracy and simplifies scoring. *J Trauma* **43**: 922-925, discussion 925-926.
55. Osler, T., Rutledge, R., Deis, J, and Bedrick, E. (1996). ICISS: and international classification of disease-9 based injury severity score. *J Trauma* **40**: 38-386.
56. Otremski, I., Marsh, J.L., Wilde, B.R., McLardy Smith, P.D., and Newman, R.J. (1989). Soft tissue cervical spinal injuries in motor vehicle accidents. *Injury* **20**: 349-351.
57. Paparel, P., N'diaye, A., Laumon, B., Caillot, J.L., Perrin, P, and Tuffion, A. (2006). The epidemiology of trauma of the genitourinary system after traffic

accidents: analysis of a register of over 43 000 victims. *Br J Urol* **97**(2): 338-341.

58. Pintar, F.A., Maiman, D.J., and Yoganandan, N. (2007). Injury patterns in pole side crashes. Proceedings of the 51st Annual AAAM Conference (2007), pp. 419-433, Melbourne, Australia.
59. Prahlow, J. (2010). *Forensic pathology for police, death investigators, attorneys, and forensic scientists.* Humana Press, New York.
60. Riddick, L., Long, W.B., Copes, W.S., Dove, D.M., and Sacco, W.J. (1998). Automated coding of injuries from autopsy reports. *Am J Forensic Med Pathol* **19**(3): 269-274.
61. Road Traffic Management Corporation (2012). *Final festive season road safety report for the period 1 December 2011 to 10 January 2012.* Road Traffic Management Corporation Pretoria East.
62. Santamariña-Rubio, E., Pérez, K., Ricart, I., Arroyo, A., Castellà, J., and Borrell, C. (2007). Injury profiles of road traffic deaths. *Accid Anal Prev* **39**: 1-5.
63. Sato, Y., Ohshima, T., and Kondo, T. (2002). Air bag injuries–a literature review in consideration of demands in forensic autopsies. *Forensic Sci Int* **128**: 162-167.
64. Saukko, P., and Knight, B. (2004). *Knight's Forensic Pathology.* 3rd ed. Arnold, London.
65. Shepard, R. (2003). *Simpson's Forensic Medicine.* 12th ed. Arnold, New York.
66. Shkrum, M.J., and Ramsay, D.A. (2007). Craniocerebral Trauma and Vertebrospinal Trauma. In: *Forensic Pathology of Trauma: Common*

*Problems for the Pathologist* (ed. S.B. Karch), pp. 519-606.Humana Press Inc., New Jersey.

67. Siegel, J.H., Loo, G., Dischinger, P.C., Burgess, A.R., Wang, S.C., Schneider, L.W., Grossman, D., Rivara, F., Mock, C., Natarajan, G.A., Hutchins, K.D., Bents, F.D., McCammon, L., Leibovich, E., and Tenenbaum, N. (2001). Factors influencing the patterns of injuries and outcomes in car versus car crashes compared to sport utility, van, or pick-up truck versus car crashes: crash injury research engineering network study. *J Trauma* **51**(5): 975-990.
68. Smock, W.S., and Nichols, G.R. (1995). Airbag module cover injuries. *J Trauma* **38**(4): 489-493.
69. Spitz, W.U., and Fischer, R.S. (2006). *Medicolegal Investigation of Death.* 4th ed. Charles C Thomas, Springfield.
70. Statistics South Africa (2010). *Mid-year population estimates 2010.* StatsSA, Johannesburg.
71. Statistics South Africa (2011). *Mid-year population estimates 2011.* StatsSA, Johannesburg.
72. Statistics South Africa (2012). *Census 2011.* StatsSA, Johannesburg.
73. Teasdale, G., and Jennett, B. (1974). Assessment of coma and impaired consciousness: a practical scale. *Lancet* **2**: 81-84.
74. The Wall Street Journal (2013). *Autosales - Markets Data Center - WSJ.com.* http://www.online.wsj.com/mdc/public/page/2_3022-autosales.html (26 February 2013).
75. Tolonen, J., Santavirta, S., Kiviluoto, O., and Lindqvist, C. (1986). Fatal cervical spinal injuries in road traffic accidents. *Injury* **17:** 154-158.

