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PLASTIC AND RECONSTRUCTIVE SURGERY: A SIGNIFICANT CONTRIBUTOR TO THE MANAGEMENT OF MODERN WAR INJURIES

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PLASTIC AND RECONSTRUCTIVE SURGERY: A SIGNIFICANT CONTRIBUTOR TO THE MANAGEMENT OF MODERN WAR INJURIES

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ABSTRACT

Plastic and Reconstructive Surgery (PRS) contributes core surgical knowledge and techniques for the early management of select modern war injuries. The majority of injuries in today's asymmetric, counterinsurgent warfare are caused by blast, ballistic and burn forces, resulting in the creation of complex wounds. It has been proven, throughout history, that maximal medical recovery and functional rehabilitation occur when these complex wounds are managed definitively at the earliest possible time. The reconstruction of these wounds poses very special and unique challenges, often requiring the special skills of a Plastic and Reconstructive Surgeon (PS). The core surgeons deployed by the coalition forces in modern warfare (General, Orthopedic, and Maxillofacial Surgeons) are typically not trained to provide Plastic and Reconstructive Surgical care. Definitive care can therefore be delayed, threatening recovery time, functional rehabilitation, and in some instances, limb salvage. Delayed recovery, leading to increased lengths of stay, also has an immense impact on the operational efficiency of the *Role 3 hospital* by severely constricting its capacity.

This thesis argues support for the inclusion of Plastic and Reconstructive Surgeons in the group of surgical specialists deployed to theatres of operation in today's conflicts. In the absence of available Plastic and Reconstructive Surgeons, there is a core subset of knowledge and procedures typically practiced by a PS that should be taught to the current and future deployed military surgical specialists.

This thesis concludes that a critical subset of Plastic and Reconstructive Surgical knowledge and skills is pivotal in the effective early management of modern war injuries.

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I finally wish to express special thanks to my parents, Doctors Audrey and Roger Thibert, not only for their lifelong dedication, devotion, and support of my educational endeavors, but also their tireless assistance as editors for this thesis.

I dedicate this thesis to the countless people injured in our modern wars, some of whom I was privileged to have contributed to their care and rehabilitation as a Plastic and Reconstructive Surgeon.

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PREFACE

In July 2008 I had the distinct honour of being the first military Plastic and Reconstructive Surgeon in the history of the Canadian Forces to deploy to a theatre of war. I was at the *Role 3* Multinational Medical unit within the Kandahar Air Field (KAF), Afghanistan. I became deeply interested in determining what role a Plastic and Reconstructive Surgeon would play in the management of acute battle injuries.

This thesis focuses on the acute management of war injuries where there was participation by NATO countries, and the wars in which Canada and our allies have been engaged lately.

It is recognized that this thesis contains material that is technical and specific to the medical profession. I have highlighted the medical terms in *italics,* and defined them in the Glossary section to assist non-medical readers in better understanding the subject matter.

INTRODUCTION

Throughout history mankind has been subjected to every conceivable type of trauma. Regrettably, humans have also had a long history of interpersonal conflict, resulting in combat as a significant source of the trauma that we have encountered. Human conflicts are not a rare phenomenon and have existed since time immemorial. People get involved in wars because of various reasons, for example, to protect what they think is rightfully theirs, to defend themselves, to decisively resolve a dispute, or just for the sake of acquiring more power, wealth or fame. Sometimes, people engage in conflicts just to prove a point[1].

However, in ancient times the wars were quite different from conflicts of today. Previously, fixed hours were appointed for the wars, and armies possessed only a restricted number of arms and ammunitions. It was the emergence of high-speed delivery systems and gunpowder that brought a never-ending number of casualties arising from blast wounds, burns and gunshots[2].

Apart from "carpet bombing," the satellites responsible for global positioning allowed for the emergence of missiles that were guided by lasers and facilitated explosives in destroying whole locations. By doing so, they caused massive destruction, killings, and an unfathomable amount of grief to the civilians who got caught between the two warring parties. Moreover,

[1] R Eldar and M Jelic, *The Association of Rehabilitation and War, Disabil Rehabil,* no. *25* (2003): 1019.

[2] Ibid, 1020.

adding to the damage caused by wars and weaponry, there have been errors, both mechanical and human, that have further aggravated the possibility or the occurrence of collateral damage[3].

The art and craft of surgery historically was practiced well before medicine was studied as a scientific discipline. There are examples from the prehistoric days when those who were familiar with surgery tried to repair the damage or injuries caused by encounters with dinosaurs, coincidental accidents, or combative cavemen. Techniques were developed out of necessity to ensure survival. Just as the modes of inflicting injury have evolved, so too have the methods to repair those individuals with these inflicted injuries. Experience gained in the World Wars, Vietnam, Korea, and in the Afghanistan and Iraq wars, has led to an evolution of new surgery manuals, techniques, and principles available to the military surgeons treating soldiers and civilian war casualties alike. The artillery that is being used in Afghanistan and Iraq is so advanced and so intense that soldiers suffer from severe, multiple trauma due to blast, bullet and burn injuries[4].

As the number of conflicts and wars increased, the necessity or the requirement to supply adequate medical and health services also increased. A need for innovative developments and establishments were required with respect to the fields of Maxillofacial Surgery, Cardiothoracic Surgery, Orthopedic Surgery, Neurosurgery, and Plastic and Reconstructive Surgery (PRS). After World Wars I and II ended, rehabilitation and the provision of Physical Medicine became important constituents of the overall treatment provided to the injured casualties[5].

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[3] Ibid, 1021.

[4] SM Stankorb, M Salgueiro, and A Grediagin, *Enteral FeedingPractices for U.S. Service Members in a Deployed Combat Support, Military Med,* no. 174(7) (2009): 685–7.

[5] Ibid

Medical doctors today have been educated by the encounters and experiences from the battlefield. Rocco Armonda, MD, who served as both a Neurosurgeon and a Colonel in the US Army, stated that the strategies of the enemies, the personal protection for soldiers, and the apparatus used for treatment formed the prevalent methods used by practitioners serving in present wars. Dr. Armonda described his experiences with treating soldiers and the general public injured during the Iraq war. He made this presentation at the 94th Scientific Assembly and Annual meeting of the Radiological Society of North America (RSNA)[6].

Military medical facilities have played an important role in providing healthcare to those individuals injured in the War on Terrorism, which is now a global phenomenon. The specific types of injury needing further improvements and refinement in treatment have included complex injuries to the extremity bones with associated massive soft tissue loss, bone and soft tissue injuries involving the craniofacial skeleton, and massive burns. These injuries have been a direct result of the wounding systems that impart high energy to the tissues[7].

What remains to be established is the best possible timing and methods of treatment for the aforementioned complex injuries. This is explained by the fact that the injuries and ailments resulting from the contemporary high-energy blast trauma have not been widely seen before and are not commonly encountered in modern civilian trauma care settings. The injuries that are caused by blast trauma can cause wounds of various shapes, sizes, involve many areas within the same person, cause massive tissue de-vitalization, inflict considerable loading of foreign bodies,

[6] Ibid, 688.

[7] AR Kumar, R Harshbarger, and B Martin, *Plastic Surgery Challenges in War Wounded, Military Wound Care Wound Healing Society,* no. 2 *(*2009): 20-29.

and team up with the ever present endemic bacterial pathogens, Acinetobacter and Mycobacteria, as well as fungi, all leading to extreme and complicated damage to the tissues[8].

Even though progress has been made in triage and accessibility to health care, specifically trauma and critical care, definitive care may not be accessed as quickly as needed. The various concomitant complex wounds that are present within each patient often tend to complicate the delivery of care, and delay access to the critical services of reconstructive care. This leads clinically to lengthy durations of stay in the *Role 3 Intensive Care Unit* (ICU), delayed or poor wound healing, poor limb salvage, delayed rehabilitation, and operationally, diminished efficiency of the *Role 3* hospital[9].

Early radical *debridement*, aggressive fixation of fractures with early bone grafting, and timely coverage of wounds with vascularized tissue are some of the significant principles of the civilian, non-war surgical practice that should also be adhered to, when possible, for war injuries. The number of concomitant injuries that afflict individuals in a war setting, along with the complex and complicated nature of the injuries, can make fracture fixation and soft tissue coverage a challenge[10].

Studies have revealed that the best possible time to provide the definitive treatment to the wound is the sub-acute period, which lasts until three weeks after the injury. The implementation of conventional fracture and wound treatment methodologies in conjunction with the formulation

[8] Ibid
[9] Ibid
[10] Ibid

and development of innovative techniques has seen successful results in the face of challenging and complex military injuries[11]

The current literature regarding modern war wounds reveals that coverage of these wounds at the earliest possible time offers the most optimal results, but at the expense of higher complication rates. Civilian extremity wounds treated in the sub-acute period have a lower complication rate than extremity wounds encountered in a war environment[12]. The difference in complication rates between these two groups is influenced in the war group by factors such as time to evacuation, exposure to complicated desert micro-flora, larger areas of wounds, and the increased incidence of simultaneously occurring complex wounds[13].

Injured soldiers are now treated as a result of evolving protocols that have been formulated during the time of the Iraq and Afghanistan battles. The situation of extremity trauma is but one example. Individuals with extremity wounds are at first provided treatment by the use of serial debridement (cutting away of loose, devitalized, infected, or *necrotic* tissue). This process proceeds until the injured tissues are considered to be clinically clean, and contain tissues that are viable. A newer technique, known as negative pressure dressing therapy, was implemented to treat the wounds in preparation for operative intervention. This method accomplishes both *debridement* of the tissues as well as the induction of *neovascularization* (new vessel growth). Definitive fracture care in Coalition soldiers is often not often carried out until the individual reaches a *Role 4* facility. It is important to note that the *Role 4* hospital option is

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[11] Ibid

[12] AR Kumar, "*Standard Wound Coverage Techniques for Extremity War Injury," J Am Acad Orthop Surg* no. 14(10 Suppl) (2006): 62.

[13] AR Kumar and LE Bermudez, "*Microsurgery in War Wounds," Presented at the 69th Scientific Meeting of the American Society of Plastic Surgeons, (Los Angeles, CA: ASPS:* 2000), 2009.

typically only available for Coalition soldiers. The injured host nation persons (civilian, police, and military) will only receive the highest level of definitive care circumstantially available in the deployed *Role 3* facility. These injured local nationals comprise 90 percent or more of those injured in the current wars[14].

After bone reconstruction has been completed, the injuries are then classified according to whether skin grafting, primary closure and/or flap reconstruction is required. In accordance with the currently accepted principles of extremity reconstruction, bone defects may also require bone grafting. Antibiotic beads are also often utilized during the stage of *tissue flap* inset in order to decrease infection rates. Following reconstruction of an extremity with fixation, bone grafts, and flaps, these individuals have often returned to weight bearing within a period of two weeks[15].

There have also been significant advances in the area of craniofacial and maxillofacial reconstruction. The defects in the *cranium* are often reconstructed in a delayed manner to enable the resolution of cerebral edema (brain swelling). Interval cranial reconstruction can then be performed safely. Rigid internal fixation has also been utilized during the treatment of maxillofacial fractures. They have also been treated with supplemental bone grafting, depending upon the requirements of the situation. All these treatments need to be provided in a timely manner to avoid complications[16].

Injured persons treated with timely reconstruction have experienced accelerated rehabilitation, with more expedient restoration of their ambulatory and functional status. As a

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[14] MR Bagg, DC Covey, and ET Powell, *Levels of Medical Care in the Global War on Terrorism, J Am Acad Orthop Surg,* no. 14 (2006): 7.

[15] Kumar and Bermudez, *Microsurgery in War Wounds, Presented at the 69th Scientific Meeting of the American Society of Plastic Surgeons,* 2009.

[16] Bagg, Covey, and Powell, *Levels of Medical Care in the Global War on Terrorism,* 7.

result of earlier reconstruction, these improvements in outcome were achieved despite the complexity of the original wounds[17].

Contemporary principles utilized in the reconstruction of civilian injuries can also be employed in war injuries. The nature and timing of the reconstruction, and hence successful outcome, are heavily reliant on the experience and judgment of the treating military surgeons[18].

The final objective of war surgery is to enable the highest possible number of injured soldiers to return to the battlefield permitting the conflict and the war to continue with as little hindrance as possible. For the injured soldiers who must be evacuated from theatre, the objective for them is the preservation of life, limb salvage, securing eyesight, and a rapid rehabilitation to maximal functional status[19].

Literature Review

The conception of this thesis began as a result of what I experienced during my deployment to KAF in 2008. As a Plastic and Reconstructive Surgeon with 25 years of trauma experience in the civilian, non-war environment, it was intuitive to me that PRS should be a part of the early management of war injuries. I was astonished to find that my detailed search of the literature contained no modern references directly substantiating the need for PRS in the early management of war injuries. On the contrary, there were only numerous references suggesting that PRS was born out of past conflicts such as WW I and WW II, and highlighting its role in those historic events. All of the references pertaining to PRS in modern NATO conflicts

[17] Kumar and Bermudez, *Microsurgery in War Wounds, Presented at the 69th Scientific Meeting of the American Society of Plastic Surgeons,* 2009.

[18] S Mannion and E Chaloner, *Principles of War Surgery, BMJ* no. 330 (2005): 1498-500.

