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Skeletal Blast Trauma: An Application of Clinical Literature and Current Methods in Forensic Anthropology to known Blast Trauma Casualties

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Skeletal blast trauma: An application of clinical literature and current methods in forensic anthropology to known blast trauma casualties.

By

Petra Banks

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Skeletal blast trauma: An application of clinical literature and current methods in forensic anthropology to known blast trauma casualties.

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In order to examine the feasibility of assessing blast event conditions from bone and to distinguish blast trauma from aircraft crash trauma, this study attempts to determine if the observations made in clinical research are mirrored in skeletal remains of individuals who died in blast events. Research was conducted by assessing the frequency of different forms of trauma and their comparison to aircraft crash trauma, the directionality of trauma, and open-air versus enclosed blast trauma. Data consisted of historic and forensic anthropology reports of individuals who died from blast events and aircraft crashes from the Defense POW/MIA Accounting Agency (DPAA). The results indicate a difference in the projectile/comminuted trauma between aircraft crash trauma and blast events, and that directionality is present in blast event fractures but should be used judiciously to determine blast direction. A sample of one open-air blast individual precluded assessment of enclosed versus open-air blast events.

DEDICATION

Dedicated to the military personnel still missing, and to their families, who continue to wait for them.

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INTRODUCTION

Introduction

Blast events, defined as an explosion, bombing, or explosive attack, result in a range of physical traumas to people who are exposed to them (see Table 1.1). These events, and the consequent traumas, are becoming more common in modern warfare, terrorist attacks, and humanitarian crises (CDC 2001). These traumas—called blast injuries when analyzed by clinicians and blast trauma when they affect the skeleton and are analyzed by forensic anthropologists—and the blast events that cause them, have resulted in an increased scope of research within several fields, including clinical medicine and the forensic sciences (see Table 1.1) (Elsayed and Atkins 2008). Research in the forensic sciences, including forensic anthropology, has grown in response to the need for accurate and deliberate forensic investigations to determine the likely mechanisms of these traumas and locate the epicenters of the blast events responsible for them (Beveridge 2012). Within the forensic sciences, findings and methods from within forensic anthropology are primarily valuable in circumstances wherein casualties from the blast events are unidentifiable based on their soft tissue characteristics and other external identifiers. In these circumstances, forensic anthropologists are able to assist in identification. In addition to identification, forensic anthropologists can also determine causes of traumatic injuries manifested in skeletal tissue from close to the time of death (i.e. perimortem trauma), either in a context of human rights violations, such as genocide, or in mass disasters, providing potential context for the death of the victims (Christensen et al. 2014; Kimmerle and Baraybar 2008). Because of this, forensic anthropological research on blast trauma is an area of applied anthropological research with great potential for further inquiry (Christensen et al. 2014).

Currently, most data on blast injuries, including blast trauma, are generated within clinical medicine (Dussault et al. 2016). While forensic anthropologists have conducted studies on blast events, their research often relies on data from clinical studies. The clinical literature on blast injuries is comprised of two types of research: experimental research, and case studies. The experimental research on skeletal blast injuries is conducted through a variety of techniques, including computer modeling, e.g. (Sarvghad-Moghaddam et al. 2017) and explosive experimentation using portions of human cadavers to determine the effects of defensive modifications to vehicles and body armor e.g. (Spurrier et al. 2015). Case studies are made up of both war and civilian casualties and span nearly 40 years, beginning with cases from Irish bombings in the 80s and extending to war casualties from current ongoing conflicts, e.g. (Cooper et al. 1983; Godfrey et al. 2017; Mellor and Cooper 1989).

Forensic anthropologists’ research into blast trauma is comprised of reviewing clinical literature and looking for patterns, and research collecting data from experimental blast events. The reviews of clinical literature aim to discover the likely locations on the body for blast trauma, the frequencies of these locations versus other locations, and what blast trauma is likely to look like based on clinical cases. This is done by examining photographs, x-rays, and the macroscopic analysis of bone exposed in traumatic amputations and compound fractures (Dussault et al. 2016; Dussault et al. 2014; Ramasamy et al. 2011).

Some of the research conducted by forensic anthropologists using clinical data attempts to distinguish blast trauma from other types of trauma, e.g. (Dussault et al. 2016). This type of research is essential because of the similarities in trauma between blast trauma, aircraft crash trauma, and gunshot trauma. In particular, aircraft crash trauma, like blast trauma, can result in impacts at high speed, creating similar trauma patterns (Wedel and Galloway 2014). There has been some research by forensic anthropologists comparing gunshot trauma locations with blast trauma using statistical techniques incorporating a variety of variables to get at the underlying structure of the data (Dussault et al. 2016). However, there has been no comparable study of blast trauma to aircraft crash trauma.

The few publications on blast trauma in forensic anthropology are primarily experimental in nature (creating simulated blast event conditions), and unlike clinical experimental research, forensic anthropology has not used human cadavers for testing the results of blast events, but instead has relied on non-human analogs, such as dead domestic pigs (Christensen and Smith 2013; Christensen and Smith 2015; Christensen et al. 2012; Pechnikova et al. 2015). Forensic anthropological experimental research on blast trauma using pigs has generated information on the types of fractures characteristic of blast trauma (Christensen et al. 2012), the location of said fractures (Christensen and Smith 2013), and the potential histomorphological effects of blast trauma on bone cells (Pechnikova et al. 2015).

Importantly, these forensic anthropological analyses represent pilot studies and provide foundational, basic information about potential indicators of blast trauma. Each of them also emphasize that more research into blast trauma is necessary to fully understand its nature and causality. For instance, within forensic anthropological research utilizing non-human analogs, particularly pigs, many authors have asserted that pigs are a relatively poor analog for humans when decomposition rates are compared (Augenstein 2016) . Scholarly debate also continues on the quality of comparisons made between fractures in the skeletal remains of pigs and humans (Zephro et al. 2014). Human bone is less robust than pig (porcine) bone, and the biomechanics of a human bone may therefore produce different trauma than that witnessed in pig bone. This would mean that the diagnostic indicators of blast trauma generated from experimental studies of pigs may differ somewhat from those indicators which could be observed in human remains (Zephro et al. 2014). One forensic anthropology book chapter incorporates two case studies of likely blast trauma, taken from the Defense POW/MIA Accounting Agency’s (DPAA) reports (Willits et al. 2015). While at least one of these cases has no confirmation in the historical record that they suffered a blast event, the chapter demonstrates the features often used by forensic anthropologists to determine blast trauma (Willits et al. 2015). This analysis of dry bone is useful for forensic anthropological research into blast trauma, because understanding how blast trauma appears in dry bone could provide a more accurate reference for identifying blast trauma (Wedel and Galloway 2014), however, sources for human skeletal remains bearing evidence of blast trauma that can be analyzed by forensic anthropologists are relatively rare. When combined with the above problems and limitations, this has resulted in very little published work within forensic anthropology—and for use by forensic anthropologists—on blast trauma (Dussault et al. 2014).

Addressing the Problem

This research attempts to address the scarcity of empirical information on the identifiable manifestations of blast trauma within human skeletal remains in a number of ways. The end goal of this research is to generate empirical findings for use by forensic anthropological researchers and investigators that reveal how blast trauma manifests in human skeletal remains, with a focus on determining whether perimortem blast trauma results in an identifiable patterning of skeletal trauma distinguishable from aircraft crash trauma. In order to do this, instances of trauma were examined within an assemblage (N=52) of dry bone human remains representing once living individuals who likely experienced perimortem blast trauma (n=22) and trauma from aircraft crashes (n=30) found within the Defense POW/MIA Accounting Agency's reports (DPAA reports), specifically, the historic reports and the Forensic Anthropology Reports (FARs) held by DPAA. In brief, the DPAA is an agency formed to attempt to account for all of the soldiers Missing in Action (MIA) and Prisoners of War (POWs) from past conflicts, with laboratories in Hickam Air Force Base in Honolulu, HI and Offutt Air Force Base in Omaha, NE. The historic reports and FARs document the likely perimortem circumstances of deceased individuals, and provide osteological data on the remains, (including standardized descriptions of each occurrence of perimortem trauma evident on the individuals), respectively.

This research is comprised of four parts, each organized around answering a different research question. The first research question is: is it possible to distinguish different types of trauma caused by a blast event (i.e. primary, secondary, and tertiary blast trauma) by the patterning of fractures? To address this, the first part of the research attempts to distinguish, identify, and characterize the patterning of fractures consistent with primary, secondary, and tertiary forms of blast trauma in human skeletal remains, as defined by clinical accounts of blast injuries and trauma. For the purposes of this research, primary blast trauma is characterized by transverse or oblique fractures, secondary is characterized by comminution, and tertiary blast trauma is characterized by blunt force trauma (Hull 1996; Ramasamy et al. 2011). The second research question is: are the frequencies of types of trauma (defined by the blast trauma form categories) different between trauma caused by blast events and by aircraft crashes? To address this, frequencies of the three forms of blast trauma are compared with the frequencies of the same types of trauma within individuals who died during aircraft crashes, as determined from DPAA reports. The third research question is: is it possible to determine the direction of the blast based on the directionality of blast trauma fractures? To address this question, the third part of the research attempted to identify features of blast trauma consistent with the direction of the blast that caused the trauma. For the purposes of this research, direction refers to the direction of the blast, while directionality refers to the impact direction of individual blast trauma (see Table 1.1). The fourth, final research question is: is there a difference between the trauma patterning from enclosed blasts (i.e. indoor) and open-air (outdoor) blast events? To address this, the fourth part of the research compares the types of blast trauma fractures, the location of these fractures on the skeleton, and the frequencies of these fractures in skeletal remains between individuals documented in the DPAA reports as having experienced perimortem blast events that were indoors (enclosed) as compared to outdoors (open-air).

Table 1.1 Terminology

Term	Definition
Blast Event*	An explosion, bombing, or explosive attack, characterized by detonation and a subsequent blast wave.
Blast Wave	An overpressurized wave of air expanding outward from the blast origin, associated with a period of underpressurization following immediately behind it.
Blast Injury	Term used by clinicians that includes all injuries associated with a blast event.
Blast Trauma*	Blast injuries manifested in the skeleton.
Direction*	The direction of the blast, moving from the blast origin outward.
Directionality*	The direction manifested in individual blast trauma, expressed in the framework of anatomical position (standing, toes pointed forward, palms facing forward, face to the front).

*Denotes terms specific to this thesis, as defined by the author.

CHAPTER II

LITERATURE REVIEW

Introduction

Research within clinical medicine and the forensic sciences on blast injuries has been predominantly driven by incidents of warfare and large-scale conflict within the last hundred years (Born 2005). In reviewing research that has been conducted on blast injuries, there is often increased interest in wartime in order to better understand blast injuries for a variety of military and clinical purposes. These include helping victims of blast events survive after they are injured and helping prevent injury through protective devices, such as personal armor or armored vehicles (Bailey et al. 2015; Bailey et al. 2017; Sarvghad-Moghaddam et al. 2017; Spurrier et al. 2015). The first war where research into blast injuries was conducted was World War I, where the new heavy mechanized warfare gave rise to new forms of injuries within civilians and combatants alike, amongst them blast injuries (Mott 1916). One early research project on blast injury, conducted in 1924, attempted to identify the causes of death associated with the blast wave (the compressed air pushed outward by the blast (see Table 1.1)), termed ‘primary shock’, which had been observed during shelling and grenade blasts by soldiers and medics during combat in World War I. The results indicated that changes in atmospheric pressure caused by the blast were the cause of injury (Hooker 1924).

Warfare drove research on blast injuries during World War II as well. For instance, Zuckerman (1940) attempted to determine the cause of a condition associated with blast events that was observed in casualties during the war, wherein individuals with no outward injuries would die of severe lung complications shortly after the blast. Zuckerman conducted experiments on non-human animals to determine the effects of a blast on lungs, resulting in the term 'blast lung' to define the lung tissue damage associated with blast events (Zuckerman 1940). Other research focused on analysis of case studies of individuals treated after blast events. By the middle of WWII, with increasing casualties from blast events, a summary of current studies of blast injuries was compiled, providing a record of research and reports done on blast trauma up to that point in time (JAMA 1942). Between the 40s and 80s there were few publications on blast injuries. This may be due to research being conducted by the military and so was not in the public domain, particularly during the Cold War, where there may have been strategic advantages to not publicizing military research. In the late 70s and early 80s, an increase in terrorist bombings in the United Kingdom led to more publications, a trend which is supported in the United States in the 90s as well, as notable terrorist attacks (i.e. Oklahoma City bombing, Unabomber, 9/11) led to further increases in publications (Cooper et al. 1983; Frykberg 2002; Frykberg and Tepas 1988; Hull 1996; Leibovici 1996). It is no surprise, then, that in a time of terrorist attacks and a more than ten-year war in Afghanistan and Iraq, that there is an increase in blast injury research in the present (Dussault et al. 2014). The research from the 80s forward will be discussed below, in addition to the basic mechanisms of blast events, forensic anthropological research, and trauma associated with aircraft crashes.

Blast Mechanics

Before discussing the current research on blast injuries, it is important to have a basic understanding of the mechanics of an explosive blast. There are two types of explosions, high energy explosions (high explosives) and low energy explosions (low explosives) (Meyer et al. 2015). High energy explosions are detonations. They include almost all explosive ordinance used in warfare, and are characterized by having an overpressurized blast wave that emanates instantaneously from the blast site when the substance is detonated. The pressure wave is caused by the air being compressed as it is pushed outward from the blast site, creating a wave of higher atmospheric pressure. This wave is followed immediately by a drop into below normal atmospheric pressure, creating vacuum-like circumstances. Low energy explosions do not commonly have a blast wave, and are characterized by deflagration, or the production of fire. Flares, fireworks, and black powder are all low explosives. There is no overpressurized wave in these cases (Meyer et al. 2015). Low energy explosions are unlikely to generate the levels of force required to cause blast trauma, so will not be considered as part of this study. For this study blast events are defined as being high energy explosions (see Table 1.1).

While the blast wave takes the same amount of time to reach the height of overpressure regardless of force, if it is a larger explosion it overpressurizes to a higher level, and the duration of overpressure lasts longer (Bandak et al. 2015). The overpressurized wave is immediately followed by a negative drop in pressure. The negative pressure has a longer duration than the overpressurized period. The effects of the blast wave drop off rapidly the farther one gets from the source of the blast, with a larger blast dropping off further away than a smaller blast. It is the negative drop in pressure that is typically most deadly, as any air pocket in the body, whether in the lungs, eardrums, or bowels, expands outward, causing considerable tissue damage (Bandak et al. 2015).

Blast Injury Mechanics

The injuries that are caused by a blast wave have been classified into four categories: primary, secondary, tertiary, and quaternary forms of injury (Elsayed and Atkins 2008) (see Table 2.1). Primary, secondary, and tertiary injuries are the most applicable to forensic anthropological research because they are all directly related to the blast wave. Quaternary injuries are not caused directly by the blast wave itself, rather they are related to the complications created by the blast, such as fires or building collapse. Each form coincides with a specific causation.

