# AN EVIDENCE-BASED AND HISTORICAL REVIEW OF WAR SURGERY OF THE FACE AND JAWS

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## ABSTRACT

War surgery of the face and jaws is a fascinating and complex area of surgery and medicine with a relatively short history of formal development as a specialty despite surgical procedures being performed on this area of the body over the centuries. It was not until the mid-nineteenth century when surgery was evolving into a science rather than a trade, that literature was being published on aspects of face and jaw surgery as well as some of the innovative appliances or techniques. The First World War was the birth of the specialties of plastic and maxillofacial surgery and provided abundant clinical material for the surgical techniques and innovations that would subsequently evolve into the surgical principles taught to successive generations of surgeons including those of today.

This thesis sets out to provide a logical sequence of linkages between history, surgical principles and evidence-based medicine by way of an historical review, case studies to illustrate the surgical principles developed from war experiences and evidence-based systematic reviews of contemporary topics on face and jaw war surgery relevant to current combat operations in order to provide recommendations for military surgeons on future deployments.

The historical development of face and jaw war surgery was as much about the necessity for innovation and adaptability as it was about the skill of pioneering surgeons such as Gillies, Pickerill and McIndoe. This thesis reviews the major innovations and developments in face and jaw war surgery that came about during major conflicts starting with the First World War and continuing through to current conflicts in Afghanistan. Surgical principles identified from this historical review of war surgery of

the face and jaws have been illustrated in this thesis by a series of case studies from the Pickerill Collection and archival material from the School of Dentistry, University of Otago which present surgeries performed by Pickerill and his co-workers during the First World War. Discussion on the advances in treatment since Pickerill's time and illustrative examples of contemporary surgeries performed in Afghanistan provides a comparison between the time periods, highlighting not only the advances in medicine and science since 1918 but also aspects of surgical care that appear to have withstood the test of time.

This thesis provides the modern face and jaw surgeon with the necessary historical background and context from which current surgical principles have been developed. By way of evidence-based systematic reviews, the importance and relevance of war surgery of the face and jaws in current military medicine and surgery is highlighted for clinicians and military planners. Current operations in Afghanistan and Iraq have seen a proportional increase in combat related head, face and neck injuries due to the survival of soldiers wearing combat body armour and patterns of injuries resulting from blast fragments. This increase in incidence and the complexity of head, face and neck war surgery, emphasises the need to include surgeons with specialist expertise in this field for future operations. The importance of having an historical perspective in order to appreciate lessons learnt from past conflicts cannot be over-stated.

**ACKNOWLEDGEMENTS**

This thesis represents the culmination of a number of passions - namely service to others, teaching and surgery. To find a research topic or field that encompasses military history, trauma surgery and academic teaching is rare but I have been fortunate enough to find such a topic which is presented in this thesis.

Equally fortunate is the opportunity to work with some very talented and generous people and I gratefully acknowledge my supervisors Professor Robert Love and Professor Tom Brooking for their guidance and patience, my research advisors Professor Ross Beirne and Dr Debra Carr for their input and advice and to Professor Jules Kieser for his mentorship and support throughout this PhD.

I am indebted to Dr Andrew Bamji, former curator of the Gillies' Archive at Queen Mary's Hospital, Sidcup for his generous support and willingness to share archival material for this PhD. Thanks also goes to the staff at the Hocken Library, University of Otago, the Alexander Turnball Library, Dr Neil Waddell and Professor Murray Thomson, editor of the New Zealand Dental Journal for their kind permission to use images and archival material.

My greatest acknowledgement and debt of gratitude is reserved for my wife Catherine, without whom I could not function as a person, husband and father and whose endless patience has allowed me to complete this thesis – *Have I told you lately…*?

Finally, to all those who serve or have served New Zealand, along with their families and extended whanau, Thank you.