[19] John J. Faillace, *Emergency War Surgery, 3rd Edition, Borden Institute (2004) [journal on-line]; available from* http://www.bordeninstitute.army.mil/other_pub/ews/EWSH.pdf; Internet; accessed 22 January 2011.

described its role once the injured had returned to their home countries, as a part of the rehabilitative phase of their management. None of the modern references described the role of PRS in the early management of select war injuries. I suspect that this has occurred in large part due to the fact that so very few Plastic and Reconstructive Surgeons have actually deployed to a modern NATO theatre of operations. Since I had the unique privilege of being one of the rare Plastic and Reconstructive Surgeons deployed in a modern war, I felt compelled to investigate this matter further, hence the birth of this thesis. In order to construct the arguments for this thesis, I have had to make an analysis of what factors are critical in establishing this proposal. In doing so, this thesis is therefore a landmark presentation of the objective facts unequivocally establishing that there is a distinct subset of those injured in war who, with the benefit of more timely reconstruction of their wounds, experience enhanced preservation of life, improved healing of their wounds, greater limb salvage, more rapid rehabilitation, and operationally, greater efficiency of the *Role 3 hospital*.

Chapter 1 starts the journey of facts by defining Plastic and Reconstructive Surgery, its historical events shaped by past conflicts, and reveals how the specialty has grown to fit the needs required to care for modern war injuries.

Chapter 2 identifies the importance of Orthopedic injuries in past and present conflicts, identifying that lower extremity injuries represent 70 percent of modern war injuries. The challenges in the management of this vast number of complex Orthopedic injuries are highlighted, acknowledging that without appropriate and timely management, severe complications such as poor healing, infection, and even limb loss, can result. The need for vascularized tissue is revealed as the main catalyst in the development of modern PRS techniques.

Chapter 3 defines the mechanisms of injury in modern wars, and defines the scope of the consequential injuries. Once again, the prevailing fact demonstrated is that in modern war injuries there is severe tissue destruction, loss, and significantly impaired vascularity (blood supply) of the injured tissues. The techniques available to a modern Plastic and Reconstructive Surgeon have been designed to circumvent these problems.

Chapter 4 describes the current system of managing those injured in modern conflicts where NATO has been a participant, and specifically, Canada has been a part of the military contribution to battlefield health care. The specifics as to how operational medicine is provided are outlined, and the legislation in place for the provision of health care is detailed. It is specifically revealed that although PRS has not been included in the regular compliment of surgeons deployed to the *Role 3* hospital, it is clear that with the demonstrated medical need to provide PRS services, then PRS too should be a part of the *Role 3* team caring for those injured in modern wars.

Chapter 5 identifies the specific injuries that could benefit from the provision of PRS in the acute phases of wound management, and details the techniques available to a modern Plastic and Reconstructive Surgeon that would be appropriate for the deployed environment. Although there are insufficient numbers of Plastic and Reconstructive Surgeons currently in the military, particularly in Canada, to mount an independent division of Plastic and Reconstructive Surgery, there are nonetheless a demonstrable subset of war injuries that would benefit from the early provision of PRS techniques. A recommendation, currently in the development phases, is to have the existing Plastic and Reconstructive Surgeons teach the basic and essential PRS techniques to the deployed surgeons (General, Orthopedic, Maxillofacial). This changes the focus of care provision from a specialty-centric model to one that is capabilities-based.

CHAPTER 1 - ORIGINS OF MILITARY PLASTIC SURGERY

The practice of surgery, which probably antedated that of medicine, began with attempts by primitive man, maimed in encounters with dinosaurs, accidents, or human combatants, to get repaired by those versed in the early techniques of reparative surgery[20].

Since the beginning of time, humans have been actively engaged in the pursuit of self-improvement. It should therefore be of no surprise that PRS is one of the world's oldest healing arts. Documentation exists regarding the surgical correction facial injuries, dating back more than 4,000 years. The next major advances in PRS weren't seen until the 20th century, when the casualties of war made PRS a necessity for many soldiers. World War I brought PRS to a new level within the medical establishment, where military physicians were required to treat many extensive facial and head injuries caused by modern weaponry. These complex life-threatening injuries necessitated innovations in PRS[21].

Plastic Surgery, the practice of reshaping body tissues for Reconstructive or Aesthetic (Cosmetic) purposes dates back to antiquity. The name Plastic Surgery is derived from the Greek *plastikos*, meaning, "to mold." War has played a significant role in the history of PRS. These innovations in Plastic and Reconstructive Surgery prompted Harold Delf Gillies (1882-1860) to establish the first hospital devoted to PRS. During WW I, trench warfare meant heads and necks were more vulnerable, and pilots and passengers in the new and dangerous airplanes often suffered serious facial injuries never seen before under any circumstances. Shattered jaws, blown-off noses, and gaping skull wounds demanded the advancement of specialized reconstructive techniques. WW II spawned the development of such PRS techniques as

[20] *Body Beautiful: A History of Plastic Surgery, Random History* [journal on-line]; available from http://www.randomhistory.com/2008/08/31_plastic.html; Internet; accessed 22 Dec 2010.

[21] Ibid

rebuilding entire limbs, extensive *skin grafts*, *microsurgery*, as well as increased knowledge about wound healing[22].

As the number and complexity of casualties accumulated in the Iraq war, the United States medical personnel found themselves developing new and innovative techniques to treat the wounded. No other field of medicine has been so transformed by the challenges of war than PRS. Through the heroic efforts of wartime surgeons such as Sir Harold Gillies, the specialty of Plastic and Reconstructive Surgery gained worldwide prominence and recognition for its treatment of the devastating facial wounds suffered by so many in WW I. Since that time, PRS has broadened its scope to include the numerous and diverse procedures that define it today[23].

The weaponry of warfare has paralleled, if at times not exceeded advancements in medical science. Technology such as heat seeking missiles, rapid-fire assault weapons, and antipersonnel mines, has brought the capacity of human beings to kill one another to record proportions. This has resulted in the creation of an increasing proportion of severely maimed yet living soldiers. Stabilization of a soldier by a forward surgical team (FST) is only the beginning of the road to full recuperation. Plastic and Reconstructive Surgeons have become pivotal amongst the medical team caring for soldiers. The soldier and Plastic and Reconstructive Surgeons, through burn care, amputation revision, or reconstructive surgery, have been intimately linked throughout history. The modern specialty of PRS was born from the disfiguring brutality of war. Specifically, PRS is thought to have emerged during WW I[24].

Albert Ross Tilley, CM, OBE (November 24, 1904 – April 19, 1988) was a Canadian

[22] Ibid
[23] Ibid
[24] Ibid

Plastic and Reconstructive Surgeon who pioneered the treatment of burned airmen during WW II. A member of the Canadian Army Medical Corps Militia, Tilley was transferred to the Royal Canadian Air Force (RCAF) Medical Branch at the start of the Second World War and became the Principal Medical Officer in 1941. In 1942, he worked at the Queen Victoria Hospital with Archibald McIndoe where burned airmen were treated. The patients called themselves the Guinea Pig Club[25].

Of the many early steps taken by Tilley and other physicians at the Queen Victoria Hospital in East Grinstead was to assemble a town gathering. They petitioned the public that they should persuade the burned soldiers to mingle with them. They warned the public that they were in for disturbing sights, because some of the airmen had lost their eyelids, and some had severely scarred and disfigured faces. They pleaded not to stare at them and make them uncomfortable. Tilley theorized that making them feel comfortable by hanging out with the town people was the first step to recovery[26].

The public adopted Tilley's advice and soon they saw burn-injured airmen, in uniform, walk around freely with the public in East Grinstead. Many of these airmen married local women as well. The public were very much part of the healing process. This goodwill environment was not limited to the public places. Even hospitals allowed the consumption of alcoholic beverages. The exception to this relaxation in conduct was that no one was allowed to drink a day before the surgery, referred to by the guinea pig club as being "chopped"[27].

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[25] P Wilton, *WW II 'Guinea Pigs' Played a Crucial Role in Refining Plastic Surgery in Canada, CMAJ* no. 159 (1998): 1158.

[26] Ibid

[27] Ibid

Tilley's contribution towards enhancing patient care in England brought Canada into the contemporary age of Plastic and Reconstructive Surgery. Tilley and others had to literally put their patients together 'piece by piece'. The surgeries included rebuilding of severely mutilated feet, to hands that were completely deformed by burns injuries. Tilley maintained that the apprehensions of the injured soldiers entering East Grinstead hospital were compensated for by the brotherhood shown by the Guinea Pig Club. He stated that this friendship allowed them to heal properly[28].

Tilley was a proud honorary president of the Guinea Pig Club's Canadian division until his death. Most of the members, now in their 70s and 80s, continue to convene every 2 years. Due to their advanced age, their usual 2-day parties decreased to 1-day gatherings, nevertheless maintaining the charm and uniqueness of earlier days.

Due to a lack or inadequacy of protective equipment, injuries faced by the early airmen were mostly due to flash burns of face and hands. Tilley began reconstruction with the ears of patients because troops could not wear their glasses without them (ears)[29].

Dr. Norman Park, an Anesthesiologist in Queen Victoria's Canadian Wing, played a very significant role. After the operation, he would ensure he was the one present when the airmen would wake up, gaining the reputation as "the sandman"[30].

Tilley continued his services as a surgeon for the Guinea Pig Club long after the war was over, serving them for a period of over 40 years. Tilley was forced to retire because of his poor health. To honor his contributions and hard work, Toronto's Wellesley Hospital named its burn

[28] Ibid
[29] Ibid,1159.
[30] Ibid

centre after him in appreciation of his contributions. In Tilley's hometown, Bowmanville, Ontario, a secondary school was named after him[31].

Tilley's contributions are a prime example of how war has enhanced the specialty of Plastic and Reconstructive Surgery. PRS is still a leading field for the development of surgical innovations. The specialty has had a significant place in the Iraq and Afghanistan Wars, where victims of the wars have realized monumental life impacts. As a result of this experience, military and civilian PS have participated in group discussions as a part of the annual meetings of the American Society of Plastic Surgeons (ASPS). In these conferences, the main focus of the discussions was the reconstructive difficulties faced by Plastic and Reconstructive Surgeons resulting from high-tech, modern weaponry[32].

Colonel Thomas Crabtree, M.D., who is also a member of the ASPS, as panel moderator, felt it was unfortunate that PS has shown its most rapid advancements only in times of war. In addition, he added that the innovations had not only benefited the wounded soldiers but also civilians caught as collateral damage as victims of violence, war, or other activities[33].

There are many areas of sub-specialization within the field of PRS, but most areas of concern for war injuries involves burns, soft tissue defects, extremity bone and soft tissue reconstruction, and reconstruction of the skull and facial skeleton. Most of the patients treated by the reporting ASPS Member Surgeons had been victims of high explosive and high velocity missiles, resulting in large-scale blast wounds. Lieutenant-Colonel Raymond Harshbarger, M.D., treated many soldiers at Walter Reed Army Medical Center who had facial and skull injuries,

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[31] Ibid, 1159.

[32] *Plastic Surgeons Face War Injuries From Iraq To Inner-city Violence, Science Daily* no. 10 *(* 2008) [journal on-line]; available from http://www.sciencedaily.com/releases/2008/10/081008114410 htm; Internet; accessed 8 April 2011.

[33] Ibid

using 3-D computerized tomography (CT) imaging of the face and skull. Surgery was planned with the help of these 3-D CT models[34].

Dr. Harshbarger, with the help of these models, helped soldiers who had lost half their skull or upper portion of face by making a prefabricated and patient-specific implant to reconstruct the lost bone. When there were many defects of both bones and soft tissues, he used woven titanium for the implant to reconstruct defects of the skull and face[35].

Harshbarger also conducted studies on the most effective way to amalgamate tissue engineering with technologies like implants and 3-D modeling. He speculated the development of an implant which would be biodegradable, and which would induce the formation of bone, such that the implant would absorb over time while new bone would be created. Harshbarger envisioned that although this would be the future of Plastic and Reconstructive Surgery, that it would take time to become reality[36].

Eduardo Rodriguez, MD, also a key player at the same conference, was experienced in treating soldiers injured from the missile accidents and gunfire. He described, as an example, having treated a young woman who while lying down, covering her child with her body, was struck by a powerful bullet, causing intense injuries to her arms and cheeks. She sustained serious injuries to her face, with almost all of her facial bones fractured and a loss of the soft tissues. He treated injuries of this type by replacing the missing tissues with tissue transferred from other parts of the body. Dr. Rodriguez stated that these cases were very complicated, and could take up to ten hours to complete. These cases could be very physically and emotionally

[34] Ibid
[35] Ibid
[36] Ibid

stressful for the PS but once completed, you could realize long lasting and incredible rewards for the injured individual[37].

The world's largest organization of Plastic and Reconstructive Surgeons is The American Society of Plastic Surgeons (ASPS). This society has the professional reputation for its credible information, research and reviews on PRS best practices. The society was founded in 1931, and currently approximately 90 percent of Plastic and Reconstructive Surgeons are registered with the ASPS. Membership in the ASPS is only by those certified by The American Board of Plastic Surgery or The Royal College of Physicians and Surgeons of Canada[38].