Primary blast injuries are caused by the wave intersecting with an individual body. These injuries are typically found in the soft tissue, but may affect hard tissue, and are usually found where air pockets exist in the body. These include the gastrointestinal tract, lungs, and ears. The overpressurized wave first increases the pressure on the body, initially causing all of the air pockets in the body to be compressed. Then, the brief drop into negative pressure results in all of the air pockets expanding, which causes them to tear, and/or impact other organs. For instance, the lungs may expand until they impact the ribcage, causing hemorrhaging in the lungs. Primary blast injury can also cause traumatic amputation, resulting in the loss of a limb (CDC 2009a; Elsayed and Atkins 2008). This is most likely related to the overpressurized portion of the blast wave, which has enough force to sever the limb, manifesting in the bone in an oblique or transverse fracture (Godfrey et al. 2017; Hull 1991; Hull 1996) (see Table 2.1).

Secondary blast injuries are caused by shrapnel colliding with an individual body. Shrapnel can include objects deliberately placed around the explosive device itself to cause more damage, or any objects hurled through the air by the blast wave that collides with a body (CDC 2009a; Elsayed and Atkins 2008). Based on the clinical literature and the forensic anthropological literature, secondary blast injuries include a variety of forms, as listed in Table 2.1. Secondary blast trauma would include ballistic comminuted trauma (wherein the bone is impacted at a high velocity, causing it to shatter into many pieces), or projectile (penetrating or perforating) trauma (Dussault et al. 2014; Ramasamy et al. 2011).

Tertiary blast trauma are also associated with the blast wave. Tertiary blast injuries are caused by an individual being thrown through the air and impacting a surface or object. Based on the clinical and the forensic anthropological literature; tertiary blast trauma would include blunt-force trauma, resulting from low velocity impacts of the individual as they encountered hard objects and surfaces, such as walls, the ground, trees, vehicles, etc. (Ramasamy et al. 2011). Blunt force trauma is characterized by butterfly fractures in long bones, and low impact cranial depressions and low speed concentric cranial fractures (Wedel and Galloway 2014).

Quaternary blast injuries are caused by complications associated with the blast, but not created by the blast wave, the injuries are by no means exclusive to blasts, and can be found in other types of incidents, such as earthquakes, storms, fires, and building collapses (CDC 2009b; Elsayed and Atkins 2008). Because of this, they are a poor means of identifying a blast event from injury, or subsequently, from skeletal trauma (Dussault et al. 2014).This broad category includes burns, dust inhalation complications, blood loss, and injuries associated with the collapse of a building, among others (CDC 2001; CDC 2009b; Elsayed and Atkins 2008). Quaternary blast injuries can be visible in skeletal remains in a number of ways, such as crushing trauma, blunt force trauma, and severe burns (Dussault et al. 2014). However, both the collapse of a building and a fire can occur whether or not there is a blast event, with the exact same injuries manifested regardless of the original cause. Because of this, to use quaternary blast injuries as a potential means of identifying blast trauma would be presumptive, and potentially inaccurate. In addition, the collapse of a building from a blast would likely result in crushing trauma, and blunt force trauma fracture patterns that could potentially be indistinguishable from tertiary blast trauma (Dussault et al. 2014). For this reason, quaternary trauma was excluded from the study. In addition, many quaternary injuries to soft tissue such as dust inhalation and blood loss are unlikely to show in skeletal material (Dussault et al. 2014).

It is common for more than one type of blast injury to be seen in one individual, with potentially all four present. For clinicians, this makes triage difficult, as the primary injuries are often the most serious, and most hidden (CDC 2001). The effects of blast lung, in particular, can cause an individual to die from a blast with no visible signs of injury anywhere else on the body. This topic was the focus of the first forays into researching blast injuries, wherein researchers attempted to understand the mechanisms of fatalities due to blast injuries (Dean et al. 1940; Hooker 1924; Mott 1916; Zuckerman 1940). The existence of multiple forms of blast trauma present in one individual is important to consider for forensic anthropologists as well, because it means that although the forms of blast injuries and blast trauma may be associated with certain proximities to the blast, there is a very real chance that having multiple forms of injury present could confound the identification of an individual's location within a blast event. In addition, for this research in particular, where all of the conditions of the blast events are not known, equating proximity to the blast by the blast trauma form would likely not reveal an accurate result. For this reason, although the presence, absence, and frequency of the different forms of trauma are observed, they are not used to discuss proximity to the blast event. Instead, each occurrence of trauma within the body was assessed on its own. The only times that all of the trauma in an individual were assessed together was to examine overall frequency and direction, and to determine if secondary and tertiary forms of trauma result in oppositional directions.

Table 2.1 Forms of Blast Injury and Trauma

Blast Injury and Trauma Forms	**Cause**	**Blast Injuries**	**Blast Trauma**
Primary	Blast wave overpressurization and underpressurization	Blast lung, rupture of GI tract, ear drums	Traumatic amputation (transverse/oblique fractures)
Secondary	Shrapnel (either explosive fragments or other objects thrown through the air by the blast)	Lacerations, penetrating injuries, contusions	Ballistic comminution, penetrating and perforating trauma
Tertiary	Individual thrown into other objects	Blunt force injuries, concussions, contusions	Blunt force trauma
Quaternary	Injuries not caused by the blast wave directly, e.g. smoke/dust inhalation, burns, building collapse	Particulate inhalation, blunt force injuries, burns	Blunt force trauma

(CDC 2009b)

Current Clinical Case Studies and Research on Blast Injuries and Trauma

Clinical research and case studies into blast events incorporate all of the forms of blast trauma discussed above, but what are most pertinent for this study are the research projects focused on the first three forms of blast injuries and trauma. Clinical accounts of primary blast injuries include descriptions of traumatic amputation caused by the shearing force of the blast wave (Godfrey et al. 2017; Hull 1991; Hull 1996). The amputation is seen as a short oblique or transverse fracture across a long bone on the diaphysis of the bone, with the region distal to the transverse fracture demonstrating comminution (Ramasamy et al. 2011). There have also been some indications that there are specific points in the bone element that are more likely to fail. In the tibia for example, traumatic amputations are more likely to occur at the level of the tibial tuberosity than on other sites on that element (Covey and Born 2010; Dussault et al. 2014; Hull 1991; Hull 1996). For the humerus, it is more common for it to fracture on the distal end of the diaphysis than anywhere else on the skeletal element, although these differences were not found to be statistically significant for either the tibia or the humerus when subjected to further analysis (Covey and Born 2010; Dussault et al. 2014; Hull 1991; Hull 1996).

There is a strong correlation between traumatic amputation and death of the injured individual. This correlation is not associated with the amputation itself, but instead, with the proximity to the blast; traumatic amputations indicate that the affected individual was in close proximity to the blast. Additionally, being in close proximity to the blast source means that they experienced the overpressurization and underpressurization of the blast wave that creates deadly brain and/or lung injuries. In these cases, even if the amputation is treated in time, the individual will typically still die from brain or lung injuries from the pressure changes of the blast wave. (CDC 2001; Covey and Born 2010). This is important for this study, because while individuals can survive secondary and tertiary forms of trauma, it is unlikely that they will survive primary trauma. This means that primary trauma may appear at higher rates in skeletal remains of individuals who experienced blast events than would be seen in rates compiled from medical personnel triaging blast events, because they are more likely to die, and thus be passed over in a triage situation. However, the likely rates of traumatic amputation differ by study. In Hull's (1996) study, in one of the first studies exclusively discussing traumatic amputation, he reports that 73 of 100 blast event fatalities had one or more traumatic amputations (Hull 1996). However, Frykberg and Tepas (1988), had previously reported that traumatic amputations occurred in only 20% of victims (Frykberg and Tepas 1988). This disparity is likely due to Hull's study only examining fatalities, while Frykberg and Tepas looked at all recorded injuries. Given that the sample used in this study is composed of skeletal remains, it is likely that the results for this study should have high rates of traumatic amputation, much like Hull's study (1996), manifested in skeletal remains as oblique and transverse fractures of long bones.

While primary blast trauma and traumatic amputations have generated clinical research in order to determine the cause of the trauma, secondary trauma has not generated this type of research. Secondary blast trauma is only cursorily discussed in most research. It is classified as ballistic type trauma, which includes a variety of different potential manifestations in bone. One clinical study describes secondary trauma as being manifested as ballistic comminution of the bone (Ramasamy et al. 2011). Wedel and Galloway (2014) discuss blast trauma as being ballistic in nature, meaning it can result in comminution, perforation and penetration. Comminution occurs when the object is traveling at high enough speeds that when it impacts the bone, the bone responds like glass, and shatters. The DPAA case studies for blast trauma describe multiple penetrating and perforating injuries (Willits et al. 2015). Penetration occurs when the object impacts the bone and is embedded inside it, and perforating trauma is when the object passes through the bone, leaving an entrance and exit wound, but not necessarily resulting in comminuted fractures or complete fractures (Dussault et al. 2014; Wedel and Galloway 2014). While these are described here as distinct different types of trauma, in reality, a perforation or penetration can result in a ballistic trauma pattern, characterized by a high level of comminution, as the speed of the object impacting the bone causes the bone to react in a brittle manner, like glass, shattering it (Galloway et al. 2014a). In some cases it can penetrate without causing comminution, leaving clear entrance and exit wounds (Wedel and Galloway 2014).

One advantage to penetrating trauma is that the pieces of shrapnel can be evident within an X-ray, allowing for easier assessment if a researcher has access to an X-ray machine. Shrapnel is likely to produce radiopacities in X-rays (regions where the X-ray could not see through, producing an opaque spot on the radiograph), as the shrapnel either breaks apart as it travels through the bone, or it is embedded in the bone, leaving metal that is detectable (Hare et al. 2007; Willits et al. 2015). For this study, the reports examined often include X-rays, and brief assessments of the radiopacities present, providing an additional avenue of potential evidence for blast trauma. However, X-rays of trauma and the skeletal remains are conducted at the discretion of the DPAA anthropologist conducting the analysis, so X-rays are not present for every report. For this reason, this study did not assess X-rays. However, when the conclusions drawn by the DPAA anthropologist were supported by the X-rays, these data were recorded.

Tertiary blast trauma may resemble the blunt force trauma seen in falls and crashes and vehicular accidents due to very similar mechanisms. In a fall, an individual is accelerated toward the ground by gravity, and in a vehicular crash an individual continues in motion as the vehicle is abruptly halted. In both cases, the individual is in motion and encounters a solid surface or object (Wedel and Galloway 2014). This is the same in tertiary blast injuries and trauma, where the individual is accelerated into motion by the blast wave, and then encounters a solid object or surface, resulting in the same types of injuries as falls or vehicular crashes (Ramasamy et al. 2011).

Depending on the proximity to the blast center, some secondary trauma could more closely resemble blunt force trauma patterns, due to the projectiles being propelled at slower speeds farther away from the blast center. As these patterns of trauma would be indistinguishable from the tertiary trauma, this complicates the identification of secondary versus tertiary blast trauma. However, although the causes may be slightly different, if the purpose of identifying the types of blast trauma is to ascertain an overall picture of the blast, slow secondary trauma may provide its own range from the epicenter that would be very similar to tertiary trauma (Cooper et al. 1983). In addition, if someone is struck with slow moving shrapnel, they may be far enough from the blast to survive, which means if these survivors are examined to help determine the cause and location of the blast, they most likely can inform investigators verbally whether they were thrown through the air or hit by shrapnel (Frykberg and Tepas 1988). For this reason, within this study, where all of the individuals were killed by blast events, it is unlikely that they were far enough away from the source of the blast to have experienced low velocity shrapnel, thus all blunt force trauma was assessed as tertiary trauma.

Blast injuries are made much worse by being in enclosed environments (Arnold et al. 2004; Chaloner 2005). The severity of injuries is more than doubled by a person being close to a wall, as the blast wave and shrapnel hit the wall and then the individual, and the individual is thrown into the wall (Chaloner 2005; Frykberg and Tepas 1988; Leibovici 1996). Ceilings and floors provide additional surfaces for ricochet and impact (Cooper et al. 1983). Due to this complication, blast trauma in an indoor setting is more severe and can lead to multidirectional trauma, wherein fractures and trauma are caused by forces (like blast waves or high or low velocity impacts) acting in multiple directions (Kosashvili et al. 2009; Leibovici 1996).

While the earliest research on blast injuries originates in WWI, there was a resurgence of case studies and research in the late 1970s and early 1980s within British periodicals. This is because the rise in IRA terrorist activities in the United Kingdom led to a need to understand the mechanisms of blast trauma and the best way to triage and treat victims of such an attack (Cooper et al. 1983; Frykberg and Tepas 1988; Mellor and Cooper 1989). Shortly thereafter, a series of terrorist attacks in the United States, including the Oklahoma City Bombing, the bombing during the Olympics in Atlanta, and the attacks of 9/11, led to case studies and research on how to triage blast events, (Frykberg 2002; Quintana et al. 1997). Following 9/11, the CDC developed a primer that serves as a comprehensive guide for what to expect during a blast event, including advice on triage, and criteria for and descriptions of primary, secondary, tertiary, and quaternary injuries (CDC 2001; CDC 2009a; CDC 2009b).

The Afghan and Iraq wars beginning in the early 21st century have led to a subsequent increase in injury profiles (meaning descriptions of the types and severity of injuries present in a blast event) for blast events. Blast injuries from civilian terrorist attacks are well documented but are less common than combat injuries, resulting in fewer case studies on blast injuries from these events in the literature. In contrast, within a war zone or conflict region, the medical personnel present may see many cases of blast injuries, and can publish on the rates and types of injuries they see, providing valuable data for triaging, and treatment of these injuries (Godfrey et al. 2017; Rosenfeld 2010; Sarvghad-Moghaddam et al. 2017). These case study reports are also useful for forensic anthropologists attempting to study the locations and types of trauma associated with blasts. In some publications regarding war zone injuries the authors parse out the differences between primary, secondary, and tertiary forms of blast injury, providing a profile of expected injury patterns (Ramasamy et al. 2011). This work is particularly useful for the current study, as it provides probable injury patterns for blast trauma.

The Afghan and Iraq wars have also resulted in a resurgence of military specific research, both for developing better technology for body armor, and for better treatment methods for the injured. This research often incorporates new technologies to better analyze the mechanisms of blasts, including mechanized blast simulators, (Bailey et al. 2015; Bailey et al. 2017; Newman et al. 2015), and detailed computer modeling of blast injuries, looking at how the tissue and bone react to blast forces. (Hull 1996; Spurrier et al. 2015; Weaver et al. 2017). Even countries that are not currently at war have been committing resources to the study of blast injury (Zhao and Zhou 2015). This research likely continues in countries not at war because they fear involvement in future wars, and want to protect their soldiers if they were to be exposed to blasts in future wars.

Forensic Anthropological Research

It is no wonder, with more clinical interest in these injury patterns, that in the last five years, forensic anthropology has begun to attempt to address blast injuries and corresponding blast trauma. An understanding of the effects of blast trauma could potentially provide forensic anthropologists and forensic investigators with the ability to distinguish blast trauma from other forms of trauma, potentially allowing researchers to identify a likely cause of death, and in an environment such as DPAA, potentially providing a means of corroborating the descriptions of eyewitnesses at the time of death. In addition, distinguishing between forms of blast trauma may help to identify the epicenter of the explosion, the conditions of the explosion (enclosed or open-air) and possibly determine the position of a person at the time of their death in a blast event (Christensen et al. 2014; Dussault et al. 2014).

In order to conduct research on blast trauma, it is important to understand previous research on the subject. Forensic anthropological research includes a case study from DPAA, some experimental research, and analyses of clinical data from a forensic anthropological perspective. The case study from DPAA (called the Joint POW/MIA Accounting Command (JPAC) at the time) included two cases who demonstrate trauma consistent with a blast event, including ballistic trauma with embedded shrapnel (Willits et al. 2015).