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| | |
|---|---|
| 2NZEF | 2nd New Zealand Expeditionary Force |
| ADDS | Assistant Director of Dental Services |
| ADMS | Assistant Director of Medical Services |
| C_ABC | Control of massive haemorrhage, Airway, Breathing, Circulation |
| CASEVAC | Casualty Evacuation |
| CBA | Combat Body Armour |
| COA | Condition on Arrival |
| CSH | Combat Surgical Hospital |
| DCR | Damage Control Resuscitation |
| DCS | Damage Control Surgery |
| DGMS | Director General of Medical Services |
| FST | Field or Forward Surgical Team |
| FTT | Field Transfusion Team |
| HFN | Head, Face and Neck |
| IED | Improvised Explosive Device |
| IMF | Intermaxillary Fixation |
| JTTR | Joint Theater Trauma Registry |
| GSW | Gunshot Wound |
| MASH | Mobile Army Surgical Hospital |
| MBChB | Bachelor of Medicine, Bachelor of Surgery |
| MC | Military Cross |
| MEDEVAC | Medical Evacuation |
| MUST | Medical Unit, Self-Contained, Transportable |

| | |
|---|---|
| NATO | North Atlantic Treaty Organisation |
| OEF | Operation Enduring Freedom |
| OIF | Operation Iraqi Freedom |
| ORIF | Open Reduction, Internal Fixation |
| R3MMU | Role 3, Multinational Medical Unit |
| RCT | Randomised Control Trial |
| RSTL | Resting Skin Tension Line |
| STRATEVAC | Strategic Medical Evacuation |

# CHAPTER ONE

## INTRODUCTION

The human face is functionally and anatomically complex, but beyond this physicality it also embodies the outward identity of an individual. As such, a great deal of emotional attachment is given to it so that injuries causing facial disfigurement are often devastating, not only from a physical standpoint but also a psychological standpoint as well. Surgical reconstruction of the face owes much of its development to war time experiences, especially those from the First World War, when surgical techniques for facial reconstruction were still in its infancy before developing more over later decades. The apprentice-type model so prevalent in surgical training, has become more formalised with a better understanding of biological processes behind the technical surgery and is guided by evidence-based best practice. However, there is a fundamental lack of the historical perspective that gives depth and context to scientific surgery, with questions such as: how did these techniques develop? Where were they developed and in what environment? Who came up with the innovation and why? The main research question in this thesis therefore is how did history influence the development and evolution of face and jaw surgery in the context of war injuries? The hypothesis being that the development of war surgery of the face and jaws owes as much to history as it does to technical skill and advances in science. A historical perspective is crucial to the understanding of the background behind surgical development. As surgical science behind surgical techniques and applications is keeping pace with new research and applications, the historical appreciation has lagged behind. This is particularly true of face and jaw reconstruction, whose fundamental principles were founded in war surgery and can be traced to a handful of innovative pioneering surgeons such as Gillies, Kelsey-Fry, Pickerill, Kazanjian and McIndoe. As the generation of surgeons who actually worked with these men retire or die, these men no longer become the stuff of living memories but rather mere names linked to surgical procedures or instruments. This thesis, therefore, uses history to give a deeper appreciation of the contemporary events and influences during the time of surgical development.

**The face from a social perspective**

The human face remains fascinating; from an infant gazing at their mother through to the cosmetic surgery to help maintain youth and beauty. The unprecedented public awareness of facial cosmetic procedures (including dentistry) is in no small part due to current media sensationalism and stereotyping. Celebrities who have undergone cosmetic procedures for purely elective reasons may elicit a degree of negativity. However, when surgery is performed to restore form and function due to disfiguring traumatic injury or congenital malformation, attitudes change from derision or ridicule to sympathy and understanding instead. Secondary surgical procedures following facial soft tissue trauma, such as scar revision, dermabrasion and laser skin resurfacing, have become more sophisticated, driven perhaps by increased public demand rather than surgical necessity. Social attitudes towards scarring have changed from when duelling scars on the cheek were regarded as a badge of honour among Prussian aristocrats at the turn of the twentieth century (Figures 1a and b), replaced instead by cosmetic make up products which promise to hide minor skin blemishes and surface irregularities.