76. Törő, K., Hubay, M., Sótonyi, P., and Keller, E. (2005). Fatal traffic injuries among pedestrians, bicyclists, and motor vehicle occupants. *Forensic Sci Int* **151**: 151-156.
77. Trowbridge, M.J., McKay, M.P., and Maio, R.F. (2007). Comparison of teen driver fatality rates by vehicle type in the United States. *Soc Acad Emerg Med* **14**(10): 850-855.
78. Ulfarsson, G.F., and Mannering, F.L. (2002). Differences in male and female injury severities in sport-utility vehicle, minivan, pickup, and passenger car accidents. *Accid Anal Prev* **36**: 135-147.
79. Viano, D.C., King, A.I., Melvin, J.W., and Weber, K. (1989). Injury biomechanics research: an essential element in the prevention of trauma. *J Biomech* **22**(5): 403-417.
80. Yoganandan, N., Pintar, F.A., Gennarelli, T.A., and Maltese, M.R. (2000). Patterns of Abdominal Injuries in frontal and side impacts. *Annual Proceedings: Association for the Advancement of Automotive Medicine* **44:** 17-36.
81. Yoganandan, N., Pintar, F.A., Maiman, D.J., Cusick, J.F., Sances, A., and Walsh, P.R. (1996). Human head–neck biomechanics under axial tension. *Med Eng Phys* **18**(4): 298-294.
82. Zhang, J., Fraser, S., Lindsay, J., Clarke, K., and Mao, Y. (1998). Age-specific patterns of factors related to fatal motor vehicle traffic crashes: focus on young and elderly drivers. *Public Health* **112:** 289-295.