In contrast to the case study, the experimental research conducted on blast trauma by forensic anthropologists often used non-human analogs, specifically pigs, arranging them in a manner consistent with a person in a potential bombing situation and then subjecting them to a blast event (Christensen et al. 2012). The results of the study were high levels of comminuted fractures, with the remains recovered in small pieces. This level of comminution is not well discussed in the clinical literature. Individuals this close to a blast and with that degree of comminution have no chance of survival, so for a clinician, who is looking at prevention and treatment, collecting data on these individuals is not as valuable as those individuals who may survive a blast event. For this reason, the observations seen here may illustrate this close proximity better than what is seen in clinical literature. However, Christensen and colleagues' (2012) acknowledge in their paper that this was a rough first study that required more research to refine the results (Christensen et al. 2012).

Christensen and Smith (2013) (Christensen and Smith 2015) later conducted similar research, again on pigs, and found the blast effects on ribs to be of particular interest. They found that there were butterfly fractures on the posterior ends of the ribs consistent with overloading from the front, causing the ribs to bend outward and break (Christensen and Smith 2013; Christensen and Smith 2015). They conclude that this is likely due to the anterior portion of the torso being either split or obliterated, and the ribs are pushed apart, bending outward, causing fracturing along the posterior margin (Christensen and Smith 2013). This differs from other rib injuries, such as those associated with repeated blunt force impacts to the anterior portion of the torso resulting in fractures primarily on the anterior portion of the ribs (Love et al. 2014) (Wiersema and

Love 2015) or rib injuries associated with compression between supporting planes, where fractures are located laterally (when pressure is anterior-posterior) (Galloway and Wedel 2014). The location of the fractures observed by Christensen and Smith (2013) more closely correlate with cases of non-accidental injury (Love 2014). These fractures are observed in cases of child abuse, where there are bilateral fractures along the spine associated with a child being held by the chest and shaken or squeezed, but are also seen in circumstances of anteroposterior compression where the spine is not supported by a flat surface (Love 2014). Posterior fractures can also be caused by lateral compression, but are associated with fractures along the sternum (Galloway and Wedel 2014)

The blast trauma to the ribs is not related to the blast lung injuries, where underpressurization leads to the over expansion of the lungs against the rib cage causing hemorrhaging. There is no indication from clinical research that blast lung could cause rib fractures of any kind (Zhao and Zhou 2015; Zuckerman 1940). In Zhao and Zhou (2015) and Zuckerman (1940) the animals used to examine blast lung injury were far enough away that they did not experience the total comminution seen with Christensen and Smith's (2013) research. Therefore, it remains possible that the expansion of the lungs in closer proximity to the blast wave could lead to rib fractures, but more research would be required to identify whether the overpressurization wave or underpressurization wave is the cause of the total comminution of the ribcage seen in Christensen and Smith's (2013) research. In addition, if there are rib fractures caused by the underpressurized wave, it is possible that they may be masked by the compression-like rib fractures caused by the overpressurized wave.

Although not experimental like the pig studies, there has been some research by forensic anthropologists compiling data from other sources. Dussault and colleagues' (Dussault et al. 2016) use correspondence analyses to compare the location on the body of blast trauma with gunshot trauma. This is an important study as it can illustrate locations of the body more likely to experience trauma in blast events or trauma from being shot. Studies such as these that also examine the likely locations of aircraft crash trauma would further help define the complications associated with distinguishing between these forms of trauma.

Aircraft Crash Trauma

When an aircraft crashes, it is falling from a great height resulting in considerable speed (Wedel and Galloway 2014). Even in slow speed aircraft crashes, the force is still considerable. These speeds are consistent with the high speeds that are encountered in blast trauma (Christensen et al. 2014). Currently, when classifying traumatic injuries in a forensic anthropological setting, particularly at DPAA where these types of injuries are often encountered in combat fatalities, they are classified as rapid deceleration trauma, as one cannot be distinguished from the other (Brown 2016). This is not formalized in the Standard Operating Procedures (SOPs) of DPAA, (the official rules of how those working for DPAA perform their duties) which means in possible aircraft crash or blast trauma situations, the classification of these injuries may not always be consistent, however, it is the most conservative assessment of trauma, and is usually how it is assessed. Jumping to potentially inaccurate conclusions undermines forensics as a whole, DPAA, and the credibility of the individual conducting the research, so it is important to assess trauma conservatively (Christensen et al. 2014).

Because of the similarities between these two types of trauma, blast and aircraft crash, it is important to discuss aircraft crash trauma as well in order to better explicate the difficulties involved in differentiating whether an individual experienced an aircraft crash or a blast event. As mentioned above, the speeds and force experienced by both aircraft crashes and blast events are similar (Christensen et al. 2014; Wedel and Galloway 2014).

Fractures from aircraft crashes will differ based on the type of crash. Aircraft crashes can be divided into a number of different types based on their velocity and the angle in which they impact the ground (Aviation 2017). These types can be seen in Table 2.2. In turn, several different types of fractures can occur with different types of crashes. These include blunt force trauma, comminution, compression injuries (Wedel and Galloway 2014), as well as amputations (Wiegmann and Taneja 2003). For example, aircraft crashes at high velocity are likely to generate comminution, with an overall low recoverability of remains. The difference between low velocity and high velocity impact, however, is not often referenced in published analyses of injuries and trauma from aircraft crashes, though when analyzed, speeds at the time of crash below 10m/s are typically defined as low velocity, and those above 10m/s as high velocity (Safri et al. 2014).

Table 2.2 Aircraft Crash Types: The crash angle, speed and resulting impact and wreckage.

Type of Crash	Description of impact	Description of wreckage
High Velocity, High Angle	High speed impact, encounters the ground at >45°	Smoking hole, fuselage is largely destroyed in impact
High Velocity, Low Angle	High speed impact, encounters the ground at <45°	Aircraft wreckage in small pieces over large swath of ground. Large pieces travel farthest
Low Velocity, High Angle	Low speed impact, encounters the ground at >45°	Small impact crater, plane largely intact
Low Velocity, Low Angle	Low speed impact, encounters the ground at <45°	Aircraft likely bounces, shedding pieces, but does not experience large deformation
Stall Spin	Low velocity, high angle, but encounters the ground while spinning, not necessarily nose first	Small impact crater, plane largely intact, but airframe deformation of plane indicates spin rotation

Source: (Aviation 2017)

Like with blast trauma, there has been very little specific forensic anthropological research done on aircraft crashes. What is known about trauma from aircraft crashes has largely been generated from clinical research on crash injuries. In part, this scarcity is because while aircraft crash investigations incorporate forensic anthropologists in order to assist with identification, recording trauma and the details of each fracture is considered to be less of a priority (Wedel and Galloway 2014). This is problematic for forensic anthropological purposes, because clinical research on aircraft injuries rarely describes the specific types of fracture evident in the deceased relative to their shape or angles, instead recording most of the fractures by the element affected (Afshar et al. 2012; Hayer 2012; Li and Baker 1997; Wiegmann and Taneja 2003). This means that when attempting to identify whether a fracture or pattern of fractures is caused by an aircraft crash, there is little clinical data with which to compare fracture types and patterns.

In order to attempt to understand which skeletal elements are most likely to be fractured and what types of fractures are evident in aircraft crashes, the clinical literature must be studied to provide some comparison for skeletal remains. One study examining the fracture rates by bone element for aircraft crashes indicates that the most common regions for fractures are the ribs, crania, tibia, and pelvis, in that order (Wiegmann and Taneja 2003). Because of its implications for tibial fracture frequency, it is interesting to note that this study analyzes the frequencies of fractures by body region (e.g. torso, forearm, etc.), with more than one bone in each region. The exception to this is the tibia, where the frequency of this one bone element is tallied separately. This may indicate that the fracturing to tibiae are considerable enough to warrant their own category, separating them from a region like: 'the lower limb', or the 'lower leg'. If this is the case, than the ratio of tibial fractures over other bone individual element fractures might in fact be much higher than indicated in the study by Wiegmann and Taneja (2003).

The high rate of tibial fracturing is discussed in more general terms in other articles, wherein results show that the lower limb experiences the highest rates of fractures in crashes (Byard and Tsokos 2006; Li and Baker 1997). In some articles the bones of the lower limb are lumped into one region and are considered the most likely region for fractures (Afshar et al. 2012; Li and Baker 1997). The high rate of lower limb fractures corresponds with what is seen in clinical literature for fracture patterns in blast trauma as well (Dussault et al. 2014; Ramasamy et al. 2011). One supposes that this is likely because blast events usually originate in a ground location, but there has been no causality attributed to these fractures. However, the correlation between the two trauma causes (blast and aircraft crash) mean that this patterning is not a useful method of distinguishing between these causes. In addition to the high rates of lower limb fractures, in most aircraft crashes many fractures are recorded for each individual, with most bones experiencing at least one fracture (Byard and Tsokos 2006; Hayer 2012; Wedel and Galloway 2014; Wiegmann and Taneja 2003). In high velocity aircraft crashes, the force of impact is higher than that of low velocity crashes, and often there is only a fraction of the total body recovered, resulting in considerable comminution of elements (Wedel and Galloway 2014), and amputations (Wiegmann and Taneja 2003).

Based on the information discussed above, a forensic anthropologist investigating an individual who experienced an aircraft crash would expect to see considerable comminution in many of the bone elements present. They would also expect the absence and non-recovery of a number of skeletal elements, especially for a high velocity crash, where the remains are often in many small pieces. For low velocity impacts, the most likely areas to experience fractures would be the ribs, skull, lower limb (tibiae, specifically) and the pelvis (Wiegmann and Taneja 2003). In low velocity impacts, the fractures are also more likely to appear as blunt force trauma rather than comminution (Emanovsky 2015; Wedel and Galloway 2014). These observations are important for research attempting to differentiate blast trauma from aircraft crash trauma, because a review of the existing published literature suggests that the potential for comminution, amputations, and blunt force trauma are all fairly consistent between what has been documented for blast trauma and that documented for aircraft crash trauma (Hayer 2012; Li and Baker 1997; Wiegmann and Taneja 2003). For forensic anthropologists the type of trauma created by both aircraft crashes and blast events is often classified as ‘rapid deceleration trauma’ even though there are different speeds of impact for aircraft crashes (Emanovsky 2015). While the purpose of this thesis is to determine whether the fracture types and patterns of blast trauma described in the clinical literature are consistent with blast trauma evident in skeletal remains from casualties of blast events, determining the differences between blast trauma and aircraft crash trauma is also an essential aspect of studying blast trauma.

DPAA History and Mission

Since WWI, many military personnel are exposed to blast events with some regularity during military conflicts, whether due to grenades, landmines, shells, or other forms of explosive, resulting in many fatal casualties, many of whom were, at the time of their death, unidentifiable (Elsayed and Atkins 2008). Particularly prior to the common use of DNA in the 90s, deceased casualties from blast events who could not be positively identified through remaining soft tissue or personal effects were often buried unidentified (DPAA). Since the 90s, however, DNA analysis has enabled identification of even highly comminuted and fragmented remains from blast events (DPAA). Identification of casualties, including through DNA analysis, is part of the mission of DPAA, which is to “provide the fullest possible accounting for our missing personnel to their families and the nation” (DPAA). This includes deceased from a variety of historic wars or incidents that the U.S. has participated in, but most of those identified by the DPAA have been recovered from sites associated with World War II (1941-1945), and the Korean (1950-1953) and Vietnam (1954-1975) Wars. While DPAA has gone through several iterations of military acronyms and command structures (the most recent prior to the present being the Joint POW/MIA Accounting Command (JPAC) in 2014), the first iteration started in 1973 with the process of identifying the remains of those missing in action (MIA) from the Vietnam War. Currently, DPAA is centered at Hickam Air Force Base in Honolulu, Hawaii, with another lab located at Offutt Air Force Base near Omaha, Nebraska. The staff of DPAA continue to search for individuals designated as MIA from conflicts preceding and following the Vietnam War, but they also attempt to identify deceased individuals who were buried as unknown personnel in a variety of conflicts, and those recovered from burial sites in the US as well as overseas (DPAA).

The process of positive identification in the DPAA occurs across multiple stages; these stages were followed during the identification process for all of the individuals from the DPAA included in this study, resulting in the historic report and Forensic Anthropology Reports upon which this thesis is based. For all individuals working at DPAA there is a set of Standard Operating Procedures (SOPs) which include all of the methods, conduct, and standards for reporting. These are continuously updated and change regularly. To begin the identification process, first, lists of individuals who are MIA or POWs who have not been recovered are compiled by the military. In order to choose which individuals are attempted to be identified, there has to be a high likelihood of success, such as a DNA sample from an existing family member. Second, once an individual is chosen, DPAA historians examine diverse sets of records, such as military reports, medical records, and eyewitness accounts, to determine the last site at which the individual to be identified was documented as being present, such as at an aircraft crash site or recorded blast event site, and the conditions of their likely death (DPAA). The historic reports provided this research with the means of determining likely blast trauma individuals. Third, when a likely location is identified, a team is sent to the location to determine if excavation to cover human remains is warranted. If so, in the fourth stage, a forensics recovery team then excavates the site. If human remains are recovered, they are returned to one of the DPAA locations. Next, the remains are sampled for DNA analysis and the samples are sent to the Armed Forces DNA Identification Laboratory (AFDIL). While the DNA samples are being processed, in the sixth stage, the recovered skeletal remains are examined by DPAA forensic anthropologists, while the recovered teeth are examined by forensic odontologists. The methods used vary slightly, dependent on the condition of the remains and the scientist conducting the analysis, but includes visual assessments, X-rays, CT scans, and physical measurements. Seventh, this information is compiled into a Forensic Anthropology Report (FAR) and a Forensic Odontology Report (FOR). The FAR includes a biological profile; an estimation of the individual's sex, age at death, maximum living stature, probable biological ancestry, and a recording of any antemortem and perimortem trauma, ideally including probable directionality of fractures and possible causes of the fractures (e.g.: gunshot, blunt force trauma). The FOR describes the conditions of the teeth, age, and possible identifying characteristics (dental work). The forensic anthropologists and odontologists record the data and generate these reports as blind analyses, having no knowledge of the suspected identity of the individual under study, the circumstances of their death, or the individual's biological profile (DPAA). The FARs were crucial to this study as they provided, in most cases, detailed descriptions of fractures including type, location, and directionality, and associated photos of fractures as well. In addition, in many cases, X-rays of fractures and of probable penetrating metal objects were provided with interpretations of the radiopacities. After the forensic anthropologists and odontologists file their reports, in the eighth stage, the remains are reassessed, and the report is peer reviewed by at least one other scientist, going through multiple revisions and assessments before it is accepted as accurate and sufficiently thorough by all involved (DPAA). Next, the reports, including a DNA report from AFDIL discussing the comparison of the sample from the skeletal remains to the sample from the decedent’s family, are then sent on to another DPAA specialist not involved in the earlier analyses who compares the biological profile generated from the remains to the known biological profile of the missing individual. Finally, if the biological profiles correspond, and DNA matches, indicating a positive identification, the positively identified remains and a copy of the reports are repatriated to the decedent’s family. If the profiles do not correspond, the remains are retained in the hopes of positively identifying them in the future. The length of time they are kept is dependent on space; preferably they could be kept until methods improve, but there is also pressure to return the deceased to graveyards out of respect, so many are reburied in graves in military cemeteries (DPAA). This means that there are not many sets of remains permanently curated at the DPAA facilities, however, the reports provide a means for reanalysis of the remains even after repatriation or re-interment (DPAA).