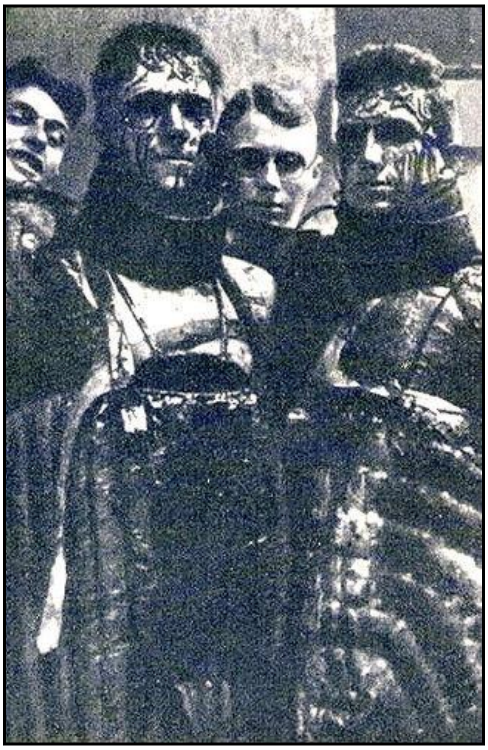
**Figure 1a**

A contemporary illustration of a duelling scar on the cheek referred to as a “schmisse” (“smite” in German).

(Public domain image)

**Figure 1b**

Prussian military cadets with fresh duelling scars. These young men are practicing a form of stylised fencing called *mensur* where light body armour was permitted but the face was fully exposed to a live blade.



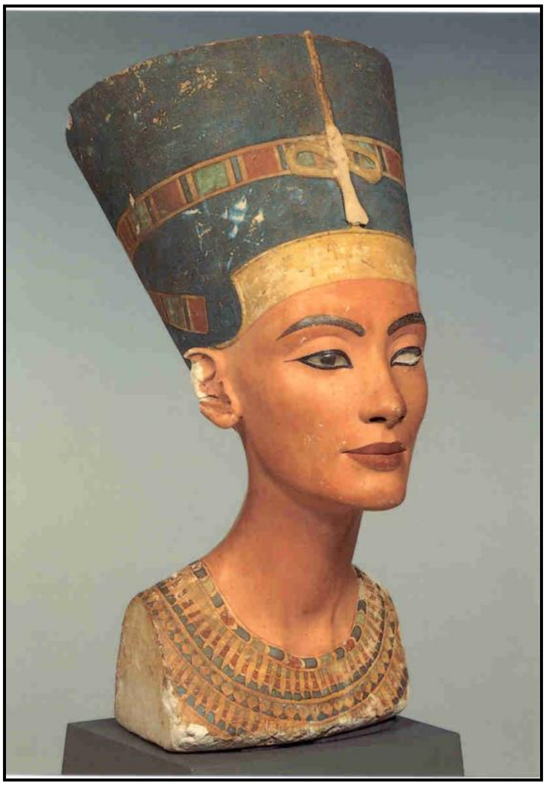
(Public domain image courtesy of www.suite101.com/view_image.cfm/177404)

The human face plays a pivotal role in communication and the unique perception of personal identity inherent from birth (Bates and Cleese 2001). Facial expressions are the basis of non-verbal communication and convey true feelings to others that words may serve to hide. First impressions of people are often formed by their facial features (sometimes erroneously). The dark side of this preconception was described in a study of 400 primary school teachers who were asked to review the report card of a 10-year-old child that included a photo of the child. The investigators, however, used different photos of several children, some more attractive than others. Despite being given the same information on performance in the report card, the more attractive children in the photographs were judged as more intelligent, capable and possessing greater social skills (Bates and Cleese 2001).

The face has been celebrated in myth and literature throughout the ages and even pervades everyday language with such phrases as face-value, ashen faced and shame faced. Take for example Narcissus, who was so handsome he became infatuated with his own reflection in the water and subsequently was turned into a flower, which hangs over river banks bearing his name. Queen Nefertiti was renowned for her beauty throughout Egypt during her life time – Nefertiti roughly meaning “the beautiful (or perfect) one has arrived”. Interestingly, the famous bust of Nefertiti (Figure 1c) focusses on her face and neck as if to accentuate these aspects of her grace and beauty. Although fingerprints may provide individuality, it is the face that is perceived as giving people their identity. Any injury or disfigurement to the face carries an enormous psychosocial impact and burden on the individual in terms of recognition and self-image. The face therefore, is more than just anatomical tissue as it also carries an important psychological component of how we perceive ourselves as individuals.

**Figure 1c**

Bust of Queen Nefertiti. By not including shoulders the neck is accentuated and heightens the elegance and beauty of the figure.