Plastic and Reconstructive Surgery, by the end of WW I, had reached incredible heights. The use of tube flaps had emerged, and work was beginning on the delayed transfer of long *pedicle flaps*. Free cartilage grafts were being used in nasal reconstructions, and bi-pedicled scalp and brow flaps were finding use in the reconstruction of the lip. As well, the use of neck flaps to reconstruct intraoral defects was seeing a strong promise. Soon the work of the reconstructive surgeons of WW I captured the attentive eye of both the general public and major academic institutions. As an organizational foundation took form and standardized treatments developed, PRS was advanced to entirely new realms with new and exciting frontiers. World War II saw further growth and refinement of the specialty. Hand surgery, in particular, emerged as a distinct subspecialty within the field of PRS. The devastation of war was the catalyst that propelled the field of Plastic and Reconstructive Surgery on the path to its current global prominence. Sir Harold Gillies could scarcely have imagined that the facial reconstruction he aimed to perfect would one day translate into a multimillion-dollar industry embracing procedures as diverse as nerve transfers and breast augmentation. Today, the world finds itself

[37] Ibid
[38] Ibid

engulfed in yet another war, with the technology of the times once again producing unique injuries in mass quantities. And while history has proven to be cyclical in nature, the science of medicine is expanding exponentially. The new directions that the field of Plastic and Reconstructive Surgery may explore are indeed as limitless as the poppies that still grow, in our modern war, within the opium fields of Afghanistan[39].

[39] R Backstei and A Hinek, *War and Medicine: The Origins of Plastic Surgery*, *University of Toronto Medical Journal*, no. 82(3) (2005): 219.

CHAPTER 2 - ORTHOPEDIC SURGERY AS A CATALYST

The majority of trauma incurred in past and present wars involved Orthopedic injuries. It is therefore critical to understand the challenges that arise in managing Orthopedic war injuries. These challenges have been the catalyst for the development of the vast majority of modern Plastic and Reconstructive Surgery techniques. These PRS techniques that have arisen out of Orthopedic Surgery have applications in all of the other areas of Reconstructive Surgery. The major areas of Reconstructive Surgery, that are now extensions of the initial principles in the management of Orthopedic trauma, include complex wound management, burn reconstruction, cranial and maxillofacial reconstruction, torso reconstruction, and *micro-neurovascular reconstruction*.

The use of *external fracture fixation* (EF) in the management of war injuries has been controversial, particularly since World War II. One of the difficulties in identifying its role is the lack of adequate follow-up, due to the rapid evacuation of patients. The main organization opposing the early use of EF is the International Committee of the Red Cross (ICRC). They do not evacuate their patients, and recommend that EF should not be carried out at the time of initial wound surgery. This is in contrast to other evaluations that have used immediate EF for the management of the majority of fractures. The advice of the ICRC must be considered in light of the high early failure rate reported by those who perform early EF. It is possible that a high failure rate would also have been seen in the other studies had there been adequate follow-up of their patients. Short follow-up was not necessarily a weakness of the various studies, as the majority of external fracture fixators had failed by this stage anyway[40].

Limb wounds are the most common injuries seen during armed conflict, accounting for as

[40] JC Clasper and S Phillips, *Early Failure Of External Fixation In The Management Of War Injuries, J R Army Med Corps*, no. 151 (2005): 84.

many as seventy percent of all wounds. The lower extremity has been the most commonly involved limb. Many of these orthopedic injuries will be high-energy wounds, and half of the injuries have been associated with a fracture[41].

The principles of treatment for war wounds have remained the same as any trauma, with the initial aim being to identify and treat any life-threatening injuries. The principles of wound care have also similar to those in the civilian environment - surgical debridement and adequate *lavage*, stabilization of the limb, and the use of appropriate antibiotics[42].

The method of early stabilization of fractures has been a matter of debate for some years. Previously, more conservative methods such as plaster would have been the preferred option. However, war wounds have often been associated with severe soft tissue injury, multi-fragmentary (comminuted) fractures, and multiple associated injuries, which made plaster immobilization of the fracture less than ideal. Unfortunately, internal fixation with plates or the use of *intramedullary* nails has been reported to have a high complication rate, particularly infection[43].

The use of an external fracture fixator for managing war wounds has therefore been debated, with opinions both for and against its use. At the end of World War II, external fracture fixators were reported to be associated with a very high complication rate, and the devices were removed from American military hospitals. More recent reports have also documented a high complication rate when EF had been used to treat military injuries, but this must be balanced against the fact that many of these injuries were highly contaminated, and associated with significant soft tissue injury. It is therefore not surprising that they would be expected to have

[41] Ibid
[42] Ibid
[43] Ibid

had a high complication rate[44].

Despite its reported complications, EF has been widely accepted, and in some reports, has been used in the early management of all ballistic fractures. External fracture fixation has even been recommended on logistic rather than medical reasons. Nevertheless, prospective studies have reported a very high early complication rate of immediate EF, and have cautioned against its universal acceptance.[45].

Instability at the fracture site occurred in sixty-seven percent of war-injured persons. Since the principal indication for performing EF was to provide bony stability, this rate of instability was therefore unacceptably high. Instability was defined as the presence of gross motion at the fracture site, such that soft tissue healing could be compromised, or delayed fracture healing anticipated[46].

With the multifragmentary (comminuted) nature of the fractures, and the resulting gap after *debridement*, the typical design of an external fracture fixator of two pins, placed on either side of the fracture line, with a single connecting bar, was considered inadequate. In addition, due to the design of the *Hoffman pin clamp*, the two pins were close together, which also reduced fracture stability. Although it was intended that only one military pack would be used per injury, multiple packs were commonly used at the time of revision, to allow the placement of three pins on either side of a fracture, or multiple bars to be used. This obviously had logistic implications for the military. The high failure rate of the frames meant that the previous guidelines had to be questioned, and suggested a need to either delay the application of the frame, or accept the need for more equipment and longer operating times[47].

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[44] Ibid, 85.
[45] Ibid, 82.
[46] Ibid, 84.
[47] Ibid, 85-86

For all long bone fractures, at least two connecting bars were required in the construction of the external fracture fixator, with at least three bars for fractures of the longer femur. Pin tract infection was a major concern and would lead to chronic problems as well as a compromise to later secondary methods of stabilization[48].

In addition, although the external fracture fixators were applied using sterile techniques, these procedures were carried out in tents, with no means of reducing any bacterial contamination in the air. As the initial *debridement* had to be carried out in this environment, this also supported the recommendation that external fracture fixators should not be applied at the time of initial surgery, but at a later stage, in a more sterile environment[49].

With the high early complication rate seen for compound (open), complex fractures, the early application of the external fracture fixator appeared to have been of limited benefit in the context of military injuries. This was a major concern, particularly since previous authors had recommended immediate external fracture fixation on the basis that it is effectively risk-free. Given this, delayed application of the external fixation frame until definitive closure of the wound, and frequent observation of the patient's wounds, may have been more appropriate, and would have reduced the initial operative time, and possibly morbidity. This was also the recommendation of the ICRC. This had to be balanced with the possibility that delaying external fixation might have increased the infection risk due to the lack of fracture stability. Other methods of stabilization, including skeletal traction, were considered, and found to be successful in the treatment of select patients[50].

Furthermore, the knee fixators, as applied to fractures, were not up to standards regarding stability, and could not ensure the level of fracture stability and cure within the realm of the

[48] Ibid.
[49] Ibid.
[50] Ibid, 85.

acceptable methodologies regarding care of ballistic wounds. Some of the other common fixators had also shown the same results in terms of poor stability, loose pins, and infections. Some individuals had performed successful ballistic fracture surgeries by applying the concepts of light inline traction, which was an alternative course of action for ensuring stability. Sometimes, instability was visible in the areas of fracture site where tissue fluid had accumulated at the pin site, and resulted in the production of infections[51].

In those cases where EF management methods were utilized, recommendations were advanced for the optimal timing of external fracture fixator application required to ensure the maximum level of stability. Additionally, pin connector bars could be further secured by installing an additional pin. This would result in a wider space between the pins on both sides of fracture, and would be much more stable when compared to the use of a clamp and pins alone. The major concern in these cases was pin site infection related primarily to instability[52].

The rate of pin related infections has always been high, even in the earlier military experiences[53]. This issue of pin site infection has been regarded as the most significant of all, due to the nature of the surgical complications that may arise, enhanced further by the contamination in the case of ballistic war wounds[54]. Another notable factor in the military injuries was the delay in the onset of initial surgical care. In some cases it was normal for allied personnel to wait for six hours before surgery, and an Iraqi individual, an astounding twenty-eight hours. The pin site

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[51] NM Rich, CW Metz, JE Hutton, JH Baugh, and CW Hughes, *Internal Versus External Fixation of Fractures with Concomitant Vascular Injuries in Vietnam, J Trauma,* no. 11 (1971): 473.

[52] F Burny, *The Pin as a Percutaneous Implant, Orthopaedics,* no. 7 (1984): 610-615.

[53] H Dubravko, R Zarko, T Tomislav, K Dragutin, and N Vjenceslav, *External Fixation in War Trauma Management of the Extremities - Experience From the War in Croatia, J Trauma,* no. 37 (1994): 831-834.

[54] JC Clasper, *Secondary Intramedullary Nailing of the Tibia in an Animal Model of an External Fixator Pin Track Infection, Thesis for Doctor of Medicine, University of Southampton* (2001): 78.

infection was therefore a big problem, and if not solved, it could have further lead to the certain occurrence of deteriorating fracture stability[55].

For optimal results, the application of the external fracture fixator should have been done in a purely *aseptic* atmosphere, to ensure bacterial free operative conditions. Even with the performance of early debridement, the maintenance of an aseptic environment was still very important. It was therefore recommended that external fracture fixators should not be applied in the initial stages for war injuries, but rather at a later time when the environment is much more free of potential bacterial contamination[56].

In military conditions, the time required for the evacuation of injured persons has received a high level of attention. This evacuation has usually been done on a priority basis. This delay in evacuation has been another major factor related to ability to apply the fixators within a healthy environment[57].

Excessive time delay before the application of the EF frame has not been considered optimal care. After the application of the external fracture fixator, under conditions when the patient's evacuation was delayed, the focus of care was shifted to ensure that the pin site and injured tissues were both well cared for and protected. However, optimal medical recommendations could lead to operational problems in the military setting. Loosening of the external fixation pin was amongst the main problems resulting from delayed fracture care. The

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[55] Has, S Jovanovic, B Wertheimer, I Mikolasevic, and P Grdic, *External Fixation as a Primary and Definitive Treatment of Open Limb Fractures, Injury,* no. 26 *(*1995): 245-248.

[56] Clasper, *Secondary Intramedullary Nailing of the Tibia in an Animal Model of an External Fixator Pin Track Infection, Thesis for Doctor of Medicine,* 78.

[57] Ibid

two factors commonly contributing to pin loosening were pin site infection and the type of the pin used[58].

It is not possible to state which problem arose first, infection or pin loosening. All the Hoffman external fixation pins that were found to be loose were also contaminated. Loose pins become contaminated, and infected pins can become loose. The use of an external fracture fixator at an early stage following injury was thus considered to have fewer advantages in the military setting. These war injuries were associated with higher complication rates at earlier stages[59]. In light of these observations, in conditions of delayed initial operative intervention, morbidity was reduced by factors such as frequent wound observation, and a delay in the application of the external fixator until the wound was closed[60].

Nevertheless, it must kept in mind that the lack of fracture stability may have been the reason for the higher incidence of infection, that may in turn have been increased by the delayed application of external fracture fixation. Some patients have been treated by other methods of stabilization, such as skeletal traction, in which there were also beneficial results for the patients[61].

This dilemma involving the most optimal management of complex orthopedic war injuries has plagued military and civilian trauma surgeons throughout history. The discussions above centered on issues pertaining to the management of complex open bone injuries, often with bone loss and contamination, and with associated defects in soft tissue. Critical factors

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[58] Ibid

[59] DI Rowley, *The Management of War Wounds Involving Bone, J Bone Joint Surg[Br],* no. 78B (1996): 706-709.

[60] RM Coupland, *The Role of Reconstructive Surgery in the Management of War Wounds, Annals of the Royal College of Surgeons of England,* vol. 73 *(*1991): 21-25.

[61] A Maricevic and M Erceg, *War Injuries to the Extremities, Mil Med,* no. 162 (1997): 808-811.

affecting clinical outcome revealed issues such as time delays until surgical treatment, fracture stabilization, and wound contamination. This has all been superimposed, in the military environment, upon the ability to evacuate casualties in a timely manner, and pressures dictated by operational requirements that influenced methods of treatment, length of hospital stay, and ability to ensure follow-up.

The biological principle central to all of these issues relates to the level of vascularity of the injured tissues. This single entity is what in fact has sparked the origins of all major Plastic and Reconstructive Surgery procedures utilized today, both in war and civilian trauma practice. Simply stated, well-vascularized tissue has the optimal probability of healing, and with the lowest rates of infection. Therefore, the challenges of past Orthopedic Surgical management issues for war injuries have been the catalyst that drove the birth of modern PRS procedures, thereby drastically diminishing the complication rates for the skeletal war injuries. Plastic and Reconstructive Surgery is thus a facilitator and adjunct to improve clinical outcomes for complex Orthopedic Surgery war injuries. This same principle applies to battlefield injuries in many other areas of the body, and is best illustrated in the next chapter that outlines the common modern war injuries.