The aspects of DPAA’s process most pertinent to this study are the historic report and the FAR. The historic report provides a context for the death of the individual. For instance; if they were a pilot and were last seen in the air, they likely died in an aircraft crash (DPAA). This context could be further confirmed when there are descriptions by local people describing plane crashes and describing where they think they happened or where the local people buried the bodies they found (DPAA). For blast trauma, eyewitness accounts of the death of the individual become crucial. When there are eyewitness accounts of individuals being killed by a shell while in their foxhole, this describes a likely enclosed blast event individual (DPAA).

While the historic reports narrow down which individuals can be assessed, the FARs provide the other half of the data, with detailed descriptions of the trauma types (including transverse, oblique, projectile, comminuted, blunt force), trauma direction, location of trauma, X-rays, and photos of trauma. From these data, the questions proposed for this research can be addressed.

CHAPTER III

RESEARCH DESIGN

Hypotheses

Hypothesis 1

Hypothesis 1: Primary trauma (characterized by transverse fractures across long bone diaphyses in clinical literature), secondary trauma (characterized by ballistic comminuted fractures and projectile trauma), and tertiary trauma (characterized by blunt force trauma), are detected in individuals who have experienced blast events.

Hypothesis 1 is contingent on three sub-hypotheses. If one or two of the sub-hypotheses are accepted, than hypothesis 1 is partially accepted. This indicates that the traits of at least one type of blast trauma can be determined, or that one type of trauma potentially masks the effects and evidence of the others. If all of the sub-hypotheses are rejected, then fracture patterning between primary, secondary, and tertiary trauma cannot be distinguished using the sample employed in this study. If all of them are accepted, then results from this study suggest that evidence of all types of blast trauma can be seen in skeletal remains generated by blast events. The sub-hypotheses are:

Hypothesis 1A: Transverse fractures and short oblique fractures, which are consistent with amputation trauma, and therefore with primary blast trauma, are detected in individuals who likely experienced blast events.

This hypothesis is supported if there are short oblique fractures and transverse fractures seen on the diaphysis of long bones associated with the individuals in the sample who likely experienced a blast event. It is not supported if there are no oblique or transverse fractures in the sample.

Hypothesis 1B: Ballistic comminuted fractures and projectile trauma, consistent with shrapnel, and therefore with secondary blast trauma, are detected in individuals who likely experienced a blast event.

This hypothesis is supported if there are ballistic comminuted fractures and projectile trauma seen in the individuals who likely experienced a blast event. It is not supported if there are no ballistic comminuted fractures or projectile trauma in the sample.

Hypothesis 1C: Blunt force trauma, consistent with tertiary blast trauma, is detected in individuals who likely experienced a blast event.

This hypothesis is supported if there is blunt force trauma seen in individuals who likely experienced a blast event. It is not supported if there is no blunt force trauma in the sample.

Because blunt force trauma can have causes other than blast trauma, this hypothesis can never be fully accepted. Therefore, if blunt force trauma is present, the hypothesis is partially accepted, indicating that tertiary trauma is possibly identifiable in human remains, and distinguishable from primary and secondary trauma. If rejected, tertiary trauma is indistinguishable from other types of blast trauma based on the sample employed in this study.

A survey of the literature indicates that little clinical data are available that record the effects of a blast event if an individual is located extremely close to an explosive device during the event. The only clinical data available are on landmine blast injuries, characterized by traumatic amputation with full comminution below the amputation point (Ramasamy et al. 2011). However, while there is little clinical data on individuals located close to explosives during the blast event, there is experimental research within forensic anthropology on the trauma generated by close proximity to blast events, based on trauma data generated from placing pigs very close to a blast event. These studies record highly comminuted fractures throughout all of the pigs' skeletal elements (Christensen and Smith 2013; Christensen et al. 2012).

The lack of clinical data on individuals located close to a given blast event may be caused by a bias towards individuals who were triaged and taken to the hospital, which in emergency and war zone situations likely do not include the individuals dead on the scene, especially those who may be highly fragmented (Peral-Guitierrez de Ceballos et al. 2005). The focus for medical personnel in these cases are individuals who may survive, and individuals who were highly fragmented may not have made it to the hospital to be recorded in case studies. This means that although the clinical data—on which the above hypotheses are based—indicate that primary blast trauma fractures should be transverse or oblique, primary blast trauma may result in the fragmentation of nearly all skeletal elements, which could instead have been recorded as comminuted fractures. This may render it impossible to detect any difference between primary and secondary fractures in skeletal remains in the DPAA sample, resulting in negative results for hypotheses 1A and 1B. A negative result for hypotheses 1A and 1B may indicate that future research on skeletal blast trauma might more accurately combine these two classifications of blast trauma into one category.

In addition, even if the different types of blast trauma can be distinguished from each other in human remains, there is a high probability that the patterning of blast trauma may still be indistinguishable from that of rapid deceleration trauma, as is seen in aircraft crashes. This problem is addressed within hypothesis 2.

Hypothesis 2

In order to examine fracture types more thoroughly, additional data were collected to allow for a comparison between individuals who likely experienced a blast event and those who likely experienced an aircraft crash.

Hypothesis 2: The fractures seen in individuals who likely experienced aircraft crashes and those who likely experienced blast events differ based on the frequency of different fracture types (transverse and oblique (primary blast trauma), ballistic and comminution (secondary blast trauma), and blunt force trauma (tertiary blast trauma)).

Hypothesis 2 is based on 3 sub-hypotheses. If one of these sub-hypotheses is accepted, than hypothesis 2 is accepted as it will indicate a difference in the frequency of trauma types generated by aircraft crashes versus blast events. If all of the sub-hypotheses are rejected, then hypothesis 2 is rejected, and there is no difference in the fracture type frequency.

Hypothesis 2A: There is a difference in primary blast trauma type fracture frequency between individuals who likely experienced aircraft crashes versus those who likely experienced blast events.

Hypothesis 2A will be supported if there is a significant difference found between frequencies of primary blast trauma type fractures in individuals who likely experienced aircraft crashes versus those who likely experienced blast events. It will not be supported if the difference is not significant, or if there is no difference between the two.

Hypothesis 2B: There is a difference in the frequency of secondary blast trauma type fractures in individuals who likely experienced aircraft crashes versus those who likely experienced blast events.

Hypothesis 2B will be supported if there is a significant difference found between the frequencies of secondary blast trauma type fractures in individuals who likely experienced aircraft crashes versus those who likely experienced blast events. It will not be supported if the difference is not significant, or if there is no difference between the two.

Hypothesis 2C: There is a difference in tertiary blast trauma type fracture frequency between aircraft crashes and blast events.

Hypothesis 2C will be supported if there is a significant difference found between tertiary blast trauma type fracture frequency in aircraft crashes and blast events. It will not be supported if the difference is not significant, or if there is no difference between the two.

Hypothesis 3

Hypothesis 3: The direction of a blast event can be interpreted from the directionality of fractures in individuals who have likely experienced blast events.

This hypothesis is contingent on four sub-hypotheses. If hypothesis 3A is rejected, then hypothesis 3 is rejected, because if directionality is not detectable in skeletal fractures, the direction cannot be determined. If hypothesis 3B is rejected, then the direction of the blast cannot be determined from the primary (transverse and short oblique fractures) or secondary (ballistic comminuted fractures) trauma. If hypothesis 3C is rejected then the direction of the blast cannot be determined from the tertiary (blunt force trauma) trauma. If hypothesis 3D is rejected then the direction of the blast on one individual cannot be determined in a significant proportion of the sample. If hypothesis 3A or 3D is rejected then hypothesis 3 is rejected. Either hypothesis 3B or 3C can be rejected and hypothesis 3 can still be supported, but if both are rejected than hypothesis 3 must be rejected.

It should be noted that for Hypothesis 3, the assumption of the research is that there is likely one blast impact causing an individual to be hit by blast wave and shrapnel from a single direction, and be thrown through the air to hit other objects from a single opposing direction. However, blast events are not always unidirectional; occasionally the blast wave and shrapnel can be ricocheted off of hard surfaces, causing a more multidirectional impact pattern. This is most likely the case with enclosed blast trauma, where ‘walls’, ‘ceilings’, and ‘floors’, whether created by buildings, foxholes, vehicles, or alleyways, reflect the blast wave and shrapnel, causing more than one direction of impact.

In addition to the above caveat (which will be addressed within the discussion section), the direction will be evaluated using standard anatomical terminology, which is based on the body being positioned anatomically; limbs straight, palms facing forward with thumbs pointing laterally so the forearm bones do not cross, and head oriented face forward. This is important to note because it is not likely that soldiers under fire were standing conveniently in anatomical position. Thus, the directionality of the fractures, even when not unified within an individual, may still demonstrate a unidirectional blast if the individual was in a non-anatomical position at the time of the blast.

As the results of this hypothesis are discussed, the above factors will be considered and addressed.

Hypothesis 3A: The direction of a blast event is detectable in the perimortem fractures of individuals who have likely experienced blast events.

This hypothesis is supported if directionality can be determined in a statistically significant number of fractures in the entire sample. The directionality will be determined by the FAR, but a visual evaluation of the photos and x-rays will also be conducted to make sure the results recorded are consistent across the sample. If there are not a significant number of fractures with determinable directionality, hypothesis 3A is not supported.

Hypothesis 3B: The transverse and short oblique traumatic amputation fractures and ballistic comminuted fractures indicate the same directionality within a single person who has experienced a blast event.

This hypothesis is supported if a significant portion of the transverse, short oblique, and comminuted trauma all indicate a single direction of force for a single individual. If the portion of directional transverse, short oblique, and comminuted fractures are not significant, then the hypothesis cannot be supported.

Hypothesis 3C: The blunt force fractures indicate the same blast direction within a single person who has experienced a blast event.

This hypothesis is supported if a significant portion of the blunt force fractures from a single individual indicate a single direction. If the portion is not significant, then the hypothesis cannot be supported. This hypothesis is separate from 3B because tertiary trauma occurs when an individual person is thrown into things as a result of a blast event, not from the blast itself.

Hypothesis 3D: Individuals who have likely experienced blast events show directionality in their fractures.

This hypothesis will be supported if a statistically significant portion of the individuals in the sample have fractures with determinable directionality. This hypothesis is not supported if the number of individuals with fractures demonstrating directionality is not significant. If hypothesis 1 is not supported than hypotheses 3B and 3C cannot be addressed. If hypothesis 1 is partially accepted with hypothesis 1C accepted, than hypotheses 3B and 3C can still be addressed.

As is mentioned above, the results will be discussed with the understanding that enclosed blast trauma may result in multidirectional forces, which would lead to a rejection of 3B, 3C, and 3D in that sample. In addition, it should be made clear that these assessments are made by forensic anthropologists describing directionality on an individual in anatomical position, however even if multidirectionality is detected, this finding may still be an indication of unidirectional force, but of a unidirectional force experienced by an individual who is not in anatomical position. The reverse of this is also true, if unidirectionality is detected in an individual, than this may not necessarily indicate that the blast is coming from one direction, as the individual could have been in a non-anatomical position. The analysis of these results will attempt to mitigate these factors through careful discussion of possible causes of the results.

Hypothesis 4

Hypothesis 4: The skeletal elements affected, the fracture types produced, and the number of fractures in an individual who has likely experienced blast events differ between enclosed and open-air blast events. This is due to the blast wave reflecting off of walls, floors, and ceilings, and the increased surfaces for an individual to be thrown against or have shrapnel ricochet off of in an enclosed event (Chaloner 2005).

Hypothesis 4 is contingent on four sub hypotheses. If one, two, or three of the sub-hypotheses are accepted, then hypothesis 4 is partially accepted. It cannot be said to be fully accepted, because if one or two sub-hypotheses are rejected, that means that there is not a complete correlation between trauma patterning and enclosed versus open-air blast trauma. However, if one sub-hypothesis is accepted, then there is a significant difference in one aspect of the trauma patterning, indicating that the hypothesis is partially correct. If all three sub-hypotheses are rejected, then hypothesis 4 will be rejected as well. This would indicate that there is no significant difference between enclosed and open-air blast trauma patterning.

Hypothesis 4A: A higher frequency of blunt force trauma (tertiary blast trauma) of the lower limb (tibia, fibula, calcaneus, talus, metatarsals, pedal phalanges) is associated with individuals who have likely experienced enclosed blast events.

Clinical data indicates that lower limb injuries are more common in enclosed blast events (Ramasamy et al. 2011). Hypothesis 4A tests this by doing a statistical analysis of total lower limb blunt force trauma of enclosed blast events and comparing them to the total lower limb blunt force trauma of open-air blast events. If there is a statistically significant difference between the two rates, then the hypothesis is supported, meaning there is a strong association with lower limb blunt force trauma (tertiary blast trauma) and enclosed blast events, if there is not, then the hypothesis is unsupported, and there is no evidence that lower limb blunt force trauma is significantly more common in enclosed blast events.

Hypothesis 4B: A significantly higher frequency of fractures overall is associated with individuals who have likely experienced enclosed blast events.

Hypothesis 4B is tested by doing a statistical analysis of overall fracture frequency of enclosed and open-air blast events. If there are significantly more fractures associated with enclosed blast events, than the hypothesis is accepted. If there is no significant difference, or if there is a significantly higher frequency of fractures associated with open-air blast events, then the hypothesis is rejected.

Hypothesis 4C: Traumatic amputation type short oblique and transverse fractures are associated with individuals who have experienced open-air blasts events.

Hypothesis 4C is tested by a statistical analysis of the rates of traumatic amputation type transverse fractures for both open-air and enclosed blast events. If there is a statistically significant association between open-air and traumatic amputation type transverse fractures, then the hypothesis is accepted, indicating that primary blast trauma is more common in open-air blast events. If there is no statistically significant association, or if it indicates that enclosed blast events are associated with amputation type transverse fractures, then the hypothesis is rejected, and there is no association between open-air blast events and primary blast trauma.

Hypothesis 4D: A significantly higher frequency of secondary blast trauma (ballistic comminuted fractures and projectile trauma) are associated with individuals who likely experienced enclosed blast events.

Hypothesis 4D will be tested by statistically analyzing the rates of ballistic comminuted fractures and projectile trauma of open-air and enclosed blast events. If there is a statistically significant association between secondary blast trauma and enclosed blast events, then the hypothesis is supported. If there is no statistically significant association, or if there is a statistically significant association between secondary blast trauma and open-air blast events, then the hypothesis is not supported. If hypothesis 1 is not supported then hypotheses 4C and 4D cannot be addressed, as there will be no clear distinction between types of blast trauma.

CHAPTER IV

MATERIALS AND METHODS

Materials

Data were collected from the historic reports and the Forensic Anthropology Reports (FARs) compiled into casefiles by the Defense POW/MIA Accounting Agency (DPAA). The historic reports contained data on whether or not the individual was in a blast event or aircraft crash, and if they were in a blast event, whether or not it was enclosed or open-air. The FARs contained descriptions of perimortem trauma, as well as photos, and in some cases, X-rays. Only those individuals who were positively identified by DPAA were included in this study. This is because, as a result of the DPAA's identification process and the use of historic reports, only these individuals carry a high degree of certainty of having been involved in blast events and, separately, aircraft crashes.