(Queen Nefertiti. c. 1348 - 1336/5 BCE Limestone, height 19" (48.3 cm). Staatliche Museen zu Berlin, Agyptisches Museum)

## The importance of a historical context

The historiography of war surgery of the face and jaws is not vast compared to general military, aviation or naval history. Books on war surgery are typically based on personal memoirs, biographies of famous surgeons with war experience, or a collective history commemorating a specific unit or particular service branch such as medics or nurses. Personal recollections and memoirs, although generally very readable and entertaining, suffer the limitations of intentional or unintentional bias and a narrow appreciation of larger events as the author can only relate to their immediate surroundings at the time. Biographies are less limited in perspective as the biographer collects material from a number of sources that covers a greater time period and overview. The biographies of Gillies (Pound 1964), McIndoe (Mosley 1962) and Pickerill (Brown 2007) provide insight into the character of these men and their surgical innovations, but by necessity the technical side of their innovations is often abbreviated, either because it does not fit the editorial nature of the biography or the author lacks the necessary background to make comment. One biographical source that has been frequently cited in this thesis is Reginald Pound's *Gillies – Surgeon Extraordinary* (Pound 1964) - which not only details the life history of Sir Harold Gillies but also devotes several chapters to Gillie's war surgery. Included are numerous anecdotal accounts from Gillies himself and his contemporaries. They provide the background behind his surgical experiences as well as present the human side of the man himself. Most pertinent to this thesis are the chapters devoted to Gillies' First World War experiences, which document the lead up to the establishment of the face and jaw unit at Sidcup and several anecdotal vignettes of Gillies' war surgery during this time. The blend between anecdotal accounts and historical commentary is important in a biography in order to make it more readable, but in doing so a more stringent historical and technical analysis may also suffer. This notwithstanding, Gillies' account of being intellectually and spiritually moved by encounters with Charles Valadier and Auguste Morestin should not be a surprise given Gillies' exceptional artistic talents both in music and painting. Through Pound's biography we learn of the motivations and influences that helped shape Gillies' military surgery career, and also of the background jealousies and politics as well. Gillies' surgical successes describe shattered faces made better but receive superficial attention, partly because of the non-surgical background of the author but also because detailed surgical critiques would not fit in with the biography. However, reading about the surgical techniques in isolation is a dry and sterile experience – which is fine for technical education, but to gain a much deeper understanding and appreciation the historical context is important and adds so much more to surgical education. The corollary to this is learning about strategic operations in a military setting, where strategic planning and operational application is put into context by learning about historical battles and events. In other words, the historical context makes the technical aspects more relevant and perhaps better understood as more insight is gained as to why things developed in the past. This thesis offers a wider historical overview of the evolution of face and jaw war surgery through various major conflicts from the First World War onwards including sections on urban violence in Israel and Northern Ireland and current military operations in Afghanistan, describing not only the historical context but also the major technical innovations and discoveries during that conflict pertinent to the on-going development of face and jaw war surgery – a theme pursued throughout the thesis.

**Beyond physical injuries**

The management of maxillofacial injuries in the context of war surgery is much more than a series of technical procedures; the reconstruction is not only physical but must also encompass psychological and social aspects in keeping with any major traumatic experience. This important facet of facial reconstruction and rehabilitation has not always been recognised and early attempts at surgery dealt mainly with physical and technical aspects, with often less than satisfactory results. The modern surgeon, therefore, has a wider role to play than a mere technician although the resources available today are far beyond what could only have been imagined a century ago. As mentioned, the face equates to identity - at least the outward part of our identity that others see most readily. Such is the impact on psychological behaviour; otherwise rational individuals have been moved to seemingly irrational behaviour to prevent facial disfigurement. One of New Zealand's greatest soldiers, Major General Sir Howard Kippenberger (1897-1957) wrote of his thoughts as a private soldier during the Battle of the Somme in 1916: "*As soon as the enemy started to fire back I became afraid of being* *hit in the face so stood as high as I could with the idea that a hit in the chest or shoulders would be nicer"* (Figure 1d) (Harper and Hayward 2003). Ninety years later Captain Doug Beattie MC of the Royal Irish Regiment serving in Afghanistan during the summer of 2006, wrote in his diary: *"Your leg or your face? Your foot or your hand? Your genitals or your arm? Which would you rather lose? For me it was anything but my face. I was scared stiff of going home with my looks twisted and scarred by battle, perhaps burnt, maybe rearranged by bullets and shrapnel. Teeth missing, jaw shot off, eyes blinded"* (Beattie 2008). These are visceral comments from a man who has been serving in the British Army for 25 years, a veteran of Northern Ireland, Iraq and Afghanistan and, therefore, by no means a stranger to combat.