CHAPTER 3 - FEATURES OF MODERN WAR INJURIES

The wars in Iraq and Afghanistan are unconventional, in that Coalition forces are engaged mainly in counterinsurgency tactics as part of an asymmetric war. While there have been numerous technological advantages by the Coalition over the enemy with regards to weapons, armour, transportation and a high level of organization, the Coalition has faced unconventional weapons and tactics in accordance with a less organized opposition. The net effect has been that patterns of injury most often encountered in wounded soldiers have reflected the enemy's dependence on improvised explosive devices (IEDs), mines and rocket-propelled grenades (RPGs)[62].

Gunshot wounds are still frequently seen in injured soldiers, however explosion-related injuries are now the most common type of injury. The catastrophic trauma that occurs as a result of explosive devices is devastating in contrast to other forms of battle injury. It would therefore be expected that the mortality rate associated with such injuries is much higher today than in previous wars. However, this has not been the case. The mortality associated with war wounds has significantly declined due to a number of factors: (1) Improvements in body armour have resulted in lower rates of thoracic injury; (2) Field medical units provide a high quality of immediate care resulting in better pre-hospital chances of survival; and (3) Transportation from the war zone to Role 4 facilities may often be achieved within 24 hours of the incident[63].

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[62] E Hankin and S Jeffery, *Challenges of Treating Modern Military Trauma Wounds,* Wounds UK, no. 6 (3) (2010): 47.

[63] Ibid.

Injuries to the bones, joints, and soft tissues of the lower extremities are of the highest frequency amongst war injuries, making up seventy percent of all injuries. Most of these prove to be fatal injuries, yet fifty percent of the wounds are associated with extremity fractures[64].

Clinical treatment protocols that apply to warfare injuries are similar to those encountered in civilian trauma. The primary objective has been to identify and treat first any wounds that could prove to be fatal. The treatment protocols have been described to include: (1) Operative removal or *debridement* of foreign material and dead tissues from the wounds; (2) Copious tissue *lavage*; (3) Stabilization of the fractures; and (4) The use of the appropriate spectrum of antibiotics[65].

In the past, the most appropriate method to stabilize fractures has been a topic of great debate. Initially, traditional techniques like plaster immobilization were the preference of choice. Modern war injuries have increasingly become associated with the occurrence of severe concomitant soft tissue damage or loss, multi-fragmented (comminuted) fractures, and multiple wounds within the same person, making plaster immobilization a less desirable option under such conditions. Unfortunately internal fracture fixation using metallic plates and screws, or the utilization of intramedullary rods has been shown to produce higher complication rates, mainly in the way of infections[66].

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[64] RB Islinger, TR Kuklo, and KA McHale, *A Review of Orthopaedic Injuries in Three Recent US Military Conflicts, Mil Med,* no. 165 (2000): 463-465.

[65] Ibid

[66] R Furlong and MP Clark, *Missile Wounds Involving Bone, Br J Surg* 1948;War Supplement No. II:29 (1971): 1310.

In reviewing the management of war injuries, the utilization of EF has shown opinions for and against its use[67]. Data from past wars, that showed a much higher complication rate with the use of EF, prompted a temporary removal of external fracture fixation techniques from those available to US military surgeons[68]. This greater complication rate associated with the utilization of EF for the treatment of military wounds was shown to have occurred due to the high degree of contamination of these wounds, and associated soft tissue injuries that produced diminished wound vascularity[69].

Gunshot and ballistic wounds are described as one of the most common sources of war wounds. Their occurrence is dependant upon the type and the severity of the conflict. Wounds caused by bullets are more prevalent and widespread in operations that are of low intensity, such as operations that involve urban terrorist activity, or in special conditions like the jungle operations that took place in the Vietnam War[70].

Injuries that are caused by bullets can lead to immediate tissue trauma as a result of the cavitation effect. Cavitation results in disruption or occlusion of the blood vessels, producing devitalized tissues. Cavitation also results in secondary bacterial contamination of the tissues, thereby producing further tissue destruction[71].

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[67] M Clevland, *The Management of Compound Fractures -Techniques of Fracture Management. In: Surgery in World War II, European Theatre, Washington: Dept. of Army,* (1956): 109-118.

[68] Ibid

[69] F Labeau, M Pasuch, P Toussaint, and S Van Erps, *External Fixation in War Traumatology: Report From the Rwandese War, J Trauma,* no. 40 (1996): S223-S227.

[70] GH Sakorafas and G Peros, *Principles of War Surgery: Current Concepts and Future Perspectives, American Journal of Emergency Medicine,* no. 26 (2008): 480–489.

[70] HM Souka, *Management of Gulf War Injuries, Br J Surg,* no. 79 (1992): 1307-8.

When a ballistic object enters a target, for example, lower extremity soft tissues, and retains considerable residual speed throughout the tissue path, the amount of tissue damage would be comparatively minimal, without resultant vascular impairment or fractures. Nevertheless, military surgeons should remain prepared for the fact that any kind of gunshot injury, whether high velocity or low velocity, can cause serious damage to the soldiers in any situation[72].

The phenomenon of temporary cavitation along the tract of the missile typically results in a larger amount of tissue damage. This is produced by the development of a temporary cavity inside the tissues due to the larger kinetic movement of the projectile within the tissues, resulting in the sudden transmission of high energy to the tissues. This effect occurs in all tissues, but to a variable extent due to multiple intrinsic tissue factors[73].

Conventionally the cavitation effect leads to the destruction of small blood vessels in the tissues along the missile's pathway. This therefore enhances tissue devascularization increasing the likelihood of forming foci of infected tissue. Cavitation in the tissues thus plays a significant role in the pathogenesis of war wound necrosis and infections[74].

The degree of injury within the tissues is also dependant upon several other factors. These include the characteristics or type of tissue (skin, fat, muscle, nerve, bone, vessels) that lies along the ballistic pathway, the nature of the missile, its angle of entry, the tendency of the missile to break into pieces on impact or change in shape, and the existence of foreign particles

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[72] Sakorafas and Peros, *Principles of War Surgery: Current Concepts and Future Perspectives,* 480–489.

[73] JM Ryan, GJ Cooper, IR Haywood, and SM Milner, *Field Surgery on a Future Conventional Battlefield: Strategy and Wound Management. Ann R Coll Surg Engl,* no. 73 (1991): 13-20.

[74] Sakorafas and Peros, *Principles of War Surgery: Current Concepts and Future Perspectives,* 480–489.

such as metal pieces, cloth pieces and soil that secondarily contaminate the missile tract within the injured tissues[75].

There are a number of distinctions between the various tissues types with respect to their reaction to similar levels of energy transfer. A common example quoted is of the brain or liver that can be damaged even if they sustain moderate transfer of energy. On the contrary, when the same amount of energy is inflicted on muscle tissue, without involvement of the blood vessels or bones, limited tissue trauma will likely ensue[76].

Blast injuries are produced when explosive munitions are converted to a large amount of gas in an extremely short period of time. The resultant explosion causes a sudden rise in the air pressure to produce a high velocity of gas molecules emitting from the explosion. This effect is commonly referred to as the blast wind. The shock front is the front edge of the blast wind[77].

Blast injuries can lead to complex and multiple wounds affecting a number of organs or simultaneous anatomic sites. Blast wounds can be categorized as primary, secondary, tertiary, and quaternary. Primary blast wounds occur at a point that is very close to the explosion and occur in organs that are filled with air. Clinically this represents the barotraumas or the middle ear, the hollow viscera, or the lungs[78].

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[75] GJ Cooper and JM Ryan, *The Interaction of Penetrating Missiles With Tissues—Some Common Misapprehensions, and the Implications for Wound Management, Br J Surg,* no. 77 (1990): 606-10.

[76] S Mannion and E Chaloner, *Principles of War Surgery, BMJ*, no. 330 (2005): 1498-500.

[77] DV Covey, *Blast and Fragment Injuries of the Musculoskeletal System, J Bone Joint Surg Am*, no. 84-A(7) (2002):1221-34.

[78] Ibid

The secondary blast wounds occur because of the generation of secondary fragments that are produced by flying objects from the blast winds. These various fragmented objects will differ with regards to size, varying from the smallest of dust particles to heavier objects that have a weight of more than twenty grams[79].

Casualties that are in close proximity to the explosive devices are likely to have a fatal outcome due to the significant overpressures resulting from high-energy blasts. Death can also occur because of amputations and severe blood loss due to blast winds or overpressures. The secondary missiles can themselves have great projectile velocity and force[80].

However, due to the irregular shape of these secondary objects, their speed tends to diminish rapidly, thus leading to various wounds produced by a comparatively low energy transfer[81].

The contemporary ballistic objects arise from the development and integration of newer munitions, such as antipersonnel mines, modern hand grenades, smaller mortars utilizing fragmentation plates, fragmentation coils that are notched, or metallic spheres. When these munitions are detonated, a huge amount of relatively small, and pre-developed pieces are yielded, that are developed to provide the maximum balance between factors such as effective terminal velocity, range, and probability of contact with the target. Tertiary blast injuries occur as a result of the blast winds throwing persons, causing them to strike something hard such as a

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[79] Ibid

[80] GJ Cooper, RL Maynard, and NL Cross, *Casualties From Terrorist Bombings, J Trauma*, no. 23 (1983): 955-67.

[81] Covey, *Blast and Fragment Injuries of the Musculoskeletal System,* 1221-34.

tree or a wall. Lastly, blast wounds may also lead to a greater number of injured persons because of damage to infrastructure. These types of blast injuries are referred to as the quaternary[82].

As has been described previously, in war situations the majority of the injuries result from antipersonnel ballistic fragments. Although the wounds caused by bullets are less in number, they cause more significant injuries, frequently produced by vascular damage[83].

The single most important factor, resulting mainly from ballistic injuries, and to a lesser extent secondary blast injuries, is the resultant disruption in the vascularity of the injured tissues. Devascularized tissues heal poorly, or not at all, and are prone to infection and further tissue destruction. The impact of impaired vascularity on wound healing is the primary reason for the development of modern Plastic and Reconstructive Surgery techniques.

[82] S Mannion and E Chaloner, *Principles of War Surgery, BMJ*, no. 330 (2005): 1498-500.

[83] Covey, *Blast and Fragment Injuries of the Musculoskeletal System,* 1221-34.

CHAPTER 4 - MANAGEMENT OF MILITARY INJURIES IN MODERN ERA

Improvements in the immediate medical and surgical care of battle casualties, and in body armour, have meant that soldiers are surviving injuries that would have killed them if sustained in previous conflicts. This has resulted in an increase in the complexity of the wounds that require reconstruction and new challenges for the Orthopedic and PRS team. Management of *wound exudate*, pain, and nutrition are vitally important, as is control of the wound microbiology. These patients are best looked after in a single facility that has on-site trauma specialties, so that corporate knowledge of how to look after these unique injury patterns can be developed[84].

Military wounds are predominantly caused by ballistic trauma. However, the usual military wounds discussed generally are meant to be those sustained through gunshots, multiple fragmentation injury secondary to grenades, improvised explosive devices (IED), landmines and suicide bombings. Solitary wounds are unusual. More commonly, soldiers have sustained multiple simultaneous injuries. This has been reflected over the years by an increase in the injury severity scores (ISS)[85].

Furthermore, each individual injury sustained may be very different in nature, requiring many varied medical specialties. Military wounds are often heavily contaminated as a result of the environment in which they are sustained, the improvised nature of the explosive devices, and

[84] C Taylor and S Jeffery, *Management of Military Wounds in the Modern Era, Wounds,* no. 5(4) (2009): 50.

[85] Ibid

the fact that soldiers are often only able to maintain basic hygiene. They are, therefore, exceedingly challenging[86].

The U.S. Department of Defence has presented Internet updates regarding the American military casualties (i.e., the total number of injuries and deaths) that occurred in Operation Enduring Freedom and Operation Iraqi Freedom[87].

These updates revealed that since 16th November 2004 a total of 10,726 service personnel endured war injuries. Of those 10,726, 1004 were killed during fights, 1361 died from non-battle causes, 5174 were severely injured during fights (not capable of returning to their respective duties), and 4191 were slightly injured and returned to their respective duties within 72 hours. No reliable data has been presented determining injury patterns amongst the host nation casualties of Afghanistan, or the relative number of American versus Iraqi nationals that have occurred. Nevertheless, the data clearly demonstrated that the U.S. military medical workforce had the largest number of injured persons to manage since the Vietnam War[88].

The rising numbers of American combat fatalities in recent wars has gathered global interest. Generally, combat fatalities have been used as an assessment tool to determine the extent and severity of wars in the same manner that murder rates are used to assess societies. Nevertheless, both of these constituents are fragile proxies. The level of performance and functioning of medical systems in war has not been entirely appreciated. Along with the military force of an enemy, the proper functioning of a military medical system is crucial in deciding the

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[86] Ibid.

[87] *U.S. Casualty Status, Department of Defense, Washington, D.C* (2004) [journal on-line]; available from http://www. defenselink.mil/news/casualty.pdf; Internet; accessed 4 April 2011.