## Appendix A

All maps from http://cybercapetown.com/Maps/Gauteng/

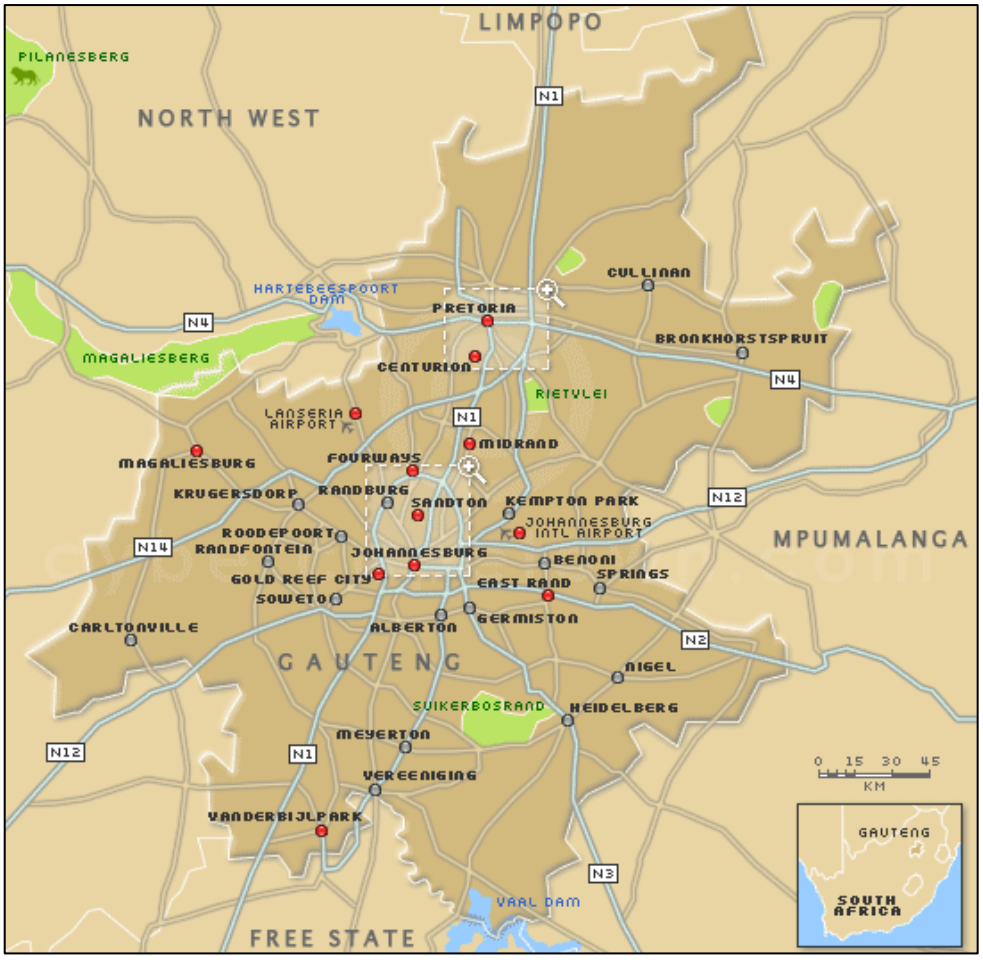



Figure 7.1: Map of Gauteng Including Johannesburg and Pretoria

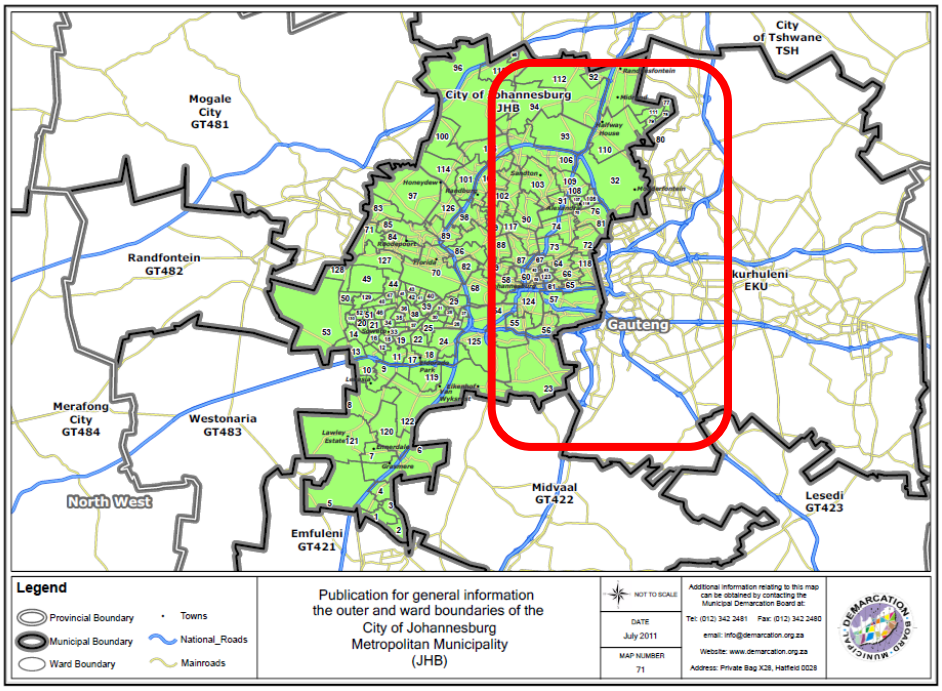



Figure 7.2: Map of the City of Johannesburg. The red ring demarcates the Johannesburg FPS Jurisdictional Area.