Individuals in the sample of those killed in blast events and those killed in aircraft crashes were selected based on the historic reports of their death. Although aircraft crashes are often associated with anti-aircraft fire and explosions, individuals who died in association with aircraft crashes were excluded from the category of blast event deaths in order to avoid analytical confusion between rapid deceleration trauma caused by falls and vehicular accidents and trauma caused by blast events. These two types of trauma may be indistinguishable from each other, so to detect any differences between these two trauma types, all aircraft associated deaths were excluded from the blast trauma category.

Each individual was given a score (1, 2) (see Table 4.1) associated with the likelihood that they died in a blast event. Positively identified individuals who were recorded as becoming MIA in heavy fighting (e.g., artillery fire, tank fire, and/or aerial bombing) and who displayed trauma consistent with rapid deceleration trauma were classified as possible blast event individuals and recorded as a 1. If there was an eyewitness account that placed them in a blast event, they were given a score of 2, indicating a probable blast event. The possible blast event individuals (1) were collected but not used in any analysis for this research, as that would create a circular argument. If blast trauma was defined by hypothetical patterns of blast trauma, this could result in inaccurate confirmation, thus these data were excluded. While the historic reports can never offer a 100% certainty in the conditions of death, it is important to keep in mind that the historic reports were used to find the individual, and the FAR and DNA data confirmed the identification. This means that while historic accounts have implicit bias from human error, a positive identification provides a measure of confirmation for the historic accounts of these events (i.e. death from a blast event).

The author surveyed 1700 DPAA case files and associated historic reports and FARs, yielding a total of 22 cases of probable blast traumas, 97 cases of possible blast traumas (n=119), and 30 cases of aircraft crash trauma (n=30), selected at random due to time constraints from a much larger sample. As mentioned above, the possible blast trauma individuals were excluded so as to not develop a circular argument, resulting in a blast trauma sample of 22 (n=22). All of the individuals were selected from an array of conflicts. This generated a total sample size of 52 individuals. While there are identification numbers assigned to each individual by the DPAA (Central Identification Laboratories or CIL numbers), these were not used in this study. Instead, a separate number was assigned based on the sequential order in which the author collected the data, thus preserving the anonymity of the cases.

Blast events were categorized as being enclosed or open-air based on the available documentation within the historic report. Those individuals with an eyewitness description of being in a structure (i.e. fox hole, building, bunker, alleyway, vehicle) were recorded as being in an enclosed blast event. It should be noted that this does not include a person *inside* of a structure that was impacted by a blast event *external* to the structure while causing little damage to the structure. An example of this would include a person inside an armored car that has a bomb go off beneath it. The injury patterning in that event would more closely resemble a vehicular collision or aircraft crash, so trauma cases generated by these blast events were not included in this study. However, those individuals who were in bunkers or vehicles that were obliterated by a blast event were included in the study, as they may still have been susceptible to the forces causing enclosed explosions. Within the reports if there was information indicating that an individual was outside, away from buildings, and out of a foxhole, than they were considered open-air blast events. Blast events that were not recorded as enclosed or open-air blast events were recorded as unknown. Within the 22 cases of probable blast trauma, only one was recorded as having been generated by an open-air blast event. Of the remainder, 7 were recorded as being unknown, and 14 were recorded as being enclosed. The circumstances of the enclosed blast events were varied, including explosions in aircraft (without a crash), foxholes, ships, and bunkers. In all cases, the explosions were caused by high explosives, meaning they detonate and produce a blast wave. Of the probable blast event individuals, 3 cases were from WWI, 11 cases were from WWII, 5 were from the Korean War, and 3 were from the Vietnam War. For the 22 individuals included in this sample, there were only 15 blast events. Some individuals were involved in the same blast event.

Table 4.1 Blast Event Individuals

	Enclosed/ open-air	Conflict	Explosion Type	Trauma count	Blast event*
1	Enclosed	WWII	Mortar Shell	31	1
2	Enclosed	WWII	Tank shell	7	2
3	Enclosed	WWII	Tank shell	2	2
4	Enclosed	WWII	Mortar Shell	1	3
5	Enclosed	WWII	Tank shell	2	4
6	Enclosed	WWII	Tank shell	6	4
7	Enclosed	WWII	Tank shell	3	4
8	Enclosed	Korea	Mortar Shell	24	5
9	Unknown	Korea	Mortar Shell	2	6
10	Unknown	WWI	Mortar Shell	2	7
11	Unknown	WWI	Mortar Shell	2	7
12	Unknown	WWI	Mortar Shell	6	7
13	Enclosed	WWII	Mortar Shell	8	8
14	Enclosed	Korea	Mortar Shell	5	9
15	Unknown	Korea	Shrapnel, unknown explosion	1	10
16	Enclosed	Vietnam	Multiple explosions in bunker	2	11
17	Enclosed	Vietnam	Tank shell destroys bunker	9	12
18	Enclosed	Vietnam	Tank shell destroys bunker	6	12
19	Open-air	WWII	Aerial Mortar Shell	4	13
20	Unknown	Korea	Bazooka blew up	2	14
21	Unknown	Korea	Bazooka blew up	3	14
22	Enclosed	WWII	Anti-aircraft shell	4	15

*Blast events numbered in order of collection (DPAA)

The Forensic Anthropology Report contains the analysis of the skeletal remains, x-rays, photos, and CT scans done by a DPAA anthropologist. From this report, the author compiled all of the available data on perimortem trauma in each case. For each recorded instance of perimortem trauma in a given case, these include the skeletal element, type of fracture, the directionality of the fracture (if documented), and a brief description of the fracture. In some cases X-rays and photos helped provide further assessments, particularly in directionality and trauma type, which were not always explicit. When directionality was not indicated, the author determined it visually from the photos and descriptions. In most cases, possible directionality of fractures was determinable. Directionality was examined for all fracture evidence on all of the cases included in the sample, including the aircraft crashes, enclosed blast events, and the one open-air blast event. In some cases, there were no photos of the fractures, the photos were insufficient to determine directionality, or the description of the fractures was incomplete; in these cases, the directionality was marked as unknown. If the images and descriptions were sufficient for analysis, but the directionality was still not clear from the fracture itself, it was recorded as indeterminate.

While there is standardization in the recording methods for the Forensic Anthropology Reports, the samples used span almost 20 years and multiple conflicts, and methods in forensic anthropology have changed over time, as have the standards of DPAA (Brown 2016). This means that while in some of the reports directionality of fractures is indicated, in others, it is not. In many cases there is no mention of directionality of fractures, leaving it unclear whether directionality could be determined but was not reported, or if directionality was indeterminate.

In order to examine the hypotheses discussing likely locations of fractures in enclosed and open-air blast events, each skeletal element affected by perimortem trauma was recorded by name. If the affected element was a fibula, tibia, calcaneus, talus, metatarsal, or pedal phalanx, it was further designated as "lower leg." All other elements were further designated as "other" in order to address hypothesis 4A. Fractures were recorded as transverse, oblique, comminuted, projectile, occurring through blunt force trauma, or other, (which includes poorly described trauma, and other types of trauma, including compression trauma, spiral fractures, greenstick fractures, gunshot wounds, etc.) and any confounding factors were noted. The comminuted and projectile fractures are usually indicative of ballistic trauma. In order to avoid confusing these data, if they were determined to be caused by gunshot by the anthropologist who wrote the report, based on entrance and exit wounds of neat semi-circle or keyhole appearance, they were not considered secondary trauma and were recorded as 'other' in the fracture type. For clarity in parsing out primary blast trauma characterized by traumatic amputation of a limb, any use of the words 'transverse' or 'oblique' in the FAR to describe trauma in a location that was not a long bone was excluded and changed to "other." This is because a transverse fracture in vertebrae or a scapula would not result in a traumatic amputation (Wedel and Galloway 2014). While the terms "transverse" and "oblique" are accurate means of describing perimortem trauma in other bone elements than long bones, they do not align with the specific forms of oblique and transverse trauma associated with primary blast traumatic amputation discussed in clinical literature (Godfrey et al. 2017; Hull 1991; Hull 1996; Ramasamy et al. 2011). Therefore, they were not incorporated unless they indicated the presence of a traumatic amputation within the case. In order to record the direction of the trauma, each perimortem trauma was recorded using standard anatomical terminology: Anterior-Posterior (A-P); Posterior-Anterior (P-A); Inferior-Superior (I-S); Superior-Inferior (S-I); Left-Right (L-R); and Right-Left (R-L)(Buikstra and Ubelaker 1994). In many cases, more than one of these terms were employed in order to describe directions that were combinations of multiple terms

Table 4.2 Data Recording

Score Type	**Variations**
Blast Event	Probable:2, Possible:1, Negative:Not collected, Plane Crash: P
Enclosed/ Open-air	Enclosed: E, Open-Air: O, Unknown: U
Conflict	WWI, WWII, Korea, Vietnam
Description of Blast Event	descriptive (not coded)
Number of perimortem fractures/traumatic defects (per individual)	numerical (not coded)
Trauma type	transverse, oblique, comminuted, projectile, blunt force, other
Bone element affected	bone element (not coded)
Lower Limb	Lower Limb: LL, or No
Directionality Present	Yes: Y, No: N, Unknown: U, Indeterminate: I
Directionality	Anterior-Posterior: A-P, Posterior-Anterior: P-A, Inferior-Superior: I-S, Superior-Inferior: S-I, Left-Right: L-R, Right-Left: R-L
Description of trauma	descriptive (not coded)

Methods

Hypothesis 1 is: The fractures seen in individuals who likely experienced aircraft crashes and those who likely experienced blast events differ based on the frequency of different fracture types (transverse and oblique (primary blast trauma), ballistic and comminution (secondary blast trauma), and blunt force trauma (tertiary blast trauma)). This hypothesis was assessed by evaluating the presence or absence of the trauma types within the sample of cases of blast trauma (n=22). If present, the hypothesis was confirmed, if absent, it was refuted.

For hypothesis 2: the comparison of primary, secondary, and tertiary blast trauma to their corresponding trauma types in cases of trauma from aircraft crashes (n=30), a Pearson's Goodness of Fit Chi square analysis was conducted, using blast trauma as observed and aircraft trauma as expected.

Hypothesis 3 dealt in directionality in fractures seen in blast events. For each sub-hypothesis, the percentage of fractures with directionality was determined and assessed. These percentages were then evaluated qualitatively and compared to the hypothesis to determine whether the result necessitated the rejection or acceptance of the hypothesis.

Hypothesis 4 dealt with the differences between enclosed and open-air blast events. Because there was only one individual who likely experienced open-air blast trauma, a statistical analysis was not feasible. Thus the only possible results for hypothesis 4 are inconclusive. In order to examine the data in a more qualitative manner, a simple distribution and evaluation of the data for enclosed blast trauma was conducted, and the open-air trauma case was compared to this distribution to see if it fell inside or outside of the normal distribution. This method was only viable for hypothesis 4B, as all of the other hypotheses had counts of zero for the results.

CHAPTER V

RESULTS

Hypothesis 1

Hypothesis 1 examines the presence or absence of primary, secondary, and tertiary blast trauma within individuals who likely suffered blast events. This hypothesis is parsed into three sub-hypotheses, 1A, 1B, and 1C. Hypothesis 1A is specific to primary blast trauma, hypothesis 1B is specific to secondary blast trauma, and hypothesis 1C is specific to tertiary blast trauma. Primary, secondary and tertiary trauma were found in the individuals who likely experienced blast events, which means that hypotheses 1A, 1B, and 1C are accepted. Therefore hypothesis 1 is accepted.

Hypothesis 2

Hypothesis 2 addresses the potential for similarities between blast trauma and trauma from aircraft crashes. Just like hypothesis 1, this hypothesis was broken into three sub-hypotheses. Hypothesis 2A, anticipated a difference in aircraft crash and blast trauma patterns associated with primary blast trauma, while hypothesis 2B anticipated a difference in aircraft crash and blast trauma patterns associated with secondary blast trauma. Hypothesis 2C anticipated a difference in aircraft crash and blast trauma patterns associated with tertiary blast trauma.

To determine if there was a significant difference between the types of trauma generated by aircraft crashes versus blast events, a Pearson’s Chi Square Goodness of Fit test was conducted to evaluate the data. For the overall Chi Square for hypothesis 2 (evaluating all of the sub-hypotheses together), the Chi square resulted in a p-value of 0.0000, which would indicate that the difference between the observed and expected data was significant. This indicates that there is some difference in the frequency of trauma types between blast events and aircraft crashes. Examining the results of the Chi square (Table 5.1) by primary, secondary, and tertiary data, allows assessment of hypotheses 2A, 2B, and 2C. Beginning with the frequency of primary blast trauma type fractures, there is little difference between the expected and observed values for blast trauma and aircraft crashes. This means that hypothesis 2A was rejected, as no difference was seen between the values. This seems to indicate that there is little difference between blast trauma and aircraft crash trauma relative to transverse and oblique (primary blast) trauma. The results are very similar for hypothesis 2C. These indicate that blunt force trauma occurs at the same rates in aircraft crash and blast trauma (although the value for blunt force blast trauma (tertiary) is only a 6, which, while not below the cut off for conducting a Fisher's Exact test instead, is still a fairly low value). Therefore hypothesis 2C was also rejected.

Table 5.1 Chi Square for Hypothesis 2

	Blast	**Aircraft Crash**	**Total**
Primary (hypothesis 2A)	8	38	46
Secondary (hypothesis 2B)	84	20	104
Tertiary (hypothesis 2C	6	40	46
Total	98	98	196

X^2=257.3842, degrees of freedom=2, p-value=0.0000

Where a difference can be noted in the results is in hypothesis 2B, in the secondary blast trauma characterized by comminution or projectile trauma. Projectile trauma was incorporated into secondary trauma when it became apparent that ballistic comminution alone would exclude probable ballistic trauma. In examining the blast trauma individuals, it was apparent that many traumatic defects were associated with projectile trauma, either penetrating or perforating injuries caused by shrapnel being propelled through an individual. In some cases, pieces of shrapnel were still present in the bone, visible in x-rays or embedded in the perforating defect. Given the low levels of ballistic comminution in some of these cases, limiting results to ballistic comminution excluded what most strongly indicated the presence of a secondary blast trauma injury. Therefore, penetrating and perforating trauma were included as projectile trauma and recorded with the secondary trauma. The results of hypothesis 2B indicated that cases of aircraft crash trauma exhibited a lower number of ballistic comminution and projectile traumas than expected. For blast trauma, however, the value was higher than expected. This indicates that projectile and comminution are more common in blast trauma. Therefore, hypothesis 2B is accepted.

Because one aspect of hypothesis 2 anticipated a difference in trauma generated by aircraft crashes versus blast events, (demonstrated by hypothesis 2B), and the Chi Square indicated there was a significant difference between blast trauma and aircraft crash trauma, hypothesis 2 is accepted. After this result, in order to identify whether comminution or projectiles were contributing more prominently to the differences seen in the initial Chi Square, a Chi square was conducted to separate comminution and projectile trauma (Table 5.2). This resulted in a p-value of 0.0000, which indicates a significant difference between blast trauma and aircraft crash trauma, even when comminution and projectile trauma are separated, with the blast trauma continuing to demonstrate higher rates of comminution and projectile trauma than expected. With only one case of projectile trauma for aircraft crashes, these results are not statistically conclusive, but in visually examining the data, there is a clear difference in the distribution of the frequency of comminution and projectile trauma between aircraft and blast events.