[88] A Gawande, *Casualties of War — Military Care for the Wounded from Iraq and Afghanistan*, N Engl J Med, no. 24 (2004): 351.

outcome of an injured individual's life. In the US, the homicide rates have declined significantly to levels that have not been seen since the mid sixties. Nevertheless, war-based attacks, chiefly entailing weapons, have increased threefold during that same time period[89].

For example, in the U.S. civilian trauma care system, deaths by gun attacks have declined from sixteen percent in 1964 to approximately five percent currently. An analogous situation has also been witnessed in recent wars. Although the military force may have escalated, the lethality of war injuries has declined[90].

This is contrasted to the experience of WW II, where thirty percent of the US military personnel who were wounded in fights died[91].

In the Vietnam War mortality figures declined to twenty-four percent, and subsequently, in the wars of Afghanistan and Iraq, only ten percent of the injured military personnel died. A nearly equivalent number of military personnel have been injured in recent wars compared to those injured in the War of 1812, the initial five years of the Vietnam conflict (1961-1965), and the Revolution. The recent wars (Afghanistan and Iraq) certainly cannot be portrayed as minor conflicts, yet there have been a higher percentage of soldiers able to successfully survive their wounds and injuries[92].

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[89] Ibid

[90] AR Harris, SH Thomas, GA Fisher, and DJ Hirsch, *Murder and Medicine: The Lethality of Criminal Assault 1960-1999, Homicide Stud*, no. 6 (2002): 128-66.

[91] *Principal Wars in Which the United States Participated: U.S. Military Personnel Serving and Casualties, Department of Defense, Washington, D.C.,* (2004) [journal on-line]; available at http://web1.whs.osd.mil/mmid/casualty/WCPRINCIPAL.pdf; Internet; accessed 4 April 2011.

[92] Gawande, *Casualties of War — Military Care for the Wounded from Iraq and Afghanistan,* 351.

This demonstrates a military medical system that has brought enormous and essential modifications to the procedures and the infrastructure of the battlefield care provided since the time of the Persian Gulf War[93].

A major limitation for military medical planners has been the limited number of members contributing to the military medical workforce, particularly Plastic and Reconstructive Surgeons, necessary to support the several hundreds of soldiers and affiliated personnel deployed in Iraq previously, and currently Afghanistan. On the whole, the US army is thought to possess 120 Regular Force General Surgeons and nearly an equivalent amount in the Reserves. It was decided to deploy thirty to fifty General Surgeons and ten to fifteen Orthopedic Surgeons to Iraq. The majority of the surgeons served in Forward Surgical Teams (FST), comprising twenty personnel: (1) Three General Surgeons, (2) Two Nurse Anesthetists, (3) One Orthopedic Surgeon, (4) Three Nurses, and (5) a variable number of medics and other support members. In the Vietnam War, nearly 2.6 percent of the injured soldiers who were brought to the FST died. Even in the presence of helicopter evacuation from the point of injury (tactical evacuation), the majority of the fatalities still occurred before the injured soldiers reached the FST[94].

Those who managed to survive were left with horrific scarring leading to a diminished self-esteem when they returned home. In recent times, more importance is given to leaner, faster-paced military divisions, in addition to the necessity of placing surgical teams further forward, much nearer to the battlefield, than previously practiced[95].

Every single Forward Surgical Team (FST) was supplied with necessary equipment to them to follow the supported infantry troops. The FST would typically possess two operating

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[93] Ibid

[94] TJ Whelan Jr., "Surgical Lessons Learned and Relearned in Vietnam," Surg Annu, no. 7 (1975): 1-23.

[95] Ibid

tables and four ventilator-equipped beds, all assembled in an unfathomable time of sixty minutes. Nearly six High Mobility Multipurpose Wheeled Vehicles (Humvees) were required by the FST to enable its movement. The FST also always carried three lightweight Deployable Rapid Assembly Shelter (DRASH) tents, which could be joined with each other in order to create nine hundred square feet of space divided between two facilities. The supplies and necessary operating equipments are carried in five backpacks: (1) a General Surgery pack, (2) an Intensive Care Unit (ICU) pack, (3) an Orthopedic pack, (4) a surgical-technician pack, and (5) an Anesthesia pack. They additionally contain sterilization equipment, medications, surgical gowns, Anesthesia equipment, surgical drapes, and urinary catheters, along with handheld units that assist the clinical staff in obtaining a *hemogram*, blood gases, and electrolytes from a sample of drawn blood. Forward Surgical Teams also have portable monitors, an oxygen concentrator capable of supplying up to fifty percent inspired oxygen, six roll-up stretchers and their litter stands, portable ultrasound machines, ventilators, and 20 units of packed red blood cells. Every team has dedicated radiography and angiography equipment. They are equipped with adequate supplies enabling them to support as many as thirty injured soldiers. Supplies and resources dictate that postoperative intensive care cannot exceed six hours[96].

When the causalities are received, the teams conduct the same Advanced Trauma Life Support practices that are also carried out in the civilian trauma setting. However, due to the extreme velocity and volume of the wounds, more than eighty percent of the patients treated by the average FST suffered from severe gunshot, blast, or shrapnel wounds. In the military forward surgical facilities, the frequency of surgery is higher than the civilian trauma centers. The

[96] Gawande, *Casualties of War — Military Care for the Wounded from Iraq and Afghanistan,* 351.

primary objective in the army surgical setting is aimed at limiting the damage to tissues rather than the healing of the wounds, unless the injury appeared immediately reparable[97].

The surgeons in a war setting work initially on injuries by washing (irrigation) and debriding the wounds, ensure that the bleeding has stopped, and that the potential for wound contamination is minimal. This helps the patient to maintain a steady temperature. It has been a goal that operations last no more than 2 hours. Following the initial surgical treatment, the person is referred to the Combat Support Hospital (CSH), which is the next highest-level treatment facility. In Iraq, there were two CSH established. Each hospital contained approximately two hundred and forty-eight beds, six operating rooms, in addition to surgical wards and laboratory service rooms. The mobile hospitals can also be set up in large trailers and made functional within 24 to 48 hours. The objective of care in the CSH was not merely to repair the injuries but to monitor initial healing as well. These patients stayed in the CSH for up to three days[98].

For those Coalition soldiers who needed a higher level of or lengthier care, they were transferred to *Role 4* hospitals, which existed in Kuwait, Spain, and Landstuhl, Germany. If the soldiers need more definitive medical attention, they are transferred back to their home country, to Role 5 facilities such as the Walter Reed Army Hospital in Washington, D.C., or the Brooke Army Medical Center in San Antonio, Texas. It is significant to note that the soldiers and civilians of Iraq and Afghanistan are given only the modalities of treatment available in their homeland. This single factor had a significant impact on the operational capability of the

[97] Ibid
[98] Ibid

deployed medical resources, and argued for the availability of more creative means of wound care and reconstruction[99].

It has become the standard practice of deployed medical teams to treat local soldiers and civilians with the best level of care available. This nevertheless meant that there were some injuries that could not receive definitive reconstructive care due to the lack of this capability in the deployed medical units[100].

Despite the success of lifesaving techniques, the military medical teams have been confronted with many complex medical and ethical situations. The length of the current war has extended more than expected. The number of injuries has increased, as has the diversity of the types of injury. These conditions demand a change and evolution in the healthcare and medical services provided for the war wounds. Specifically, due to the large numbers of individuals with complex war wounds necessitating earlier reconstruction, the inclusion of Plastic and Reconstructive Surgery would ensure a higher quality of life for the survivors. The blast, suicide attack, IED and land mine injuries have increased significantly in the past few years. It has been very difficult to effectively manage these injuries in the war setting given the current resources and deployed surgical skill sets[101].

Still many questions remain unanswered regarding the most appropriate level of care in the early post-injury phase. The Orthopedic Surgeons have in the past been puzzled as to the best means of managing complex injuries to bones, and soft tissues, with vascular injuries compounding the problem[102].

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[99] Ibid
[100] Ibid
[101] Ibid
[102] Ibid

The potential injuries can be very complex and can involve the most difficult methods of Orthopedic Surgical care. Military physicians have tried to apply civilian trauma principles to ensure better outcomes, but this process has not been successful for war injuries. The primary reason has been that the limb wounds are more complex and severe and the associated massive soft injuries can have deleterious consequences on other organs of the body. All efforts aimed at limb salvage have failed, and endanger life due to issues such as blood loss, sepsis and tissue ischemia[103].

There are many difficulties that arise during the provision of military surgical and medical care. War is not static and conditions are always changing. There is a need for teams that are active and fit to suit those dynamic conditions. War has prolonged effects and to make different teams fit, there is need of transforming the CSH into fixed facilities. There were no policies regarding the range of enhanced care received by civilians in the military hospital. Additionally there was an increased volume of pediatric cases seen in most deployed hospitals[104].

In a military setting, there are also standards of care that are superimposed upon the normal professional and ethical medical obligations to patient care. These standards have been published in the doctrine for joint operations of the various coalition countries. Common to all are references to the Geneva Conventions as well as NATO standards that govern the provision of health services support within the operational setting[105].

Rodig goes on to state regarding NATO standards of medical care that "the aim of military medical care in operations is to achieve outcomes of treatment equating to best medical

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[103] Ibid

[104] Ibid

[105] E Rodig, *Paper presented at the RTO HFM Symposium on Combat Casualty Care in Ground Based Tactical Situations: Trauma Technology and Emergency Medical Procedures*, held in St. Pete Beach, USA, 16-18 August 2004, and published in RTO-MP-HFM-109, p.2.

practice. The application of this principle must be guided by the principles embodied in the concepts of Clinical Governance and Evidence Based Medicine". Regarding timelines for the provision of medical care, the guideline for NATO operations states that advanced trauma care should be available within one hour of injury[106].

The Canadian Forces Operations Joint Doctrine Manual stipulates, "that without discrimination, all persons entitled by The Hague and Geneva Conventions and Protocols will be treated on the basis of their clinical need and resources available". In the section regarding the level of health care to be provided the manual states "health care shall be provided at levels of accessibility and quality comparable to those being afforded to Canadians, in general". Finally, regarding the capabilities of the various medical facilities the same document outlines that "*Role 3* capabilities may be enhanced with specialist surgical (Neurosurgery, Maxillofacial, Plastic Surgery, etc.) capabilities, advanced and specialist diagnostic capabilities (CT scan, arthroscopy, sophisticated laboratory tests, etc.), major medical, surgical, dental, and nursing specialties, and environmental health and industrial hygiene capabilities. The resultant accessibility to health care should be comparable to that available to Canadians, in general" [107].

In the United Kingdom (UK) Joint Doctrine Operational document regarding standards of medical care, it is stated that patients should receive the highest appropriate level of medical care. It is their aim to "achieve outcomes of treatment which equate to best medical practice as identified in Surgeon General's (SG) Policy and Standards for Operations, reflecting Evidence

[106] Ibid

[107] Canada. Department of National Defence. B-GJ-005-300/FP-000. Canadian Forces Operations – Joint Doctrine. (Ottawa: DND, Canada, 2005), 28-1 – 28-2.

Based Medicine" The same document reflects upon the importance of time to outcome, and stipulates that definitive surgery not be delayed beyond four hours[108].

At one time, becoming a military surgeon was considered an attractive opportunity. Yet as a result of the aforementioned facts, resistant attitudes, and lengthy deployments, and ethical challenges, military medicine has lost its attractiveness. The numbers of individuals overall that join the military has also sharply decreased in recent years[109].

Plastic and Reconstructive Surgeons have only recently been included in deployed military surgical care, taking on new roles and augmenting care previously the responsibility of other military surgeons such as General Surgeons, Orthopedic Surgeons, and Maxillofacial Surgeons. A change in the deployable surgical positions, in addition to those mentioned above, to include Specialists such as Urologists, Plastic and Reconstructive Surgeons, Neurosurgeons, Ophthalmologists, Cardiothoracic Surgeons, and Pediatricians has been discussed, but currently not implemented[110].

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[108] UK Ministry of Defence. *Medical Support to Joint Operations.* Joint Doctrine Publication 4-03 (JDP 4-03) 2nd Edition, January 2007, 2-1 – 2-23.

[109] R Pear, *U.S. Has Contingency Plans for a Draft of Medical Workers, New York Times*. October 19, 2004:A22.

[110] Ibid

CHAPTER 5 - WAR INJURIES BENEFITTING FROM PLASTIC SURGERY

The first Plastic and Reconstructive surgical procedures date back to 800 BC, with skin grafts in India for the treatment of traumatic and punitive wounds. Progress in the field of Plastic and Reconstructive Surgery didn't occur until WW I. During WW I, physicians were treating many extensive facial and head injuries, including shattered jaws, blown-off noses and lips and gaping skull wounds caused by modern weapons. These injuries required innovative reconstructive procedures[111].

Plastic and Reconstructive Surgery as a specialty was therefore born out of WW I. What is now considered Modern PRS arose after the appearance of surgeons such as Morestin, Lexer, Ganzer, Lindemann, Kilner, Burian, Esser, Kasanjian, Blair, and Gillies. Sir Harold Gillies, at the Queen's Hospital, Sidecup, developed the most important treatment center for British and allied military casualties[112].