**Figure 1d**

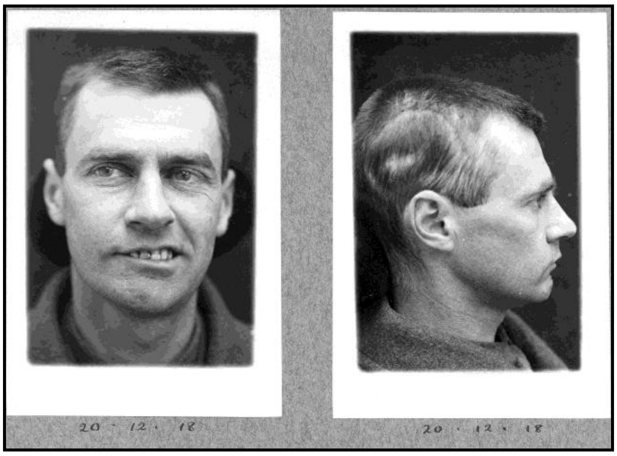
Lt Col Howard Kippenberger (later Maj Gen Sir Howard Kippenberger DSO) with Lt Charles Upham (later Captain Charles Upham, VC and Bar) Egypt circa 1941.

(Reference Number:DA-02149-F:Alexander Turnbull Library)

The social impact of facial disfigurement could have a much wider affect than just on the individual – it involved the immediate family and even whole communities. Stories of soldiers maimed in battle being shunned by friends, family and sometimes society itself are common. One soldier (whose surgery had not been completed and was given a painted prosthetic mask of tin to wear) was granted home leave only to have the disheartening experience of his own children running away in terror at the sight of his expressionless face (Pound 1964). Another, a French soldier called Lazé, after visiting home confided to his nurse: "*Having once been a man, having once understood the meaning of this word and wanting nothing more than just to be a man, I am now an object of terror to my own son, a daily burden to my wife, a shameful thing to all humanity".* Subjected to yet another episode of terrified cries from his son after another failed attempt at a home visit, Lazé said in resignation "*It's finished. It's too late. I terrify him"*. That night he committed suicide (Winter and Baggett 1996). Although not recognised by medical staff at the time, the rehabilitation of wounded soldiers was not only surgical but also psychological, and the need for social re-integration in a planned manner was overlooked. It seemed that it was up to the soldiers themselves to rehabilitate each other. Wounded soldiers after the Great War often met informally and formed their own support groups and associations. These were forgotten men who had only each other, as only they could understand what they had been through and what life had left for them after the battlefield. Only they could truly appreciate the sacrifice that had been made and the utter despair of no longer being seen as part of a society and a world they once knew. Meetings would be organised in places where the men could retreat to and recuperate, as one French Colonel put it "…*a place worthy of them, a château like those acquired by the men who got rich when we lost our faces"* (Winter and Baggett 1996). Even when able to physically re-integrate into society, some soldiers never fully recovered psychologically from their facial injuries. There are anecdotes of soldiers becoming social recluses or breaking off their engagement to a fiancée, all because in their own mind, their facial features remained disfigured despite reconstructive surgery. The long-term effects of facial injuries are not only aesthetic but often functional as well. Second Lieutenant Buddle of the New Zealand Rifle Brigade received fragment injuries to his right skull and face in 1918 (Figure 1e) and although his surgical records are incomplete, the surgery involved bone grafting harvested from the tibia. In 1927 he wrote to Pickerill and described constant headaches and a loss of sensation of the right lower jaw. Although not mentioned but evident in his photographs, Buddle has a right sided facial nerve weakness. According to Callister (2008), Buddle is the only wounded New Zealand soldier whose correspondence has been preserved within his medical records at Sidcup.

**Figure 1e**

2/Lt Buddle NZ Rifle Brigade. Note the right sided facial nerve weakness and the extensive scar in the temporal region.