For hypothesis 2, therefore, the results indicate, the frequency of primary and tertiary trauma is much higher in cases from aircraft crashes, and the secondary frequency is much higher in cases from blast events. While an analysis of whether comminution or projectile contributes more to the statistical difference is not conclusive due to the small number of projectile trauma in aircraft crashes, overall, these results indicate that blast trauma features more comminution and more projectile trauma than trauma from aircraft crashes. The higher frequency of secondary trauma in blast trauma, including comminuted and projectile, is responsible for the difference between these two trauma causes.

Table 5.2 Chi Square for Hypothesis 2 separating secondary trauma

	Blast	**Aircraft Crash**	**Total**
Primary	8	38	46
Comminuted	49	19	68
Projectile	35	1	36
Tertiary	6	40	46
Total	98	98	196

X^2=1255.953, degrees of freedom=2, p-value=0.0000

Hypothesis 3

Hypothesis 3 deals with the directionality of fractures in blast trauma. Hypothesis 3A examines this by looking at all the fractures resulting from blast trauma. Of 130 total perimortem trauma recorded within 22 individuals of probable blast trauma, there were 73 fractures wherein the direction was apparent, and 57 wherein the direction was either unknown or indeterminate. This means that 56.15% of the fractures examined exhibited direction. Hypothesis 3A anticipates that individuals who have experienced blast trauma will show directionality. While 56.15% is not a tested statistic, it does demonstrate that directionality can be detected more than half of the time in blast trauma. Therefore, hypothesis 3A is accepted.

Hypothesis 3B examined directionality of primary and secondary trauma within an individual. Given that most individuals had less than ten fractures recorded, in order for an individual to be positive for directionality in primary and secondary fractures, all of the primary and secondary fractures within that individual needed to indicate the same directionality. The only exception to this was if more than one direction was indicated for one fracture. However, as long as one of those directions corresponded with the direction of the fractures on the individual, the positive directionality was maintained (e.g. if one fracture was designated A-P, I-S, and the rest were A-P, then it was still classified as a positive directionality). Findings from the analysis of primary and secondary blast trauma fractures indicated that in the 9 individuals who had primary or secondary blast trauma, 6 had all of their fractures indicating the same directionality within the individual. Thus, 66.67% of individuals with primary and/or secondary trauma demonstrate a unified direction. This trend indicates that there is a unified blast direction in more than half of the individuals who experienced blast trauma. Although this finding is not statistically significant due at least in part to small sample size, this does demonstrate that directionality within an individual can be present. Therefore, hypothesis 3B is accepted.

Hypothesis 3C relates to the directionality of tertiary blast trauma within an individual. There were three cases of individuals with tertiary trauma, and all three demonstrated unified directionality. This indicates a 100% result, meaning that hypothesis 3C is accepted. However, with a sample size of 3, this finding does not allow any conclusive statements regarding the results.

Hypothesis 3D relates to the directionality of blast trauma at an individual level rather than at the fracture level. Of 22 individuals who experienced probable blast trauma, 11 demonstrated a consistent (100%) directionality in their fractures. This results in 50.00% of the directionality of fractures being visible in blast trauma by individual (rather than by individual fracture). This indicates than in half of the cases, directionality of blast trauma within an individual can be determined. Hypothesis 3D was that individuals who have experienced blast events show directionality in their fractures. In this case, although not statistically significant, the results indicate that there is demonstrable direction within individuals who experience blast trauma, although it is not present in all of them. Therefore hypothesis 3D is accepted.

With all four sub-hypotheses accepted, hypothesis 3 is accepted; within this sample, the directionality of a blast event can be interpreted from the direction of fractures in individuals who have experienced these events. However, given that this analysis was almost entirely done on individuals who experienced enclosed events, (only one individual of the 22 probable blast event individuals experienced an open-air blast event) this indicates that directionality may be less multidirectional in enclosed events than anticipated. This result will be discussed in more detail in the discussion section.

Hypothesis 4

Hypothesis 4 deals with the differences between blast trauma in enclosed and open-air environments, stating that the skeletal elements affected, the fracture types produced, and the number of fractures in an individual who has experienced blast events will differ between enclosed and open-air blast events. With only one confirmed instance of open-air trauma, the analysis of open-air versus enclosed blast events is not feasible. This results for all sub-hypotheses for hypothesis 4 are therefore inconclusive, leaving hypothesis 4 inconclusive as well.

While no statistical analysis could be conducted, a comparison using the second sub-hypotheses, 4B, was attempted. In order to look at how the one open-air individual would compare to the enclosed individuals by fracture frequency, a histogram of the enclosed fractures frequencies was created (Figure 5.1). The distribution of the enclosed sample indicates a distribution of a 95% confidence interval of 2.79 to 12.93. The open-air sample has a fracture frequency of 4, indicating that the open-air has a normal number of fractures in comparison with the enclosed fractures. This indicates that for this one open-air sample, the frequency of fractures is not unusually lower or higher than the frequencies of fractures of enclosed blast events. This type of analysis could not be conducted on hypothesis 4A, 4C, or 4D, because there were no cases of blunt force trauma in the lower limb (4A), no cases of primary trauma (4C), and no cases of secondary trauma (4D) in the open-air individual.

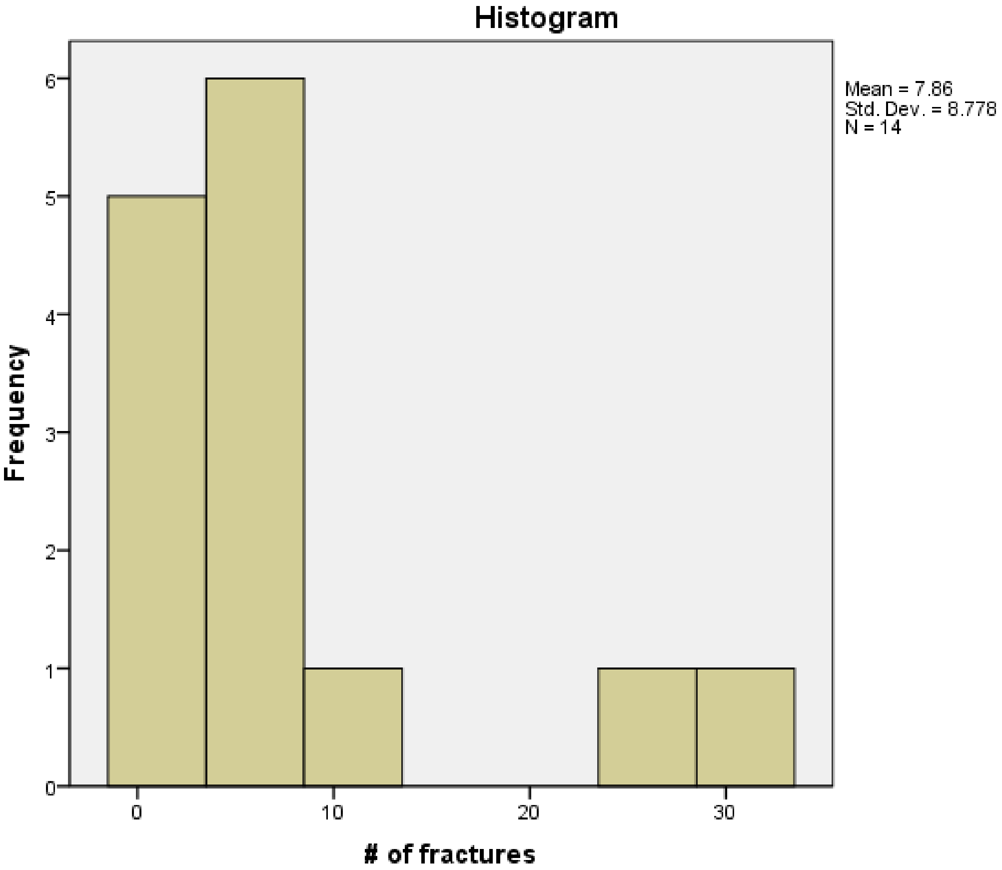

Figure 5.1 Hypothesis 4B: Histogram of 14 enclosed blast event individuals by their number of fractures.

The open-air blast event had 4 fractures, placing them within the normal interval.

Hypotheses 4A, 4B, 4C, and 4D were inconclusive. This indicates that hypothesis 4 is inconclusive. The hypothesis cannot be accepted or rejected because there are too few data. More data is required to make any concrete determination. While the total number of fractures for the one open-air blast event individual fell within the normal distribution of enclosed blast event individuals, a sample of considerably more than one individual for open-air blast events, and preferably more than 14 enclosed blast events, are required to analyze these hypotheses in a conclusive manner.

CHAPTER VI

DISCUSSION

Hypotheses

Hypothesis 1

The presence of primary, secondary, and tertiary trauma within the results correlates well with clinical research, which indicates that the three types of blast trauma are seen in blast injuries (CDC 2009b; Elsayed and Atkins 2008; Ramasamy et al. 2011). The presence of these fractures in the clinical literature and in skeletal remains of individuals who experienced blast trauma means that the clinical literature is supported by the results seen in skeletal remains. Clinical literature is thus proven to be an accurate source of descriptions for skeletal blast trauma types. This may mean that other aspects of clinical literature regarding blast trauma may be equally accurate for skeletal analysis, providing forensic anthropologists attempting to understand blast trauma more sources for research and comparison.

It should be noted, however, that although the types of blast trauma (e.g. transverse, oblique, etc.) were present, whether or not the trauma recorded by anthropologists correctly aligns with the type of blast injury form is unclear. The lower rates of tertiary trauma than anticipated could indicate that there may be some confusion in how blast trauma is defined by clinical literature. Although all of the fracture types expected by clinical literature are observed in this sample, the causes may be quite different.

One of the aspects that could potentially be causing the most confusion in data is where blunt force, transverse, oblique, comminuted, and projectile trauma interact with each other. While these categories were defined as indicative of tertiary, primary, and secondary blast trauma forms within this study, each of these categories have some degree of overlap with others. Comminuted, transverse, and oblique fractures can all be forms of blunt force trauma in the right circumstances (Galloway et al. 2014b). In addition forensic anthropologists often look at trauma based on three basic categories; sharp force trauma, gunshot trauma, and blunt force trauma, a method which is demonstrated by Spatola (2015) to have considerable crossover between types (Spatola 2015). There are only finite ways in which bone can react to force (Galloway et al. 2014a).

Fundamentally, the classification of trauma is based on the velocity of the impact of the bone and an outside force, and the surface area that is impacted by it (Spatola 2015). For slow moving small surface areas, the trauma is classified as sharp force trauma, for fast moving small surface areas, it becomes like gunshot trauma, and for slow and fast moving large surface areas, it is classified as blunt force. However, because blunt force encompasses two categories of velocity and surface area, there is greater potential for variation within this fracture type (Spatola 2015). This is important to this research because it demonstrates why there is a great deal of overlap between the trauma types indicated in this study. A better way to define the trauma types would be to classify them by velocity and surface area, thus providing a more exhaustive and means of determining trauma causality. This would transfer well into blast trauma, although there will most likely always be trauma types that fall in between categories, as velocity and surface area both continuous variables.

Hypothesis 2

Aircraft crashes result in heavy fracture patterns and many fractures on the whole (Wedel and Galloway 2014). The results for hypothesis 2 indicate that there is a difference between expected and observed values for primary, secondary, and tertiary blast trauma type between aircraft crashes and blast trauma. This is predominantly the case in secondary trauma, which includes comminuted fractures and projectile trauma, whereas for primary and tertiary trauma the values were relatively close. These results indicate that secondary trauma may be a useful method for determining whether an individual died in an aircraft crash or a blast event.

When examined via Chi Square analysis with projectile and comminuted trauma separated, neither trauma type contributes more than the other to the difference between blast and aircraft crash trauma for secondary type trauma. While statistics are valuable in measuring significance, a visual assessment of the data can be useful as well. A cell count of 1 for projectile trauma for 30 aircraft crash individuals versus a cell count of 35 for projectile trauma for 22 blast event individuals seems to demonstrate a considerable difference in projectile trauma in aircraft crashes versus blast events. This result could be useful in distinguishing the two events by trauma in skeletal remains, but would require verification through further research. This further research could be conducted using DPAA reports. There is considerably more cases of aircraft crash individuals within the

DPAA reports, which would likely eventually result in a cell count for projectile trauma of a reasonable size. If it did not increase the cell count, that too would indicate the rarity of projectile trauma within aircraft crashes. For this study, the statistical analysis was limited by the low cell count for projectile trauma in aircraft crashes, an issue which will be discussed more thoroughly in the limitations section.

For hypothesis 2A, the results indicated that there was no statistical difference between oblique and transverse type trauma in aircraft crashes versus oblique and transverse fractures in blast events. This indicates that distinguishing between aircraft and blast events would be difficult using these types of fractures as an indicator. Oblique and transverse fractures are used in this study as potential markers of traumatic amputation based on the descriptions of clinical research on traumatic amputation (Godfrey et al. 2017; Hull 1991; Hull 1996; Ramasamy et al. 2011). Based on the clinical research, there should be less primary blast trauma than secondary and tertiary (CDC 2009a), which is consistent with the results when the numbers for secondary and primary are examined. The similarity between the primary blast data and the equivalent trauma in aircraft crashes indicates that oblique and transverse trauma would not be a good distinguishing feature of blast trauma.

For secondary trauma, characterized by ballistic comminution, there is secondary trauma present in individuals who experienced a blast event, which correlates with the clinical literature (CDC 2001; CDC 2009a; CDC 2009b; Hare et al. 2007; Ramasamy et al. 2011). This indicates that a higher level of comminution and projectile trauma may be indicative of blast trauma, and could potentially be used as a means of distinguishing blast trauma from aircraft crash trauma. Aircraft crashes do not typically result in objects being thrown through the air at velocities faster than that of the individuals experiencing the crash. The forces at work in a plane crash more closely align with falls, tertiary blast trauma, or other vehicular crashes, where an individual is in motion at a high rate of speed and is brought to an abrupt stop. This does not result in lots of small objects moving at an individual at high speed in the same way that is seen with blast events. There are certain limitations to this result, however, which will be discussed further below.

While the comminution rates could be inaccurate and less different than is indicated in the results, as is discussed further in the limitations section, there is no indication that there is considerable projectile trauma in the aircraft crash sample that is effectively hidden by the preservation of the remains. Therefore, it is still possible that there is a difference in the projectile trauma rates that is consistent with the results. There is only one case of projectile trauma for the entire aircraft crash sample, and 35 within the blast trauma sample. When one considers that there are 22 individuals in the blast event sample versus 30 in the aircraft crash sample, this may indicate that projectile trauma may be the most indicative means of distinguishing between aircraft crashes and blast trauma, and may be the most distinguishing feature of blast trauma overall. Having a means to distinguish between these types of trauma could be invaluable. For DPAA, the means to accurately identify whether an individual experienced an aircraft crash or a blast event could help accurately identify the individual, and may provide valuable context to their death for their families. For forensic investigators, the ability to distinguish between these types of trauma could provide better understanding of the circumstances of aircraft crashes. If there were a bomb that blew up a plane and caused it to crash, a means of distinguishing between blast trauma and aircraft crash trauma could help identify the potential cause of an aircraft crash.