The most important center of Plastic and Maxillofacial Surgery in Europe, between 1917 and 1921, was The Queen's Hospital, Sidecup. Thousands of patients with war wounds of the face - mainly gunshot- were admitted to that hospital under the care of Gillies. The patients were treated using procedures like the frontal flap based on the *supratrochlear artery*, described initially in India. Antibiotics and Anesthesiology were far from today's advances in those fields. Gillies developed the concept of using tube flaps as the best means to transfer large amounts of soft tissue to the face in order to reconstruct the severe war deformities in the soldiers. The tube flaps were the cornerstone of PRS for the treatment of complex injuries for a period of sixty

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[111] J Vlchek, Plastic Surgery Advances in Wartime, [journal on-line]; available from http://bestofbothworldsaz.com/2010/11/11/plastic-surgery-advances-in-wartime; Internet; accessed 22 December 2010.

[112] Ibid

years following the war[113].

Plastic and Reconstructive Surgery has seen huge evolutionary advances, including craniofacial surgery, microsurgery, the knowledge of the vascular patterns of the flaps, the use of tissue expanders, *distraction osteogenesis*, *osseointegrated implants*, and microsurgical techniques for the free transfer or tissues and limb re-implantation. Today it is possible to transfer large amounts of tissue in a single surgical procedure because of the knowledge of vascular anatomy and a better design of flaps. Flaps, like the frontal, described around 800 BC (in India the nose use to be amputated from the conquered after a war, or as punishment of infidelity for women) are still the first option in the nasal reconstruction. The muscle and muscle-skin flaps, popularized during the seventies, are very useful single stage procedures. They offer the advantage of diminishing the larger number of procedures required for the tube flaps. Muscle flaps are important tools in head and neck reconstruction, however they are used most often for their length as *pedicled flaps*[114].

Today microsurgery is the ideal method to transfer, in one surgical procedure, great amounts and kind of tissues, providing the necessary elements to reconstruct the complex head and neck wounds left by the war. The evolution of the surgery for reconstruction of extremities, mainly the lower limbs, has been extremely different. The lower extremities were frequently amputated during World War I and World War II as the procedure of choice for severely injured limbs. During the Vietnam War, following advancements in vascular surgery, it was finally possible to save hundreds of limbs, but the issue of saving functional extremities still remained[115].

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[113] Ibid
[114] Ibid
[115] Ibid

Throughout history, war has been the driving force behind most PRS developments and this specialty continues to see advancements as a result of experiences with the war in Iraq and Afghanistan. Plastic and Reconstructive Surgeons now face unique challenges created by today's weaponry. As a result, there have been advances in reconstruction of the extremities, face, torso, and burn management. The patterns of injuries change as weapons change, and advancements in PRS will continue to accelerate as a result of the experiences gained during wartime[116].

Reconstructive Surgery can be used within a framework of management of war wounds by basic principles. It falls into three groups: (i) Primary (emergency) reconstruction; performed as part of initial surgery and as a life-saving procedure; (ii) Delayed primary (essential) reconstruction; performed at the time of delayed closure; and (iii) Elective or non-essential reconstruction. All surgeons involved with the early management of war wounds should be prepared to perform primary and delayed primary reconstruction[117].

Most war wounds require surgical excision. This primary treatment is the most important facet of their management. Initial wound surgery might leave brain, lung or repaired vessels exposed. The importance of immediate closure of these wounds has long since been recognized. In the presence of even moderate tissue loss, this is impossible by direct means. The surgeon performing initial wound surgery would need to cover vital structures with a skin or muscle flap. In the absence of Plastic and Reconstructive Surgery, there is little knowledge about how this might be achieved[118].

Limb wounds account for approximately seventy percent of the workload of a military

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[116] Ibid

[117] RM Coupland, *The Role of Reconstructive Surgery in the Management of War Wounds, Annals of the Royal College of Surgeons of England,* vol. 73 *(*1991): 23.

[118] Ibid, 21.

hospital. Long bone fractures and exposed joints are both common and difficult problems. Primary treatment involves correct wound excision, which lessens the need for, and yet facilitates, later reconstruction. Delayed reconstruction of limb wounds by suture, skin graft or reconstruction is best after four or five days, usually at the time of the first dressing change. This delay in reconstruction allows re-excision of the wound and a chance to diminish bacterial contamination of the wounds. Simultaneous performance of EF and soft tissue reconstruction are also best performed at the time of delayed closure. This ensures the pin sites do not interfere with the raising or moving of the flap. These procedures can then be carried out on a routine surgical list and not as emergencies, when time and staff may be in short supply. Delayed closure by *myoplasty* (muscle flap) to cover the tibial stump in below-knee amputations for improvised explosive device (IED) injuries has proven to be effective. The limb war wounds that most commonly require soft tissue reconstruction are those with exposure of the tibia, knee joint, forearm and wrist. Flaps incorporating skin, fascia or muscle can be used, depending on the expertise of the surgeon and clinical indications. Muscle flaps are preferred because the bone is protected from infection, thus providing a good environment for bone callus formation and improved bone graft results[119].

Armed conflict generates an enormous number of chronic, non-life-threatening problems for which Plastic and Reconstructive Surgery is the only solution. Examples include burn contracture release, correction of severe *fracture malunion*, nerve repair, tendon transfer for nerve lesions and tendon injuries, and *myoplasty* for management of chronic wounds associated with *osteomyelitis* (bone infection). The history of PRS is strongly linked with reconstruction of the war-injured face. The practical and philosophical implications of performing elective reconstructive surgery in the situations where the ICRC is working are considerable. At present,

[119] Ibid, 23.

only the most severe and disabling problems are dealt with in the battlefield military hospital setting[120].

Plastic and Reconstructive Surgery is commonly thought of with regards to cosmetic operations like facelifts, breast augmentation, and an assortment of popular esthetic issues. However, the methods to be used for reconstructing modern war injuries are included in the PRS methods that were not primarily used for the restoration of the facial burns of earlier wars. These newer methods have great utility for contemporary war zones such as Afghanistan, Iraq, Belfast, Vietnam and the Falklands[121].

Many of the new and contemporary methods of PRS were founded in the days of the First World War when a huge number of facial injuries occurred. These people wanted to eradicate the scars of those wounds. After receiving trauma to the face you were naturally entered into the world of Plastic and Reconstructive Surgery. The rehabilitative aspects of reconstructive surgery were known since the Middle Ages, but it was Sir Harold Gillies who established founding methods for the restoration of the chins, jaws, mouths, noses and ears.[122].

Gillies established a clinic in 1917 in Sidcup, Kent at the Queen Mary's hospital. Gillies invented a very basic form of a flap. It was an actual flap of the skin that could easily move back and forth on the injury while attached on one margin. The difficulties of operating on the face, if an anaesthetic mask concealed it, were manifest. Ivan Magill assisted Gillies in inventing a tube for oral anesthesia that permitted Gillies to have unhindered freedom in performing operations on the patients' faces. The reconstructions are for their time impressive. Many lessons were

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[120] Ibid, 23,24.

[121] P Kingsley, *War Wounds: Plastic Surgery From the Frontline,* The Guardian, 2011.

[122] R Pear, *U.S. Has Contingency Plans for a Draft of Medical Workers,* A22.

learned; the importance of treating infection, of lining flaps, of providing support using non-artificial materials, of restoring normal tissue to normal position and then grafting the gaps[123].

Keeping all of this in mind, the wounds inflicted in war situations potentially have the highest complication rates, due to advancements in war weapons and the use of antipersonnel mines[124].

These unconventional arms and ammunitions, such as the antipersonnel mines, were not utilized during the First World War. The modern techniques of war-fighting and advancements in power and velocity of weapons has resulted in wounds that are much harder to manage and have given rise to newer types of wound complications. Also, the extent of the injuries that are caused by these weapons are much more severe than typical gunshot injuries seen in older wars[125].

The management of the war wounds has become increasingly difficult. During the First World War, cutaneous tube flaps, as described by Gillies, were commonly employed in the reconstruction of soft tissue deficits. This was an effective technique at that time. However, use of pedicled tube flaps came with the tradeoff that patients had to be maintained in positions that were temporarily uncomfortable (for example, a nose reconstructed with a tube flap from the elbow)[126].

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[123] P Kingsley, *War Wounds: Plastic Surgery From the Frontline,* 2011.

[124] P Banks et al, *Gunshot Wounds. Maxillofacial Injuries.* Ed. Rowe & Williams. Churchill Livingstone. London, (1985): 560.

[125] J Keegan, *War and our World, Vintage Books, Random House, New York.* (1998).

[126] Ibid

In modern times, *pedicled flaps* have largely been replaced with the microsurgical transfer of tissues from one area of the body to another, becoming an important technique for the reconstructions of war wounds[127].

The timing of reconstructing the severe war injuries by microsurgical methods has generally been accepted to be after seventy-two hours in order to avoid the early wound complications[128].

This timing for the reconstruction of war injuries is influenced by the fact that most of the wounds are inflicted in an area that is not in close proximity to the hospital, thereby inserting additional delays between the time of injury and when the patient finally arrives in the advanced care hospital for definitive treatment[129].

To assess the overall success rate of the various microsurgical free flaps, the success rate was compared between non-war and war wounds. The complication rate was significantly higher in war wounds, and negligible in non-war wounds[130].

When one encounters the significant kinds of wounds that result from war injuries, reconstruction with free flaps is a useful tool. Although there was a greater failure rate for free flaps in war injuries, these patients suffering from war wounds have limited treatment options[131].

As more experience was obtained, the success rate in implementing free flap reconstruction for war wounds saw an increase[132].

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[127] Ibid

[128] M Godina, *Early Microsurgical Reconstruction of Complex Trauma of the Extremities. Clin. Plast. Surg.,* no. *13 (1986): 619.*

[129] Ibid
[130] Ibid
[131] Ibid

The wounds resulting from war injuries are characterized by an extreme damage of the skin, leading to the emergence of various skin related problems. The injuries likely involve the loss of the skin from the affected area. The immediate closure of such an injury, under tension, could lead to circulatory problems and impairments in wound healing of a severe nature[133].

Injuries located near a joint, heal with a wound contraction that is likely to restrict joint performance. When a fracture is associated with an open wound, it is known as a compound fracture. When the injury has a considerable amount of skin loss and tissue damage, healing may proceed slowly or not at all. This loss of soft tissue produces a wound with tissues that are inadequate to cover the damaged bone[134].

In order to unite the fracture in a reasonable time, it is essential that infections also be avoided. A wound infected beneath a plaster cast becomes a natural culture medium and will exuding an enormous amount of purulent *exudate*. These war wounds are often contaminated by diverse kinds of bacteria. Secondary surgery of tendon, bone and nerve may need to be delayed due to the poor healing and infection beneath the plaster[135].

The probability of an infection arising in these injuries is also increased by the loss of skin covering the bone and the *periosteum*. The exposed bone may become a devascularized *sequestrum*, adding to the risk of *osteomyelitis* (bone infection). Exposed tendon will also definitely slough in the absence of overlying vascularized tissue. In order to heal these severe

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[132] Ibid

[133] JM Converse, *Orthopaedic Aspects of Plastic Surgery. The Early Replacement of Skin Losses in War Injuries of the Extremities, Proceedings of the Royal Society of Medicine, (*1990).

[134] Ibid

[135] Ibid

wounds, intensive PRS is necessary to restore blood supply to the injured tissues. If sufficient attention is paid to the loss of skin initially, many of the later-stage problems can be avoided[136].

The severity of the deformities resulting from open wounds is directly related to the duration that the wound stays *de-epithelialized*. One of the major processes of wound healing is the primary contraction. It considerably decreases the size of the wound to a level that is manageable for the healing process. When the wounds are deep and severe, the contraction draws in the surrounding tissues so that the defect can be filled[137].

The significance of primary contraction, as an essential part of the healing process, lies in its ability to influence quality and speed of wound repair[138].

The ability of a wound to heal by contraction is immediately linked to the presence of muscle tissue in the areas surrounding of the wound. To illustrate this point, wounds that are present in the thigh are likely to heal quicker than those located in the tibial area[139].

There is a particular rate at which cellular migration, multiplication and enlargement facilitates the regeneration of wound epithelium. Larger wounds will take a much longer time for the process of epithelialization to occur. This is also likely to occur in the face of unfavorable circumstances for contraction. When there is a delay in the process of epithelialization, the chances of fibrous tissues undergoing deforming contraction increases[140].

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[136] Ibid
[137] Ibid
[138] Ibid

[139] Converse, *Orthopaedic Aspects of Plastic Surgery. The Early Replacement of Skin Losses in War Injuries of the Extremities,* 1990.

[140] Ibid

Large wounds in the pre-*tibial* area, in the absence of sufficiently vascularized soft tissues and epithelium, may experience bone atrophy that may enhance the potential for the development of tibial *osteomyelitis*[141].

When there is considerable loss of the skin and the contraction within the wound is not sufficient to lead to wound closure, this will lead to the development of scar dense fibrous tissue. This process also contributes to the impairment of the circulation around the wound, predisposing to infection and impaired growth of the epithelium. When this happens fibrous tissue growth is further encouraged, which perpetuates this process in a vicious cycle. The ultimate end result is a wound that remains unhealed[142].