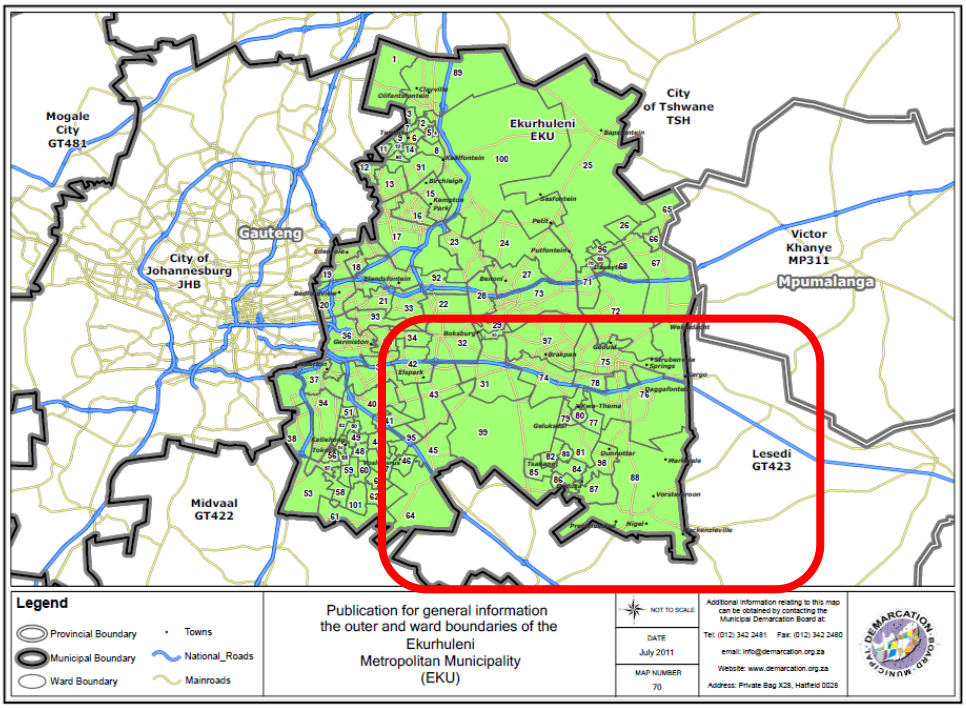



Figure 7.3: Map of the Ekurhuleni Municipality. The red ring demarcates the Germiston FPS Jurisdictional Area.

**Appendix B**

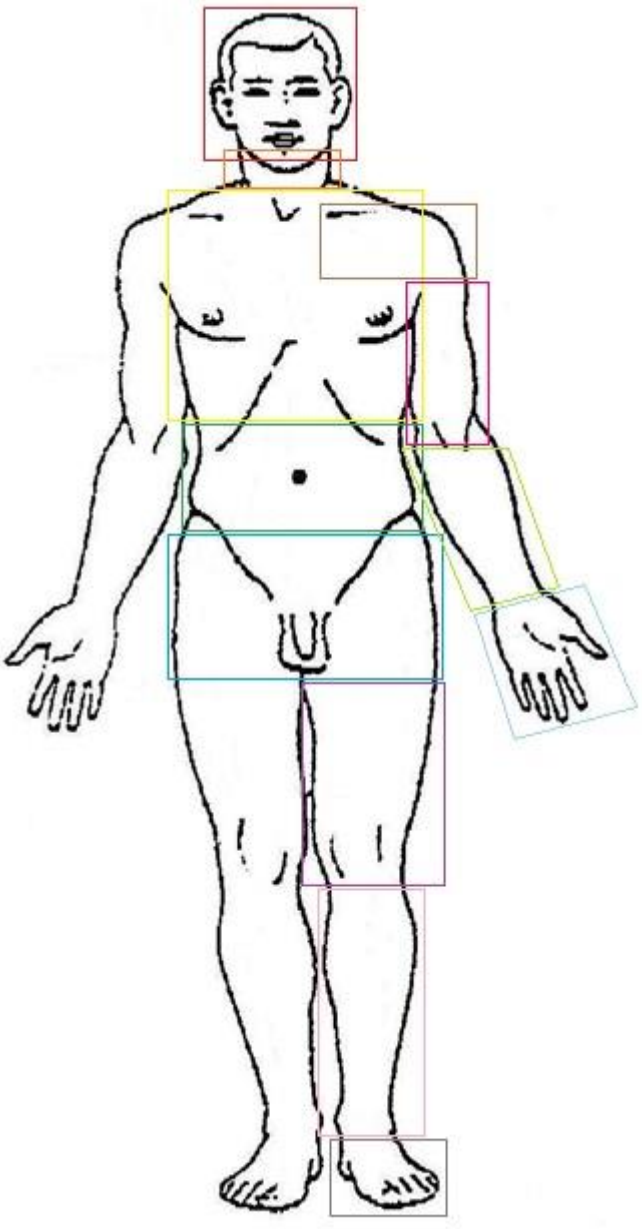


Figure 7.4: Diagrammatic representation of the 12 body regions used for the injury scoring