(By kind permission of Dr Andrew Bamji, Curator, Gillies Archives, Queen Mary's Hospital, Sidcup, UK)

As part of a reply to an inquiry from Pickerill about his general progress , Buddle wrote: *"My jaw is of course no interest to you and is a continual source of expense to me. The feeling has never altogether returned"* (Callister 2008). Buddle's matter-of-fact account indicates some of the changes that have occurred for Buddle since coming home injured and an almost pessimistic acceptance of complications post-surgery. Callister (2008) points out that photographs cannot tell us about what these wounded soldiers actually feel and experience, in other words these issues extend beyond the physical appearance captured on film.

Perhaps the most brilliant exponent of the holistic bio-psycho-social rehabilitation of the patient was Sir Archibald McIndoe (1900-1960) and his Guinea Pig Club (Figure 1f) during the Second World War. Integrating these horrifically burned airmen into local village society gave these men hope and in time the local villages came to see these men as "their boys" (Mayhew 2006). Surgeons of the day had little or no training in facial plastics and there were no reference texts or surgical guides from which to compare. McIndoe, in particular during the Second World War, perhaps with a typical Kiwi sense of black humour, dubbed his patients "guinea pigs" as many of his surgical techniques for burn injuries had not been tested before.  Thus the highly exclusive Guinea Pig Club came into being. One biographer of McIndoe captures the essence succinctly and brilliantly: *"New faces he could give them; they had to help themselves to regain their spirit"* (McLeave 1961).

**Figure 1f**

Sir Archibald McIndoe (centre at piano) with members of the exclusive Guinea Pig Club.

(Public domain image courtesy of www.historylearningsite.co.uk)

Physical manifestations of psychological trauma should also be mentioned briefly here and is perhaps best exemplified by post-traumatic stress disorder (PTSD), more commonly known during the First World War as "shell shock" or "neurasthenia". With no outward physical signs of injury, the impact on the mind nonetheless could be equally as profound and was often accompanied by feelings of guilt and grief. The soldiers themselves were often seen as "lacking in moral fibre" adding to their feeling of guilt and poor self-image, the implication and lasting stigma of cowardice. The celebrated British war poets Wilfred Owen (1893-1918) and Siegfried Sassoon (1886-1967) were both diagnosed as suffering from shell shock as a result of traumatic events while serving on the Western front[1]. It was while convalescing at Craiglockhart War Hospital in Edinburgh that the two poets met and perhaps fuelled by mutual inspiration and their underlying melancholia, Owen and Sassoon produced some of the most haunting poetry written in the twentieth century.

**Facial surgery and war**

From ancient times, the treatment of injuries to the face and jaws has been recognised as an area requiring particular skill. According to the works of Hippocrates: "*Those physicians who have not judgment combined with their dexterity, expose themselves in fractures of the jaws…".*[2] This implication that particular skill and knowledge is required to treat such a complex area as the face persists to this day. The website of the American Association of Oral and Maxillofacial Surgeons states in their section on facial trauma:

*"Their broad-based and extensive dental and medical training in the hospital-based environment uniquely qualify oral and maxillofacial surgeons to treat and repair injuries to the face, jaws, mouth and teeth. Oral and maxillofacial surgeons are experts in treating trauma, including fractures of the upper and lower jaws and orbits, and the cosmetic management of facial lacerations. Their knowledge of how jaws come together (dental occlusion) is critical when repairing complex facial fractures. In fact, the*

[1] There is no evidence of a lack of moral fibre here: Sassoon was awarded the Military Cross for acts of bravery on the Western Front. His near suicidal exploits earned him the nickname "Mad Jack".

[2] http://classics.mit.edu/Hipprocrates/artic.33.33.html. Accessed 10 Dec 2008.

*American College of Surgeons' guidelines for optimal care require Level I and II trauma centers, those that treat the most serious and complex facial trauma patients, to have oral and maxillofacial surgeons on call to perform complex reconstruction of the maxillofacial and craniofacial complex, including the mouth, face and jaws. Moreover, many of the techniques that are standard in today's hospital emergency rooms were developed by oral and maxillofacial surgeons in combat hospitals during World War II, Korea, Vietnam and today's international conflicts'*'[3].