For tertiary trauma, the results indicating no difference between aircraft crashes and blast trauma is understandable because an aircraft crash is essentially a person falling into an object or objects, usually the ground, but this includes the chair they are seated in, the controls for the aircraft, and the interior of the aircraft, amongst many other potential objects (Wiegmann and Taneja 2003). This means that, especially in slow moving aircraft crashes, where complete comminution does not occur, the likelihood that an aircraft crash will look like tertiary blast trauma is extremely high (Wedel and Galloway 2014). There may still be patterns unique to individuals seated in aircraft seats within aircraft crashes, which could be used to distinguish blunt force blast trauma (tertiary) from that of blunt force trauma in an aircraft crash, but research on this type of specific fracture pattern in comparison to blast trauma has yet to be conducted. With no clear differences between tertiary blast trauma and aircraft crash blunt force trauma, at this point in time distinguishing between the two is not possible. Based on this study, the best means to determine the differences between blast and aircraft crash trauma is through the secondary blast trauma (projectile or comminuted).

Hypothesis 3

Hypothesis 3 demonstrates that direction within blast events can be determined in some cases. For hypothesis 3A, the percentage for overall fractures that demonstrated directionality was 56.15%. While it is not clear how often directionality is visible in other types of trauma, when compared to the percentage of the fractures in the aircraft crash sample with directionality (15.16%) the blast trauma seems to indicate a substantial percentage of directionality. More research is required to determine if this is a normal percentage of directionality for all types of trauma. If other research into the directionality of fractures of all types of trauma indicates that most other causes for trauma result in similar percentages as those for aircraft crashes, this would indicate that blast trauma has an unusually high rate of directionality. However, if other research demonstrates that other causes of trauma have similar rates of directionality to blast trauma, than the results for blast trauma would simply be typical expected directionality for fractures. Having a high rate of directionality is useful in attempting to determine where the blast originated, and what position the individuals were in. In addition, having a high rate of directionality in blast trauma means that if there are many people involved in a blast event, a careful recording process of where they are located and the direction of their fractures could mean that determining the source of a blast would become more possible. That directionality is present at least half the time indicates that blast trauma can have directionality.

The results of 3B and 3C indicate it is easier to determine directionality in secondary and tertiary trauma than in primary trauma. This is fundamentally due to the type of fractures involved. For primary fractures, they are transverse or oblique, which makes determining the direction difficult as the fracture pattern does not as easily indicate direction. In blunt force trauma, a butterfly fracture can easily demonstrate direction, and for projectile trauma there is often an entry and exit wound, indicating the direction the ballistic object traveled. Comminuted fractures are sometimes less easy to determine, but they usually have a projectile-like entry or exit wound, or they have what can appear as a complex butterfly fracture. Within secondary blast trauma, it is simpler to determine the direction of the projectile trauma than of the comminuted trauma. Even when projectile trauma lacks an exit wound, it likely has a radiopacity embedded in the bone that can be used to infer direction when compared to the entry wound (Wedel and Galloway 2014). This is important for forensic investigators of blast events, because this means that individuals who only have primary trauma (which means they are likely close to the source of the blast) are less likely to have directionality in their trauma. Therefore when determining directionality, it is more likely that the source of the blast and position of individuals can be determined by shrapnel trauma.

While not measured statistically, the results of hypothesis 3B result indicate that the direction of a blast event can be estimated two thirds of the time by using primary and secondary blast trauma. This is a relatively large percentage and means that in very specific cases, like where it is a known blast event, and the person's position could be estimated (e.g. individuals seated in a stadium), then the direction of the blast trauma could potentially provide an indication as to the source of the initial blast.

Hypothesis 3C examined the directionality of tertiary blast trauma, or blunt force trauma. Although the result indicated a 100% direction within an individual, the results were limited by a small number of cases, which are discussed further in the limitations section. While finding more robust samples elsewhere may be difficult, there are still a few more decades worth of data at DPAA that could be added to this study, which may result in a more robust sample (although the earlier decades have fewer individuals and less detailed reports, a limitation discussed further below). In addition, there is potential for experimental study, which could provide more rates of blunt force trauma if it is conducted at a larger distance from the epicenter of the blast than previous studies.

However, it should be noted that for every case of blunt force trauma in blast trauma within this study, a direction could be determined. This means that blunt force trauma, despite its apparent paucity in blast events, seems to be a good indicator of direction if found within blast events.

In order to ascertain whether or not blunt force trauma is oppositional to primary and secondary trauma—as it should be if the blast itself and things thrown by the blast cause primary and secondary trauma, while an individual thrown into things should demonstrate tertiary trauma (CDC 2001; CDC 2009b)—the three positives were examined for blunt force and unified directionality. One of the individuals had secondary trauma, and the direction indicated that it came from anterior/right and traveled posterior/left. The tertiary trauma for the same individual was right to left. This means that in the one case where both blunt force trauma and primary and/or secondary trauma were present together, they did not indicate the oppositional direction that was anticipated for blast trauma (CDC 2009a; Frykberg and Tepas 1988). Although it is a sample of one, this indicates that it may be more difficult to determine the direction of a blast event than is indicated by the results of hypotheses 3C and 3B.

For hypothesis 3D, of 22 individuals, 11 demonstrated a consistent directionality in their fractures, which results in directionality being present half the time. The hypothesis was accepted because it shows that directionality can be present, however, it would be difficult to rely on using directionality to help determine blast direction if it is only present slightly more than half of the time. If there were lots of individuals involved in one blast, and their locations immediately after the blast were known, the percentage may be high enough to determine direction, but with only one or two individuals determining the direction of the blast would be more difficult. While this appears to be a fairly positive result, it should be noted that there are 22 probable blast event individuals and only 15 blast events. This means that many blast events that had multiple casualties had one person with directionality in their fractures and one or more individual with no directionality. Of the 11 with directionality, two were in the same blast event. Whether these two individuals were in an enclosed or open-air environment was unknown, however it was known that they, along with one other individual who did not demonstrate unified directionality, were killed by a mortar shell in WWI. The unidirectionality of two individuals for one blast event may indicate that they were in an open-air environment, because the blast was not bounced off of other surfaces creating multidirectional trauma. Before relying too much on this conclusion, it should be noted that the majority of the blast event sample are from enclosed blasts, and many of them demonstrate unified directionality. This seems to indicate that there may not be as strong a correlation between multidirectional trauma and enclosed blasts as anticipated. Given the myriad conditions of these enclosed blast events (e.g. foxholes, buildings, ships, planes, tanks) there may be differences in unidirectional and multidirectional trauma based on the enclosed environment within which the blast event takes place. As there are very few enclosed blasts environments in this sample that match any other, this analysis was not attempted for this study.

Based on these results, when evaluating individuals who have experienced blast trauma, an examination of directionality should be attempted, but it is possible that the trauma may indicate multiple directions or no direction at all. When the individuals who had demonstrable, but not unified, direction are included in the number of individuals with directionality, the number rises to 16 out of 22, resulting in 72.72% of the sample demonstrating directionality. It should also be noted that one of the cases positive for unified directionality had 31 fractures. This indicates that the directionality could be more present and consistent than is indicated initially by hypothesis 3D.

All four of these sub-hypotheses would benefit from a larger sample of data. While the data used for this study did not include all of the individuals who have ever been recovered by DPAA, they did include the last two decades worth, and it is likely that the previous decades could yield more data. However, there are fewer individuals per year the further back into DPAAs records one looks, so there may not be many more individuals with probable blast trauma than those collected. Another potential source of more research could be more experimental research, perhaps using slow motion cameras to determine how bones are fractured, and the direction of force at the time of impact. Either one of these avenues of research could provide more depth to this study.

Hypothesis 4

Hypothesis 4 states that there is a difference between the fractures seen in enclosed blast trauma and open-air incidents. There was only one open-air blast event, which could offer no statistical comparison between enclosed and open-air blast events. In addition, the one open-air individual had no lower limb fractures, however, there were many enclosed individuals who also did not have lower limb fractures. Therefore, drawing any conclusions from these comparisons would be presumptive. For the enclosed sample, none of the blunt force trauma were of the lower leg either, which means perhaps the only thing that can be said about this result is that there are less blunt force trauma injuries in lower legs from blast trauma overall than are indicated in clinical literature

(Ramasamy et al. 2011). Ramasamy and colleagues (2011) indicate there should be considerably more tertiary trauma to the tibia and fibula than any other bone element or body region. In addition, the trauma to the tibia and fibula should be more pronounced in an enclosed environment rather than an open-air environment (Ramasamy et al. 2011). This result indicates that the results from clinical literature are not demonstrated in the skeletal remains, however, there are many lower limb bones missing from the 22 blast event individuals. While very few are associated with a fracture, their absence may indicate that in some of these cases there were higher rates of fractures in the lower limbs, but they are not visible due to difficulties with preservation or potentially due to the blast event itself.

It should also be noted that there is not a significant difference between overall (combined enclosed and open-air) blunt force trauma in the lower limbs versus that of the rest of the body, which further indicates that there is not a predisposition for trauma in the lower legs over the rest of the body. In order to examine these results further, the other parts of the body were divided into more specific locations on the body, dividing them into cranium, torso (including pelvic and shoulder girdles), forearm and hand, upper arm, upper leg, and lower leg. When divided in this way, the location with the highest number of fractures is the torso with 56. The crania have 23 fractures, the lower leg has 20, the upper arm has 12, the upper leg has 11, and finally the forearms and hands have 8 fractures represented. While not analyzed statistically, it is interesting to note that of the limb injuries, the lower leg indeed has the highest rate of fractures. While this does not directly correlate with the anticipated hypothesis, there is a slightly higher rate of lower leg trauma than other limb areas for all blast trauma. The high rate of lower leg trauma is valuable because it may indicate ways in which blast trauma can be determined by fracture frequency and location. However, this directly correlates with the expected injury patterns for aircraft crashes as well, so despite this being a possible pattern for blast trauma, high rates of lower leg trauma would still be relatively indistinguishable from aircraft crash trauma. If the types of trauma and the specific bone elements for each trauma category were analyzed, this may allow for a more distinct difference between aircraft crash trauma and blast trauma. Aircraft trauma often results in severe fracturing of the calcaneous and talus, which may differ from blast trauma with more thorough investigation. In addition, there are many more aircraft crash individuals present in the DPAA records, which if included in future research may provide a more robust sample for comparison. With more analysis these results could be determined to be consistent enough to be predictable.

For hypothesis 4B, because there are so few open-air blast trauma individuals, the data could not be evaluated statistically, but the comparison of the one open-air individual indicated that their frequency of fractures was within the normal range for enclosed fracture frequency. This means that in this one case, there was no difference between enclosed and open-air blast trauma frequency, however, to base any real discussion on one sample would be poor analysis. Because there is not enough data for this sub-hypothesis, nor for hypothesis 4C and 4D, drawing any conclusions comparing open-air blast trauma to enclosed blast trauma is impossible for this research. The low rates of open-air trauma were surprising, as one would imagine that there would be more cases of individuals encountering shells, grenades, and landmines out in the open. However, it may be that these individuals were underreported, as there are a many unknowns in the sample as well. While it may be unlikely to have more open-air blast event individuals from the DPAA reports, it is possible that there are other reports indicating blast events in open areas. While often associated with civilian deaths, landmines are high explosive blast events that affect roughly 10,000 individuals each year (Sheets 2003). Perhaps incorporating blast trauma from landmines could provide a more robust open-air sample, allowing for more interpretation. In addition, more experimental research could be conducted, creating controlled environments to test the effects of a blast in an enclosed area versus an open-air area. The problem of a low sample size for open-air blast events is discussed further in the limitations section below.

Limitations

As mentioned above, there are limitations to these results that are important to consider. The way in which the reports were written, the condition of the skeletal remains, the difficulties with historic accounts, the number of individuals in the samples, and potential other causes for trauma types, all create difficulties in recording data and in conducting a rigorous analysis. These limitations did not mean that the analysis of these data was impossible, however, more robust samples, or more experimental research is required to determine whether the results indicated in this thesis are conclusive. Although 1700 cases were examined, there are likely more cases at DPAA that can be incorporated into this research, which perhaps could lead to a more robust sample. There also may be data on blast trauma available through other sources, such as military records, or data collected for reports for humanitarian efforts, like data on landmine injuries or terrorism. While existing publications discuss these data, the original data may be accessible for other analyses specific to blast trauma. In addition, controlled experimental research may provide data regarding probable fracture types, locations, directionality, and the differences between enclosed and open-air trauma. Experiments could include analysis of the biomechanics of blast trauma, and could incorporate predictive computer modeling to help determine what likely patterning is possible through biomechanical analyses. They could also include experiments similar to those conducted by Christensen et al (2012, 2013), but include slow motion cameras to attempt to see what is taking place as the fractures occur. More data would provide more conclusive results in some cases, and provide corroborating or contrary evidence to what has been concluded within this study, making the trauma caused by a blast event more predictable and better understood. Part of the reason more research is required is due to the limitations of these data.

This research was limited by the way in which the reports were initially written and the condition of the remains. There is a possibility that these results are not consistent, due to differences in recording through time and by different individuals. While the classification of each type of fracture was attempted to provide consistency across the sample, in some cases no photo was available to assess the fracture, or the photo was not of an angle wherein a fracture type was discernable. In those cases the assessments made by the forensic anthropologists who did the initial analysis were the only record of these fractures. While the DPAA uses SOPs (Standard Operating Procedures) to keep all reports consistent, these data span almost 20 years of research, and the standards are continuously changing as new methods and requirements are determined to be relevant to the research. What was explicitly recorded and what was cursorily mentioned is very dependent on when and who did the analysis, the current accepted methodology, the training of the individual reporting, and the overall goal of the reports at the time. In some cases, there were perimortem fractures mentioned, but no descriptions of them were made, and no photographs were present. In these cases, the fractures were recorded as present, but any analysis of fracture type or direction was impossible. In other cases, the direction was not indicated, but it was not clear whether it was not indicated because it was not evident, or if it was not indicated because it was not analyzed or reported. If not analyzed or unreported, then it is possible that there was direction present, which could alter the results. More recent analyses were much more detailed and uniform in their form and descriptions. The older reports are indicative of different methodologies for forensic anthropologists, and different SOPs, used in the past.

Some of the problems with recording are reflected in the testing of hypothesis 2, wherein a much smaller number of tertiary trauma is present than was anticipated. Secondary and tertiary trauma are expected to compose the majority of injuries (CDC 2009b). For blast events, however, the primary and tertiary trauma also both occur at low frequencies. This is an anticipated result for primary trauma, as traumatic amputations are not considered common forms of blast injury (Born 2005). However, based on clinical research, there should have been more tertiary trauma. This inconsistency in the results could be partly due to the lack of standardization over time in the DPAA reports discussed above. Another possible explanation for these results is that the individuals experiencing this trauma type were more likely to survive, so do not appear in a sample of those killed by blast trauma. If someone was far enough away from the blast epicenter, they may have been knocked onto hard objects, creating tertiary (blunt force) truama, but would not suffer any fatal injury. Another possible cause for the low tertiary trauma results is that this is accurate, and there is less blunt force trauma generated by blast events than was anticipated.