Giving consideration to this process, it becomes apparent that the wound must be covered with epithelium as soon as it is possible to avoid the production of a chronic, non-healing wound. When spontaneous regeneration of the epithelium does not appear to be a reasonable probability, then surgical means should be attempted in the way of skin grafting[143].

Skin grafting is indicated when: (a) There is considerable loss of the skin that is likely to cause deterioration in the performance of the extremity; (b) There are wounds that are located around joint surfaces or wounds that are circumferential and have the potential to impair the circulation; (c) When it is not probable that the spontaneous wound healing will result; (d) In people that are debilitated and aged; (e) When the wound is present in an undesirable anatomical location overlying the bone; and (f) When it is desirable that wound healing should occur quickly[144].

[141] Ibid
[142] Ibid
[143] Ibid
[144] Ibid

The bacteriological status of the wound before the *skin grafting* operation has been determined to be important for skin graft survival[145].

Aside from adhering the finer technical details of performing the grafting procedure, the two significant factors determining graft survival include wound fibrosis and wound infection. Suppuration results from infection. In an infected grafted wound, the graft would be lifted from its bed due to the pressure exerted by purulent *exudate*. [146].

When the infection is severe and *haemolysis* is present, alpha *haemolytic* Streptococcus is usually the offending organism. This usually occurs when the grafting process has not been meticulous[147].

The emergence of powerful antibiotics in recent years has made possible considerable dominance over the *haemolytic* Streptococcus. It has become possible to achieve wounds that are streptococcus free, all achievable within a few days following the initiation of antibiotic treatment[148].

Skin grafting has been successfully carried out in the presence of *haemolytic* Streptococci with the administration of oral and topical antibiotics. Over seventy percent of granulating wounds have been identified as having bouts of Streptococcal infection, therefore routine antibiotic therapy becomes all that more important. Daily antibiotics following surgery are required for those wounds recently exposed to Streptococci[149].

The development of tissue fibrosis within the deep granulation tissue layer of the wound leads to a reduction in the blood flow. This produces conditions that lead to an inadequate

[145] Ibid
[146] Ibid
[147] Ibid
[148] Ibid

[149] L Colebrook and AE Francis, *Elimination of Streptococci from Superficial Wounds by Sulphanilamide Powder, Lancet.* 1941 (i), 271.

foundation for skin grafting. Therefore, in wounds that are older, it is favorable to carry out an excision of the wound, whenever possible, to achieve a vascular foundation for the skin graft[150].

Excision of the fibrous tissue in the wound has been shown to result in a significantly greater incidence of graft survival. When the excision is not carried out, very poor graft take was noted. As for secondary excision, this involves an excision of the entire wound. This process is carried out until the well-vascularized tissues of normal appearance are exposed[151].

The graft can also be applied to vascularized *fascia* and muscle. It has been noted that complete secondary excision may not be possible at all times due to factors related to a person's anatomy, the proximity of a joint capsule, bone and significant nerves or blood vessels[152].

Granulation tissue itself can harbour and grow bacteria. Graft take has been improved by superficially removing excess granulation tissue, thereby decreasing the potential for infection[153].

Thus when severe loss of the skin and soft tissue occurs, this leads to inflammatory alterations and fibrotic changes within the wounds. The presence of contractures, chronic wound complications, unhealed wounds, and constrictions will hinder the restoration of wounded patients to their original health, or to active work. If the wounds have undergone large amounts of skin loss only, primary skin graft should be carried out as the reconstructive method of choice. More advanced techniques such as local skin flaps (advancement, rotation, island), *pedicled flaps*, tubed flaps, muscle flaps, and microsurgical free tissue transfers are utilized in all other circumstances for the reconstruction of complex wounds with tissue deficiencies[154].

Surgeons performing either the initial primary surgery or delayed closure of war wounds

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[150] Converse, *Orthopaedic Aspects of Plastic Surgery. The Early Replacement of Skin Losses in War Injuries of the Extremities,* 1990.

[151] Ibid
[152] Ibid
[153] Ibid
[154] Ibid

are unlikely to be Plastic and Reconstructive Surgeons. There are simply an inadequate number of military Plastic and Reconstructive Surgeons available to fulfill all of the deployed tasking roles. There are a limited number of basic reconstructive procedures that can be used, to great advantage, within well-proven management principles and protocols. The most useful are skin grafts (split and full-thickness), gastrocnemius, soleus and latissimus dorsi muscle flaps, scalp rotation and transposition cutaneous flaps, abdominal, thoracic, and groin skin flaps. The current surgeons, who are primarily responsible for the management of war wounds, often lack formal training in PRS. In the absence of a large number of military Plastic and Reconstructive Surgeons, the primary trauma surgeons should familiarize themselves with these core Plastic and Reconstructive Surgery procedures to ensure that the most appropriate wound management is performed at the earliest possible moment, thereby encouraging greater successes in later delayed and elective reconstructive procedures[155].

[155] Coupland, *The Role of Reconstructive Surgery in the Management of War Wounds,* 24.

SUMMARY AND CONCLUSIONS

Throughout history, mankind has been exposed to many sources of trauma. The sources of man's injuries have included, but not limited to, environmental disasters, workplace accidents, leisure activities, and human interactions. This latter group has included events such as self-inflicted injuries, mutilations rendered as a form of punishment, and finally, injuries that resulted from man's warring activities[156]. Of these various sources of wounding, this paper addressed the management of war injuries. Revealed were the types of war injuries, and the specific features of modern battle injuries that dictated unique and timely medical care interventions.

Conflicts, struggles and war are as old as human beings themselves. By their nature, they are very widespread, and depicted every day in the news. The documented records of humankind are a tale of a limitless series of aggressive conquests and conflicts. Burns were very common during ancient times due to the fact that fire was the choice of weapon in historical conflicts[157].

Injuries sustained as a result of war activities have been documented dating back to ancient times. There has been a progressive evolution in the types, patterns, severity, and multiplicity of injuries sustained on the modern battlefield. Simultaneously there has been a parallel evolution, out of necessity, in the growth and development of the level and sophistication of medical care available to treat the injured soldiers[158].

Injuries resulting from modern war activities have included burns, cranio- and maxilo-facial trauma, upper extremity injuries, neurosurgical injuries, ocular trauma, torso wounds, and lower extremity injuries. The nature, severity, and complexity of these injuries has resulted from

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[156] R Eldar and M Jelic, *The Association of Rehabilitation and War, Disabil Rehabil*, ;no. 25 (2003):1019-23.

[157] Coupland, *The Role of Reconstructive Surgery in the Management of War Wounds,* 24.

[158] Stankorb, Salgueiro, and Grediagin, *Enteral Feeding Practices for U.S. Service Members in a Deployed Combat Support,* 685–8.

advancements in the power, velocity, and advancements of modern weapon systems, the use of advanced chemical, biological and nuclear systems, the environment of modern battlefields, endemic biological influences, and mismatches between the weapon systems and the available soldier protective equipment[159].

Modern war wounds are unique due to their severity, complexity, and multiplicity in an overall sense. The vast majority of modern war injuries (seventy percent) involve Orthopedic trauma of the lower extremities. Specific features of modern orthopedic war injuries that have led to recommendations for their optimal care include: (a) severe destruction of bone and soft tissues; (b) wound contamination with highly destructive bacteria (Acinetobacter, Mycobacteria, and fungal species), and (c) the resultant impairment of wound vascularity. These three factors have led to an ongoing debate as to the optimal methods and timing of intervention for the care of complex lower extremity fractures and wounds. This debate focused on the controversy regarding the optimal timing for fracture management due to the inherent risks of external fracture fixation pin loosening and infection. The result of these complications has been delayed, or poor wound and fracture healing. The net effect has been a necessity to develop principles of wound care and techniques of reconstruction that could mitigate the effects of these three factors. It is ultimately the *devascularization* of tissues and large open wounds (susceptible to infection) that are the key biological entities that lead to complications. This critical insight was pivotal in the necessary development of reconstructive procedures, and recommendations related to their use in the acute and subacute phases of wound care[160].

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[159] Kumar, Harshbarger, and Martin, *MILITARY WOUND CARE: Plastic Surgery Challenges in War Wounded,* 2009.

[160] Clasper and Phillips, *Early Failure Of External Fixation In The Management Of War Injuries,* 84.

The emerging role of PRS reflected the special requirements inherent in the care of modern war injuries. A high complication rate was shown in the case of military ballistic orthopedic injuries. These complication rates were much higher than that occurring in orthopedic trauma within the civilian, non-war setting. Improvements in body armour, enhancements in forward medical care, and dramatically improved trauma evacuation systems were shown to be non-medical factors that improved soldier survival, limb salvage, and rehabilitation[161].

Principles of wound management demonstrated that *debridement* should be performed in the initial stages of wound care, and serially, at frequent intervals, to diminish the levels of tissue bacteria, fungi, and necrotic, *devascularized* tissue. This process was not to be permitted to have a deleterious impact on the physiology of the patient, which would have had significant ramifications regarding wound healing. The existence of large wounds with *devascularized* tissue encouraged the implementation of reconstructive methods early in wound management. The addition of vascularized tissue flaps to these wounds improved local blood flow, decreased the potential for the growth of microorganisms, and facilitated wound healing[162].

The complex nature of modern war wounds, and the fact that the bacterial and fungal contamination was so deeply embedded into the tissues, heralded a high complication rate (mainly infection) when early wound closure was practiced. This suggested that definitive wound management was best performed in the subacute period[163].

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[161] Taylor and Jeffery, *Management of Military Wounds in the Modern Era,* 50–8.

[162] S Hughes and D Birt, *Continuous Peripheral Nerve Blockade on Op Herrick 9, J Roy Army Med Corps,* no. 155(1) (2009): 57–8.

[163] S Geiger, F McCormick, R Chou, and AG Wandel, *War Wounds: Lessons Learned From Operation Iraqi Freedom. Plast Reconstr Surg,* no. 122 (2008): 146.

The value of PRS techniques in safely permitting the early management of Orthopedic war injuries was specifically demonstrated with regards to the matter of EF. Plastic and Reconstructive Surgery techniques were shown to have a positive impact on the early care of lower extremity skeletal trauma. The inclusion of these PRS techniques lowered the complication rates of war orthopedic fractures, and improved the incidence of limb salvage. These same principles utilized for lower extremity trauma are equally useful in the management of wounds in other areas of the body[164].

When considering the demography of those individuals injured in modern wars, it was revealed that the vast majority were local nationals, distributed amongst civilians, host nation armies and the local police force. The source of injured persons has a significant impact on who provides medical care, and to what level. Highly specialized care such as Neurosurgery and Plastic and Reconstructive Surgery are currently not routinely and/or consistently provided in *Role 3* military hospitals[165].

Historically, injured soldiers of World War II and beyond became closely associated with Plastic and Reconstructive Surgeons as part of the process of rehabilitation from war injuries. Plastic and Reconstructive Surgery as a specialty, after all, was born out of war. Modern PRS developed in response to the injury patterns of World War II. The fathers of modern day Plastic and Reconstructive Surgery have included names like Sir Harold Gillies and Archibald McIndoe in Britain, Ross Tillie and Fulton Risdon in Canada. These pioneers all provided significant contributions to the care of those injured in war. Plastic and Reconstructive Surgeons performed their reconstructions once the members had returned from the battlefield, in the safety of their

[164] Taylor and Jeffery, *Management of Military Wounds in the Modern Era,* 50–8.

[165] Ibid

countries of origin where more advanced resources were available. This pattern has largely been reproduced in modern times, not out of medical necessity, but a reflection of available manpower. Delays in access to early reconstruction, in many instances, would result in reconstructive outcomes that, although technically successful, produced less satisfactory cosmetic and functional results[166].

It is also important to effectively manage war burn injuries. Burn management is a specific domain of PRS. Not only must one possess the requisite medical knowledge, but in a military setting, one must also have the requisite detailed technical knowledge regarding weapons system. Each of these weapons systems has been shown to have different features that influence the type of burn injury, and therefore the method of burn care. Primarily Plastic and Reconstructive surgeons who have been specifically trained, educated, and experienced in all aspects of burn management manage burn care. Burn care is an area of medicine where skilled, knowledgeable and experienced medical intervention has had a significant impact on survival and healing[167].

The specialty of Plastic and Reconstructive Surgery has existed a great many years, and has without question demonstrated its effectiveness in the care and reconstruction of war injuries. At its foundation, PRS has involved reforming or reshaping the tissues of the body in order to reconstruct for improved function, or to achieve better aesthetics. The literal meaning of the Greek word *plastikos* is to mold. In modern times, this specialty has become a very important and valuable medical practice. Many landmark reconstructive cases, such as limb re-implantation and face transplantation, have raised the profile of PRS well beyond its reputation received from

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[166] *Body Beautiful: A History of Plastic Surgery, Random History* [journal on-line]; available from http://www.randomhistory.com/2008/08/31_plastic html; Internet; accessed 22 Dec 2010.

[167] Taylor and Jeffery, *Management of Military Wounds in the Modern Era,* 50–8.

Cosmetic Surgery practice. Plastic and Reconstructive Surgery today has had significant influences in many cultures throughout the world[168].

Plastic and Reconstructive Surgery for war wounds can be performed in the timeframes of either: (i) Primary (emergency) reconstruction; (ii) Delayed primary (subacute) reconstruction one to three weeks after injury); and (iii) Elective reconstruction. All surgeons involved with the early management of war wounds have been exposed to either having to perform, or make critical decisions regarding primary and delayed primary reconstruction[169].