**Appendix C**

Table 7.1: The Soft Tissue Injury Scoring System

| Injury Grade | Description of the Injury |
|---|---|
| Grade 1 | Mild, Superficial Epidermal Injuries Including Contusions, Abrasions and Superficial Lacerations. Involving:<br>- Only the Superficial Skin. |
| Grade 2 | Moderate Soft Tissue Injuries (Minor and Gaping Lacerations) Involving:<br>- Skin and Underlying Structures<br>- Vasculature<br>- Musculature |
| Grade 3 | Severe Soft Tissue Injuries Exposing Viscera and Skeletal Structures. |
| Grade 4 | Traumatic Amputations |

## Appendix D

Figure 7.5: Data Collection Sheet 1

**DATA SHEET 1 - INJURY PATTERNS IN MVAS (Lewis 2011 & FPS JHB)**

Case number: ..... Date of Autopsy: .....

Date of Death: ..... Age at Death: ..... (Est./Actual)

Ancestry: B / W / C / A / ? Sex: M / F Stature: .....

Doctor: .....

Date of Analysis: .....

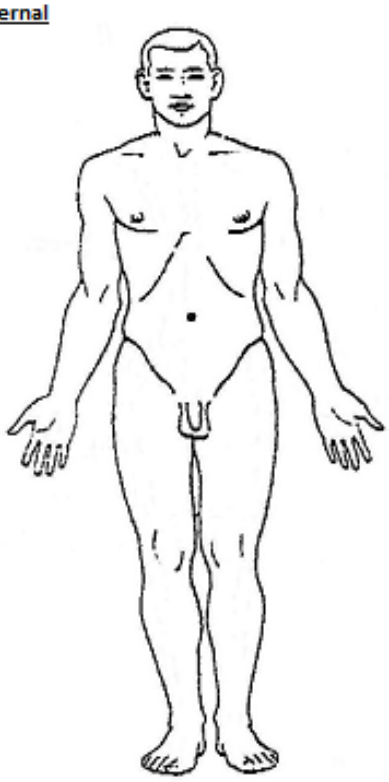
**External Injuries:**

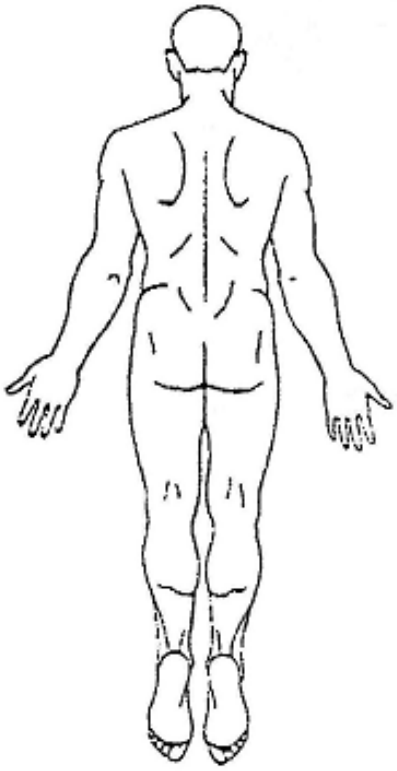
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Body Area Injured:

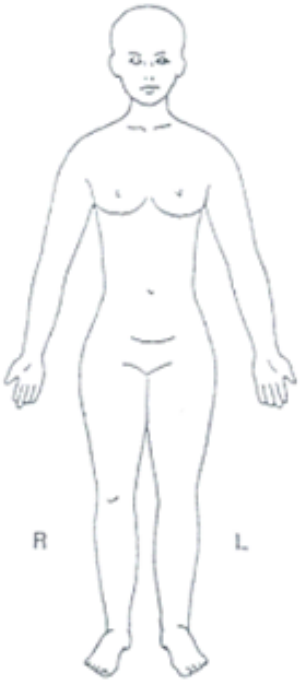
- ☐ Head
- ☐ Shoulder Girdle [Left]
- ☐ Thorax [Anterior]
- ☐ Abdomen [Anterior]
- ☐ Pelvis [Anterior]
- ☐ Upper Limb [Left]
- ☐ Hand [Left]
- ☐ Lower Limb [Left]
- ☐ Foot [Left]
- ☐ Neck
- ☐ Shoulder Girdle [Right]
- ☐ Thorax [Posterior]
- ☐ Abdomen [Posterior]
- ☐ Pelvis [Posterior]
- ☐ Upper Limb [right]
- ☐ Hand [Right]
- ☐ Lower Limb [Right]
- ☐ Foot [Right]

**External**







**Overview of Visceral Injuries:**

- ☐ Oesophagus
- ☐ Lung [Left]
- ☐ Heart
- ☐ Gall Bladder
- ☐ Pancreas
- ☐ Small Intestine
- ☐ Kidney [Left]
- ☐ Great Blood Vessels
- ☐ Genital Organs
- ☐ Trachea
- ☐ Lung [Right]
- ☐ Liver
- ☐ Spleen
- ☐ Large Intestine
- ☐ Stomach
- ☐ Kidney [Right]
- ☐ Bladder
- ☐ Brain

**Overview of Skeletal Fractures:**

- ☐ Head
- ☐ Shoulder Girdle [Left]
- ☐ Thorax [Anterior]
- ☐ Abdomen [Anterior]
- ☐ Pelvis [Anterior]
- ☐ Upper Limb [Left]
- ☐ Hand [Left]
- ☐ Lower Limb [Left]
- ☐ Foot [Left]
- ☐ Neck
- ☐ Shoulder Girdle [Right]
- ☐ Thorax [Posterior]
- ☐ Abdomen [Posterior]
- ☐ Pelvis [Posterior]
- ☐ Upper Limb [right]
- ☐ Hand [Right]
- ☐ Lower Limb [Right]
- ☐ Foot [Right]

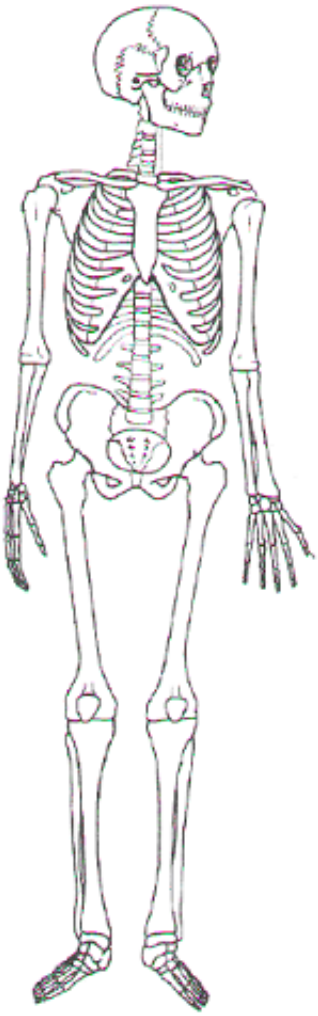
Fracture Details:

- Head:
  ……
  ……
  ……
- Neck:
  ……
  ……
  ……
- Shoulder Girdle:
  ……
  ……
  ……
- Thorax:
  ……
  ……
  ……
- Abdomen (Lumbar Spine):
  ……
  ……
  ……
- Pelvis:
  ……
  ……
  ……

Upper Limb: ……

- .....
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- Hand:
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- Lower Limb:
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- Foot:
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**Skeletal**