If there is less blunt force trauma generated by blast events than anticipated, this could indicate some other possibilities. First, that blunt force trauma is not an accurate means to measure tertiary trauma, and that there is some other fracture type that is more common for tertiary blast trauma that would have to be researched further through careful experimentation, controlling for possible variables and examining the biomechanics at work to determine its nature. Second, that there is less tertiary trauma than anticipated, and that most blast event trauma is reflected in comminuted fractures and projectile trauma. All of these theoretical causalities indicate that experimental studies examining the forces at work on an individual thrown in the air by a blast wave and cast into hard objects would be valuable for future conclusions regarding blast trauma.

While correct current recording standards for DPAA and forensic anthropology in general were not always present in the older reports, even when they were present convoluted results could still occur. One way difficulties in this analysis could result even when all the correct methods were followed, was in determining blast direction from the fracture directionality using standard anatomical position. This method, which is standard for recording trauma in forensic anthropology and bioarchaeology (Buikstra and Ubelaker 1994; DPAA), unfortunately cannot fully identify blast direction. If the position of the person during the blast was known, or if the blast is unidirectional and the epicenter known, determining the direction of the blast, or the position of the person, respectively, would be simple. However, with both variables unknown, as is often the case in a blast event, determining both the body position and direction of the blast/s becomes difficult. The position of an individual prior to a blast event would vary to a large degree. While in an aircraft explosion or a stadium people would most likely be in their seat, even in that circumstance there would still likely be variation in how they sit in a chair. In addition, the epicenter of the blast may be indicated by other forensic means, but in cases of building collapse or fires this may be less clear. The analysis of the DPAA sample relied on the assumption that there was likely one overall blast direction for each event, but it is possible that the trauma may indicate multiple directions or no direction at all. Multi-directional results could indicate a number of different causalities. Since many of these individuals experienced blast events in enclosed environments, there is a good chance that they were experiencing ricochet forces off of ‘walls’, the ground, and other surfaces (Chaloner 2005; Frykberg and Tepas 1988). In addition, a body does not stay neatly in anatomical position as it is impacted, so even though an individual may have a superior to inferior trauma pattern on the skull and an anterior to posterior trauma pattern on the torso, this may simply indicate that they had their head down as the blast wave or shrapnel impacted them.

The non-anatomical position of most individuals at any given moment applies to all of the hypotheses discussing directionality. Using directionality in examining blast events would need to be conducted very carefully, as depending on the position of the body, different interpretations can be argued. Ultimately, it is the responsibility of the forensic anthropologist to record data in the most accurate way possible, meaning that direction should be mentioned, and if it seems to correlate with trauma on other skeletal elements, that should be mentioned. In addition, there are other traumatic injuries that can provide information on directionality, but which were not always discussed in detail in

FARs done by DPAA anthropologists. Injuries associated with hyper- and hypoflexion can show directionality in which the body is impacted by force, either the blast wave or other other object, which can also indicate direction. In one of the DPAA cases, the anthropologist noted that there were compression fractures and spinous process fractures along the vertebrae, which indicated that the torso was hyperflexed (DPAA). While not explicitly indicative of direction in the same way that a single butterfly fracture is indicative, this type of holistic approach to determining direction in blast trauma could provide a clearer picture of the direction of the blast. As discussed above, this is still complicated by circumstances involving multidirectionality and body position, but a holistic approach to the problem could lead to more accurate results overall. Ultimately, attempting to determine the location of a blast is not a job for a forensic anthropologist, but instead for a forensic investigator or detective. Despite the possible confirmation that a forensic anthropologist could provide in these circumstances, there is a good chance that there is other forensic evidence that can be incorporated into the analysis by other experts (Christensen et al. 2014).

In addition to the way in which the reports were written and the data recorded, the data are constrained by the condition of the skeletal remains. In many of the aircraft crash individuals, there were only a few small bone fragments used to evaluate the conditions of the entire skeleton (DPAA). The small number of bone fragments often still have considerable perimortem trauma present, (e.g. four fragments, and four perimortem fractures). The number of fragments was not used to determine the number of fractures. Rather each case of perimortem trauma that was identifiable based on the condition of the fracture margins seen on a fragment was recorded. For some fragments there was no clear perimortem trauma visible. If the entire skeleton of these individuals was comminuted, resulting in trauma on almost every element, then the data for comminuted fractures in aircraft crashes could be substantially under-recorded in this study, meaning that the difference between aircraft crash-caused comminuted and projectile trauma and secondary blast trauma may be exaggerated. This may be true of the comminution, however, for projectile trauma the difference between the aircraft crash trauma and blast trauma remains pronounced.

The second limitation is the historic documentation. Dealing with historic accounts is always difficult because of some of the fundamental difficulties associated with historiography. Much of the data used to determine the location of an individual and the details of their death comes from their military files, wherein reports were filed by commanding officers detailing their deaths. These reports were most likely partly reliant on eyewitness accounts. Luckily, many of the reports were filed within a few days of death, which meant the accounts were fresh in the minds of the eyewitnesses. However, in other cases, soldiers had become POWs and their statements were only taken when they were released, leaving a long time between the time of an individual's death and the eyewitness account being reported. In some cases, the eyewitness account corroborates with where the remains were found, which offers some measure of confirmation of their story, but in other cases, there is little confirmation of the eyewitness' account, which could in some circumstances be inaccurate.

In addition to the eyewitness account problem, the historic data often do not provide the details that would have been ideal for this investigation. In particular, the enclosed versus open-air conditions of the blast event were difficult to determine. In many cases, all the information offered was that an individual was hit by a shell, mortar, or grenade. While this would definitely be a blast event, no data were provided to indicate whether they were in a foxhole, standing between tanks, or in an open field. While more historic research may indicate likely locations for these individuals was dependent on if the group of people they were with were in a defensive or offensive position (e.g. foxholes versus moving forward over open ground), without more detail about their circumstances, any assessment would be mostly supposition.

The historic circumstances of the DPAA sample also may be contributing to complications in data interpretation. Even if the circumstances are assumed to be perfectly accurate, the differences between the DPAA sample and the clinical research that it is being compared to could be leading to inaccuracies in the interpretation of the analyses. For example, Ramasamy and colleagues' research, on which many aspects of the hypotheses were based, were conducted on modern combat casualties from Afghanistan (Ramasamy et al. 2011). In these modern cases there is a high likelihood that the casualties were wearing some sort of armor, which would perhaps exaggerate the frequency of lower limb injuries by having less injuries in the torso and head than if they were not wearing armor.

The third limitation were small sample sizes, precluding a more rigorous statistical analysis. There were low sample sizes that resulted in complications in the analysis for all hypotheses except hypothesis 1. For hypothesis 2B, when the secondary blast trauma was separated out, it resulted in a cell count of 1 for projectile trauma in aircraft crashes. A cell count that small can lead to statistical 'noise' which can skew results inaccurately (Gelman 2011). In addition, for hypothesis 2C, tertiary trauma for blast trauma had a total cell count of 6, which, although statistically appropriate to use, is still small, and caused difficulties in analyses in hypotheses 3 and 4 as well.

For hypothesis 4, because the historic data were often inadequate for providing more detail on whether the circumstances of death of an individual were open-air or enclosed, only one individual was confirmed as experiencing an open-air blast event. A sample size of one does not allow for any analysis of trends or patterns within that sample's particular circumstance or event. Even the values for enclosed blast events were low for a statistical analysis, with only 14. While analysis of the data is still possible with small sample sizes, perhaps a comparison with military medical records, or reports from landmine casualties would help confirm or deny the results of this study on a scale that could help predict patterns more accurately in the future.

The last limitation that influences these data is other potential causes of blast trauma. All of these trauma types can be caused by other mechanisms (Wedel and Galloway 2014). This means that determining whether an individual experienced a blast event requires a careful examination of the evidence. Hypothesis 2A indicates that oblique and transverse frequencies in trauma are not unique to blast trauma. There is no marked difference between aircraft crashes and blast trauma in regards to oblique and transverse fractures. While they are present in individuals who experience blast events, they are not specific to blast events, and thus should not be relied upon to determine blast trauma. Perhaps in an individual who has been identified as experiencing blast trauma through other means, oblique and transverse fractures can be used to help distinguish the proximity to the blast event. However, there is a possibility that this type of trauma can possibly be confused with aspects of a comminuted or blunt force fracture. More research is required to correctly assess the exclusivity of transverse and oblique fractures to primary blast trauma within individuals in a blast event before determinations of an individual's proximity to a blast center can be accurately made. This research would either require access to X-ray records of individuals who experienced blast trauma, either through military or hospital records, or experiments specific to the skeletal effects of traumatic amputation due to blast events. The assessment of associated comminution or missing distal portion of a bone could be used to help distinguish oblique or transverse primary blast trauma, however, this is further complicated by taphonomic conditions, which can result in missing portions of bone (Christensen et al. 2014), obfuscating potential results.

In comparing the differences between blast and aircraft crash trauma, the projectile trauma seemed to indicate a means to distinguish between blast and aircraft crash trauma. However, it is important to recognize that there are other mechanisms of trauma that can result in similar patterning. When discussing projectile trauma, one must consider how gunshot trauma may be confused with these results. Projectile trauma can perhaps be used to exclude aircraft crash trauma, but it does not exclude gunshot trauma. Before this result could be used for any kind of conclusive analysis a comparison between gunshot trauma and blast trauma would be necessary to determine if blast trauma is significantly different. Studies similar to this have been attempted in the past. For instance, Dussault et al. (2016) conducted a study examining the locations of blast trauma on the body compared with the locations of gunshot trauma on the body, and were able to determine that gunshot wounds tend to be more focused on the head and torso, while blast trauma is more diffuse. However, while their research examines location, the appearance of the traumatic lesions caused by shrapnel versus the traumatic lesions caused by gunshots may provide another method of distinguishing whether an individual has suffered a blast event or gunshot, perhaps by the morphology of the entrance and exit wounds. One aspect that was present in 4 of the 22 blast trauma individuals is embedded metal or radiopacities (small points on a radiograph that are opaque, indicating a higher density, most likely metal). While gunshot individuals also can have radiopacities, there may be a difference between their frequency, location, and shape, which could perhaps also be used to distinguish between blast event and gunshot individuals.

While the limitations of the data collection process, the condition of the remains, and the historic context of the sample cannot be easily mitigated, many of the other limitations can be accounted for and addressed through future research. For most of the limitations discussed above, a larger sample size and/or a controlled and well-recorded experiment would allow for more complete and detailed analyses.

Future Research

As discussed in the background chapter within this thesis, there is a great deal of room for future study of blast trauma within forensic anthropology. The results of this thesis indicate that much more experimental research should be conducted to help determine the causes and appearance of blast trauma in human bone. In order to help explain and analyze the results seen in hypotheses 1 and 2, more studies similar to Christensen et al's (Christensen and Smith 2013; Christensen et al. 2012) studies where the proximity of blast events are studied would be beneficial. Using a slow-motion camera could possibly indicate what type of trauma is taking place, which could then be correlated with fractures in bone. In addition, studies examining the differences in appearance between shrapnel ballistic trauma and gunshot ballistic trauma done in much the same way as the comparisons between blast trauma and aircraft crash trauma done in this study would help distinguish between blast trauma projectile trauma and gunshot trauma.

Hypothesis 3 would also benefit from an experimental study with different proximities and a slow motion camera to determine the exact direction within fractures. Hypothesis 4 would benefit from experiments with enclosed and open-air conditions of blast trauma, especially since there is so little data present.

All of the hypotheses would benefit from experimental data done using human cadavers to determine results of blast waves on the human skeleton. Using human cadavers eliminates possible confusion in results based on non-human analogs. In controlled circumstances, the exact blast trauma causes could be identified, and the associated traumas classified based on these results. For example, traumatic amputations could be simulated in an environment where the cadaver is only impacted by a blast wave. In combination with a slow motion camera, this could allow researchers to determine the type of fracture created with this form of blast injury. Using cadavers within this avenue of research, especially in combination with slow-motion capture cameras, the exact circumstances of fractures could be better understood.

Obtaining cadavers for research is not always feasible in terms of access and availability. When this is not an option, there are still data sets that may be augment the DPAA data set. There are likely military medical records that thoroughly document many blast event injuries. These may include X-rays and photos, which could provide a forensic anthropologist trained in radiograph analysis, the means to examine other blast trauma and provide another dataset where blast trauma research can be conducted.

It should also be noted that although upwards of 1700 case files were examined for this study, there are still many thousands of case files at DPAA. While there are fewer DPAA cases further back in time, there may still be more probable blast event individuals who could be incorporated into an extension of this study and further evaluated in the future. In addition, future studies using the same data but incorporating new lines of research could reveal further differences between aircraft crash trauma and blast trauma. One method could be to examine the trauma by homunculus (a map of the skeleton used for recording skeletal remains), where the trauma are examined at the level of the individual compared to other individuals. This could potentially highlight differences based on the regions of the body affected, whether or not bilateral trauma is seen in aircraft crash trauma or blast trauma, or if there are certain bone elements that correlate within an individual experiencing a blast event or aircraft crash.

CHAPTER VII

CONCLUSION

Due to a paucity of blast trauma individuals, much of the results for this analysis remain inconclusive and require more data to determine their efficacy in potentially identifying individuals who have experienced blast events from their skeletal remains. However, while there is more research required, there are some conclusions that can be drawn from these results.

The results from hypothesis 1 demonstrate that the variety of trauma types coinciding with primary, secondary, and tertiary blast trauma can be found in individuals who have experienced blast events. The results from hypothesis 2 lead to the conclusion that secondary trauma, projectile trauma in particular, may indicate a means to distinguish between aircraft crash and blast trauma. Before this method could be used as a means of distinguishing blast trauma from other types of trauma, an analysis comparing gunshot projectile trauma and blast projectile trauma must be conducted to allow for those two to be distinguished from each other.

For hypothesis 3, the results were more qualitative. Directionality is definitely visible in blast trauma, particularly in secondary and tertiary trauma. This means that in the future, direction of trauma could be used to provide details on where blasts may have originated if the location of individuals was known. Caution must be taken in determining the meaning behind direction, as an individual could be in many different positions when exposed to a blast event. Directionality does not neatly align to anatomical position.

Finally, due to the paucity of confirmed open-air blast event individuals, hypothesis 4 remains the most inconclusive. With only one individual who is recorded as having experienced open-air trauma it is difficult to determine whether there are any trends between open air and enclosed blast trauma. When examined qualitatively, the open-air individual has no lower limb blunt force fractures, versus the 6 lower limb blunt force fractures present across the enclosed sample. This is not conclusive, but it is consistent with the hypothesis. The one open-air individual is also limiting when examining the distribution of total fractures, the comparison indicates that there are less total fractures in the open-air individual than in the enclosed sample, which is again consistent with the hypothesis but to draw any conclusions from these data would be presumptive and inaccurate. The one open-air trauma individual means that the comparison between open-air and enclosed in this study should be considered more of an exploratory analysis, and would benefit from more research in the future with a more robust sample size. However, when the regions of the body that were fractured for both enclosed and open-air were combined, they resulted in a similar distribution to the clinical literature, with the lower limb having more fractures than any other long bone region.

While more research is required for all of these hypotheses, it is interesting to note that projectile trauma may be used as a means of distinguishing blast trauma from aircraft crash trauma. Directionality can be seen in blast trauma in some cases, and could potentially provide valuable information about blast location in a forensic investigation, although it should be approached cautiously. Forensic anthropological research into blast trauma continues to be a field in which there is a great deal of room for future study.

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