It has been demonstrated that early reconstruction of select war wounds has been associated with higher complication rates only when utilizing highly specialized techniques such as microsurgical free tissue transfers. There have also been a defined subset of military wounds (e.g., large open wounds located near joints, and complex areas such as the face, perineum, hands, and feet) that, when reconstruction has been delayed, have had a significantly higher incidence of wound complications, poor or non-healing, disfigurement, limb loss, and permanent functional impairment [170].

Positive medical consequences have been demonstrated for the inclusion of PRS techniques in the early management of both civilian and complex war wounds. By regulation, the military Joint Operational Doctrine of Canada[171], NATO[172], and the United Kingdom[173] all

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[168] Ibid

[169] Coupland, *The Role of Reconstructive Surgery in the Management of War Wounds,* 21.

[170] M Godina, *Early Microsurgical Reconstruction of Complex Trauma of the Extremities, 619*.

[171] Canada. Department of National Defence. B-GJ-005-300/FP-000. Canadian Forces Operations – Joint Doctrine. (Ottawa: DND, Canada, 2005), 28-1 – 28-2.

[172] Rodig,E. *Trauma Technology and Emergency Medical Procedures,* 2.

specifically stated that individuals injured in war, regardless of origin, and without discrimination, have been entitled to the same level of and accessibility to medical care as would be available in the coalition member's country. This would include the provision of specialist medical care, for services such as Neurosurgery, Ophthalmology, Otolaryngology, Pediatrics, and Plastic and Reconstructive Surgery to name a few[174].

The main obstacle currently preventing the routine access to these surgical sub-specialist assets (such as Plastic and Reconstructive Surgery) has been that either the specialist surgeons don't exist, or are in short supply within the militaries of most small to medium sized coalition forces, like Canada. In the Canadian Armed Forces, there currently exists only three Plastic and Reconstructive Surgeons in uniform, one in the Primary Reserve (myself), and two on the Primary Reserve list. Plastic and Reconstructive Surgery in the Canadian Armed Forces is a Reserve, but not a Regular Force qualification. In larger armed forces, such as the US and Britain, this specialist manpower shortage has not occurred on a regular basis. Military agencies representing the various smaller coalition countries have recognized the need to provide specialized reconstructive care at earlier stages in wound management.

To deal with the manpower deficiencies in Plastic and Reconstructive Surgery, these countries with smaller Armies have made plans to have essential Plastic and Reconstructive Surgery and Neurosurgical techniques and knowledge taught to the core surgical specialists currently deployed to the Role 3 setting (General Orthopedic, and Maxillofacial Surgeons). The concept of developing a highly trained 'war surgeon' has been under review.

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[173] UK Ministry of Defence. *Medical Support to Joint Operations.* Joint Doctrine Publication 4-03 (JDP 4-03) 2nd Edition, January 2007, 7-3.

[174] Ibid, 2-5.

As a Canadian Plastic and Reconstructive Surgeon who has since become a specialist Medical Officer in the Canadian Forces, it was critically important for me to appreciate not only the celebrated history of my profession in relation to military activities, but to gain an understanding of the role of PRS in the care of modern war injuries.

We have seen that without question, mankind has had a lifetime history of war activities, unfortunately productive of a great many injuries. Some of these injuries prove to be lethal, whereas others inflict survivable wounds that require reconstruction and rehabilitation. As the sophistication of battle techniques and weapons has evolved throughout the years, so too have the number and complexity of injuries inflicted.

In modern wars, medical personnel are faced with people who have sustained not one, but multiple injuries. The complexity of each of these wounds has dramatically increased due to the power, velocity, and technical components of the ballistic and explosive systems. The damage inflicted is often enhanced by environmental factors and the introduction into the wounds of destructive microorganisms.

The most common injuries encountered in modern wars are orthopedic injuries of the lower extremities. Many of these result from the explosive effects of anti-personnel IED mines. The principles and practice of trauma surgery as applied to civilian, non-war orthopedic injuries have been established for many years. Only relatively few of the very basic wound care principles become applicable in the military environment where the wounds are far more complicated, more highly contaminated, and timely care not often possible due to the logistics of casualty evacuation.

The recurring theme present in all of the complex lower extremity injuries was that there was a combination of bone injury with severe soft tissue destruction and/or loss. These lower extremity injuries required very unique management due to: (a) The amount and severity of tissue destruction and loss; (b) The degree of deep tissue contamination with highly destructive bacteria and fungi; and (c) The severe vascular impairment of the wounds that resulted from the higher forces imparted by modern weapon systems. These factors led to a higher complication rate in the way of poor bone and soft tissue healing, and significantly higher infection rates when compared to comparable civilian trauma. These same factors were seen to occur not only in injuries of the lower extremity, but virtually all wounds throughout the body.

These higher complication rates were clearly unacceptable, resulting in higher morbidity, mortality, and loss of limbs. This also had a significant impact on the operational efficiency of the Role 3 military hospitals. The higher complication rates seen in these modern war injuries spawned the growth of an entire generation of modern PRS techniques developed to mitigate these unique challenges in wound care.

Recommendations were developed regarding the timing of reconstructive care. These categories saw wounds that needed (a) acute, (b) subacute, and (c) delayed reconstruction. The modern Role 3 military medical unit is comprised of a typical set of surgical specialists, including General Surgeons, Orthopedic Surgeons, and Maxillofacial Surgeons. Currently these are the only deployed surgeons who are responsible for the provision of acute care to those injured in war. The coalition members injured in the war setting have the capability of being evacuated out of the battle zone quickly to a facility staffed by surgeons capable of providing acute level Neurosurgery and PRS. For the local nationals injured in war, this level of care is not

available. It is significant to note that the local nationals comprise the largest group injured in war who present for care to the *Role 3* facility.

There are a subset of complex injuries that occur in the modern war setting that can benefit from knowledge, experience, and technical capabilities in Plastic and Reconstructive Surgery. These would include burns, complex facial injuries, massive torso wounds, and extremity injuries, particularly the more common lower extremity injuries.

The table of organization and equipment (TOE or TO&E) is a document published by military Departments of Defence that prescribes the organization, staffing, and equipment allocations of the various units. The current TOE does not provide for the inclusion of Plastic and Reconstructive Surgery (or Neurosurgery and other subspecialties) in the group of core surgical specialists deployed to a Role 3 hospital. This is contrary to the recommendations issued in the Joint Operational Doctrine of most countries, as well as NATO standards for medical care that stipulate that the level of medical care provided to all those injured in war is to be of the same standard and availability as is encountered in the various coalition home countries.

A review of the probable rationale behind the current TOE composition of surgical specialists revealed that for most of the surgical specialties, including Plastic and Reconstructive Surgery, there are simply an inadequate number of military Plastic and Reconstructive Surgeons that would be required to mount an effective and sustainable contribution to the Role 3 surgical staff.

Nevertheless, there is a definite need to provide acute PRS care to those injured in war. At the present time, the only viable option would be to educate the currently deployed surgeons (General, Orthopedic, Maxillofacial) in the basic knowledge and skills required to provide this

acute level of care. Work on this project, of which I am a part of, has been initiated. In August 2009 I was invited by Colonel Walter Henney to present, at the Summer Congress of the Interallied Confederation of Medical Reserve Officers (CIOMR), my experiences as a Plastic and Reconstructive Surgeon during my 2008 deployment to KAF. The presentation was titled " Plastic and Reconstructive Surgery Improves the Operational Efficiency of the Role 3 MMU"[175].

As a result of my presentation in Sofia, director of education for CIOMR, Colonel Walter Henney, wrote to me requesting that I assemble the curriculum for a course to be taught to the surgeons of CIOMR that would establish a core set of knowledge and techniques in the basics of Plastic and Reconstructive Surgery for war injuries[176]. Colonel Henney approved the course content, and arrangements have been in progress to schedule the first course[177]. Through this initiative, those wounded in war would receive timely definitive care: promoting diminished complication rates; facilitating the ability to successfully perform more complex reconstructions in the subacute interval; increasing limb salvage rates; expediting rehabilitation; and ensuring the efficient operation of the Role 3 hospital.

This thesis has demonstrated that Plastic and Reconstructive Surgery is a significant contributor of core surgical knowledge and techniques that are essential for the early management of select modern war injuries.

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[175] CIOMR. *Military Trauma Care and Tactical Combat Care: Abstracts of Presentations* (Sofia, Bulgaria, 2009), 45.

[176] Colonel Walter Henney, e-mail communication with author, 10 August 2009.

[177] Henney, 22 November 2009.

GLOSSARY

1. *Aseptic*: Free of, or using methods to keep free of pathological microorganisms.

2. *Cranium*: The skull minus the mandible

3. *Debridement*: The medical removal of a patient's dead, damaged, or infected tissue to improve the healing potential of the remaining healthy tissue.

4. *De-epithelialized*: The removal of the epithelium, or upper layer of the skin

5. *Distraction Osteogenesis*: The surgical process used to reconstruct skeletal deformities and lengthen the long bones of the body.

6. *External Fracture Fixation*: The surgical treatment used to set bone fractures in which a cast would not allow proper alignment of the fracture. Holes are drilled into uninjured areas of bones around the fracture and special bolts or wires are screwed into the holes. Outside the body, a rod or a curved piece of metal with special ball-and-socket joints joins the bolts to make a rigid support. The fracture can be set in the proper anatomical configuration by adjusting the ball-and-socket joints. Since the bolts pierce the skin, proper cleaning to prevent infection at the site of surgery must be performed.

7. *Fascia*: The connective tissue that surrounds muscles, groups of muscles, blood vessels, and nerves, binding those structures together in much the same manner as plastic wrap can be used to hold the contents of sandwiches together.

8. *Fracture Malunion*: The healing of a fracture in an abnormal (non-anatomic) position.

9. *Haemolysis*: The rupturing of erythrocytes (red blood cells) and the release of their contents

(hemoglobin) into the surrounding fluid.

10. *Hemogram*: The written or graphic record of a differential blood count that emphasizes the size, shape, special characteristics, and numbers of the solid components of the blood.

11. *Hoffman Pin Clamp*: The clamp used with the Hoffman external fracture fixation system to stabilize the pin and bar system.

12. *Intramedullary*: Within the marrow cavity of a bone.

13. *Lavage*: The general tern referring to cleaning, irrigating, or rinsing of tissues.

14. *Micro-neurovascular Reconstruction*: The reconstruction of microscopic-sized nerves and/or blood vessels.

15. *Microsurgery*: The performance of surgery on extremely small structures with the assistance of magnification or a microscope.

16. *Myoplasty*: The use of muscle tissue for reconstruction of wounds.

17. *Necrotic*: Dead cells and living tissues.

18. *Neovascularization*: The formation of functional microvascular networks with red blood cell perfusion.

19. *Osseointegrated Implants*: The process of bone growing right up to the implant surface. No soft tissue connects the bone to the surface of the implant. No scar tissue, cartilage or ligament fibers are present between the bone and implant surface. When osseointegration occurs, the implant is tightly held in place by the bone.

20. *Osteomyelitis*: An infection of the bone or bone marrow.

21. *Pedicle Flaps*: A mass of tissue for grafting, usually including skin, only partially removed from one part of the body so that it retains its own blood supply during transfer to another site.

22. *Periosteum*: a membrane that lines the outer surface of all bones, except at the joints of long bones.

23. *Role 3 Hospital*: The minimum capabilities emphasize resuscitation, initial surgery, postoperative care, and short-term surgical and medical patient care. Diagnostic services such as x-ray and laboratory, and limited scope internal medicine and psychiatric services are available. Other ancillary capabilities include liaison teams for tracking Canadian casualties/patients in allied or Host Nation facilities, teams providing assistance with stress reaction and mental health management, and co-ordination of preventive medicine activities in the AO. Role 3 capabilities may be enhanced with specialist surgical (Neurosurgery, Maxillofacial, Plastic Surgery etc.) capabilities, advanced and specialist diagnostic capabilities (CT scan, arthroscopy, sophisticated laboratory tests, etc.), major medical, surgical, dental, and nursing specialties, and environmental health and industrial hygiene capabilities.

24. *Role 4 Hospital*: This Role includes definitive-care hospitalization, re-constructive surgery, rehabilitation, storage and distribution of national medical and dental materiel/stocks inclusive of blood, blood products and intravenous fluids, and major repair or replacement of medical and dental equipment.

25. *Sequestrum*: A piece of dead bone that has become separated during the process of necrosis from normal/sound bone.

26. *Skin Grafting*: A type of medical grafting involving the transplantation of skin. The transplanted tissue is called a skin graft.

27. *Supratrochlear Artery*: One of the terminal branches of the ophthalmic artery, branches off where the ophthalmic travels posterior to the trochlear notch of the skull.

28. *Tibia*: The shinbone, or shankbone is the larger and stronger of the two bones in the leg below the knee

29. *Wound Exudate:* Exudate is a liquid produced by the body in response to tissue damage. It bathes the wound continuously, keeping it moist, supplying nutrients, and providing the best conditions for migration of new tissue to heal the wound. Open wounds should be moist, but not overly moist. A healthy healing wound should be moist without measurable exudate.

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