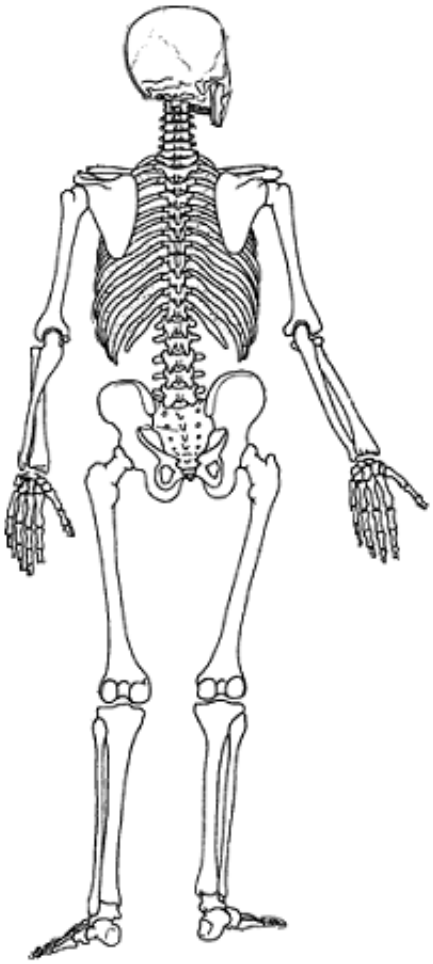


Figure 7.6: Data Collection sheet 2

**DATA SHEET 2 - INJURY PATTERNS IN MVAS (Lewis 2011 & FPS JHB)**

Case number: .....

Investigating Officer: .....

CAS Number: .....

1. Scene of accident:
   - High way
   - Urban road

2. Information from Police Report:
   - Driver/Passenger [Front Seat/Back Seat]
   - Evicted from vehicle

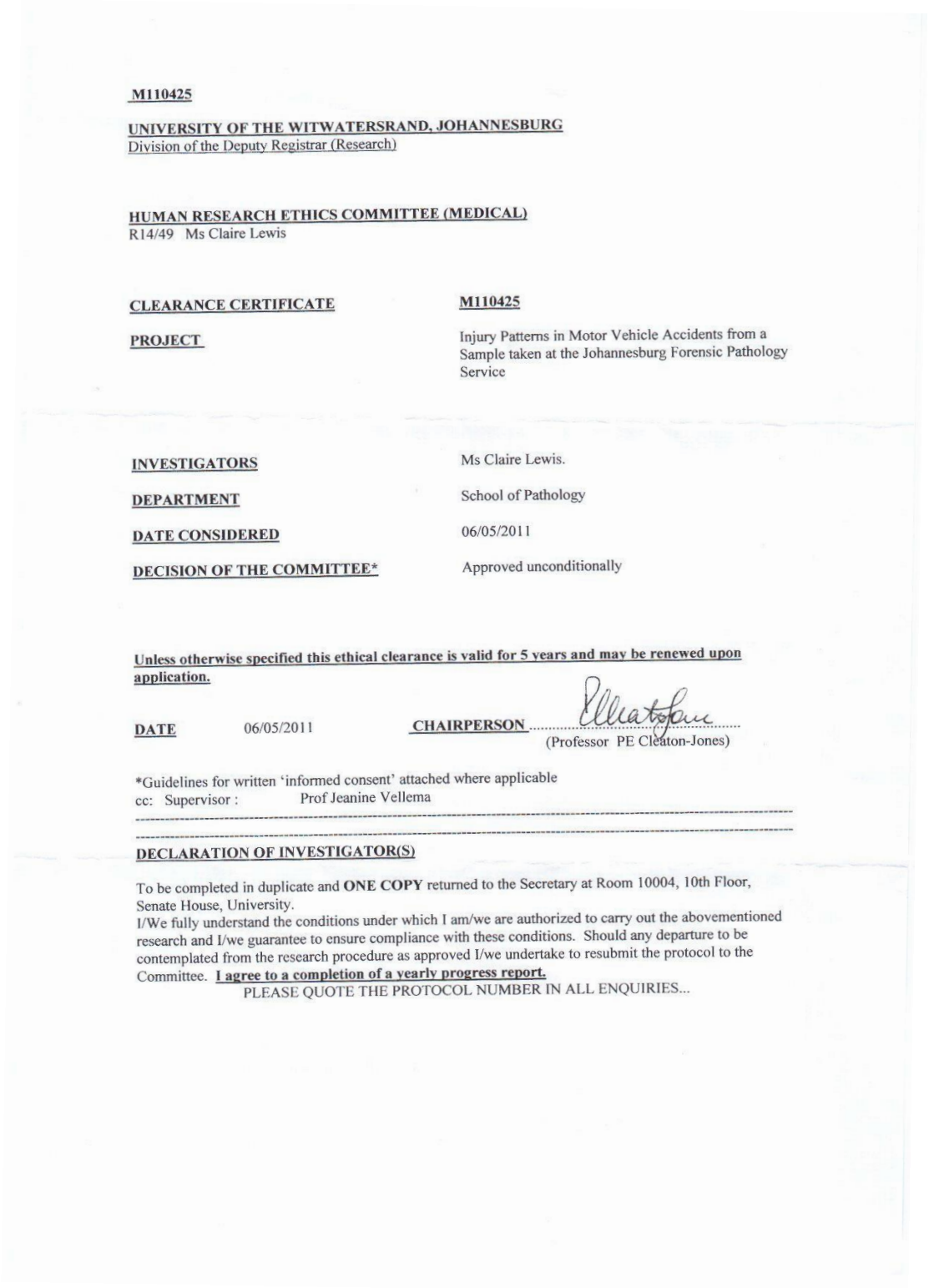
3. Information from SAPS:
   - Type of vehicle: [SUV/PU/MV/Passenger vehicle].....
     .....
     .....
   - Type of accident: .....
     .....
     .....
     .....
   - Object/Other vehicle involved: .....
     .....
     .....

4. Safety Features Employed:
   - None
   - Seatbelt
   - Airbags [Front/Side Curtain]

5. Additional Information/Notes:
   .....
   .....
   .....
   .....
   .....
   .....

## Appendix E

Figure 7.7: Ethics Clearance Certificate



M110425

**UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG**
Division of the Deputy Registrar (Research)

**HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)**
R14/49 Ms Claire Lewis

| | |
|---|---|
| **CLEARANCE CERTIFICATE** | **M110425** |
| **PROJECT** | Injury Patterns in Motor Vehicle Accidents from a Sample taken at the Johannesburg Forensic Pathology Service |
| **INVESTIGATORS** | Ms Claire Lewis. |
| **DEPARTMENT** | School of Pathology |
| **DATE CONSIDERED** | 06/05/2011 |
| **DECISION OF THE COMMITTEE*** | Approved unconditionally |

**Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.**

**DATE** 06/05/2011 **CHAIRPERSON** .....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Prof Jeanine Vellema

**DECLARATION OF INVESTIGATOR(S)**

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**
PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Figure 7.8: Permission Letter from Head of Department of Forensic Medicine and Pathology



Umnyango wezempilo no Kuthuthukiswa Komphakathi
Lefapha la Maphelo le Tshebeletso le Ntshetsopele ya Sechaba
Department of Health and Social Development
Departement van Gesondheid en Maatskaplike Ontwikkeling

Prof Jeanine Vellema
Chief Specialist & Head of Division
Forensic Pathology Service: Johannesburg
☎ Tel: 011 - 489 1659/00
✆ Cell: 082 777 0737
🖷 Fax: 086 656 8413
E-mail: vellema@telkom sa.net

TO WHOM IT MAY CONCERN
RE: RESEARCH REQUEST BY MS. CLAIRE LEWIS

Permission is hereby granted for Ms. Claire Lewis to conduct her research as proposed. She is being granted access, pending ethics approval, to the autopsy suite to observe the autopsies as they are carried out as well as access to the scribe notes/ autopsy report with the understanding that the strictest confidentiality will be maintained and that all data will remain anonymous and unlinked.

Yours truly,

.....
Prof Jeanine Vellema
Professor, Chief Specialist & Head of Division
Forensic Pathology Service: Gauteng Southern Cluster

25A Hospital Street, (c/o Kotze Street), Braamfontein. Private Bag X9, Braamfontein, 2017
-1 -