The face has always been a vulnerable area in combat and there are numerous accounts of devastating wounds to the face and jaws in literature and contemporary accounts of battle, resulting in disfigurement and sometimes death. Arrows, swords and spears (including lances) were the main combat weapons prior to firearms and could inflict devastating injuries. Homer's *Iliad*, mentions no less than 54 accounts of injuries specific to the head and neck (Sapounakis et al. 2006), one graphic example being the combat between Idomeneus of Crete and Erymas of Troy: "*Idomeneus stabbed Erymas in the mouth. The point came out under the brain and broke the bones; his teeth were knocked out, and both his eyes filled with blood, which spurted up through nostrils and mouth as he gaped. Then the dark cloud of death spread over him*" (Homer, WHD Rouse transl. 1938).

This level of descriptive detail is repeated throughout the rest of the Iliad and gives the impression that the anatomy of the head and neck was well known, not only to surgeons but also the warrior class who utilised this knowledge to deal lethal blows (Mylonas et al. 2008). Further accounts of head and face injuries can also be found in contemporary writings during the Napoleonic Wars. Bladed weapons such as swords and lances were

[3] http://www.aaoms.org/the_oms.php. Accessed 10 Dec 2008.

used to lethal effect by cavalry against infantry. Elizabeth Longford in her biography of Wellington describes a typical encounter during the Battle of Waterloo: "*Life guardsman Shaw cleft a skull so violently that the face fell off like a bit of apple"* (Longford 1969). Facial injuries from musket balls and shrapnel were also common and although not immediately life threatening, could still result in death due to sepsis, bleeding and malnutrition – an officer in the Foot Guards who lost his lower jaw and tongue during Waterloo died from malnutrition two years later in England (Keegan 1988). Unfortunately at the time, treatment for such injuries was primitive at best and surgeons had no formal training to deal with the complexities of maxillofacial injuries. It is no wonder then, at the time of the First World War (1914-1918) that the management of maxillofacial injuries remained primitive when compared with the advancements of modern weaponry.

The First World War was the watershed for maxillofacial surgery. The principles that are taught and used today in contemporary maxillofacial trauma surgery can be traced back through a lineage of experiences and techniques often borne out of necessity and innovation. Wounded soldiers were often malnourished, physically worn out and their injuries contaminated – shock and sepsis made a lethal combination for soldiers injured in the First World War and herein lie several fundamental differences between war surgery and civilian surgery: the state of the patient when injured, the severity of injury, gross wound contamination and the availability of medical resources at the time. Even today, the modern combat soldier remains under enormous physical and mental stress during combat operations and the nature of injuries due to fragments or small arms fire remain the same as in the First World War, in other words grossly contaminated and severe in nature. The biggest difference however is in the evacuation chain- whereas a soldier could be kept waiting for hours or days until seen by a surgeon on the Western Front in 1916, whereas US-led coalition soldiers serving in Iraq or Afghanistan can expect to be evacuated to a Base Hospital in Germany within 36-hours after receiving life-saving resuscitative treatment in a field hospital environment. The management of maxillofacial injuries in the context of war surgery therefore, differs from civilian practice in terms of the tactical environment, the type of patients involved, the severity of injuries and emphasis on initial stabilisation and management prior to evacuation for definitive treatment. Furthermore, although expertise may lie within one's specialist training, the military surgeon must be flexible enough to assist other surgeons and on occasion perform procedures outside of their field of normal practice, a concept not lost on surgeons in past conflicts and one that is still valid today (Lieber et al. 2008). These differences may not be readily apparent to surgeons unfamiliar with military operational environments. The principles that are taught to trainees in maxillofacial surgery today relate directly to the lessons learnt in the hard school of warfare and as Lord Smith of Marlow wrote - "*... it is remarkable how quickly the lessons learnt in time of war are forgotten as soon as hostilities cease. Surgeons in World War II, anxious to record for the use of others the lessons painfully wrung from bitter experience in the treatment of battle casualties, all too often, as they consult the literature from earlier days, found that they had merely been retracing the steps trodden by their predecessors in World War I* " (Owen-Smith 1981). This is a pertinent reminder for surgeons today from where these techniques and principles have been derived and bear wonderful testimony to the endeavours of pioneer surgeons in the field of maxillofacial surgery almost a century ago.

**Linking history and Surgery**

This thesis links historical and technical information by a three part step-wise process. The first part provides an overview of the developments of face and jaw surgery within the context of major conflicts, describing the nature of the conflict and what the state of the art for face and jaw surgery was at the time and the innovations that came about. This gives the necessary contextual background to understand the recurring themes and surgical issues that confronted surgeons during those time periods. Having identified or highlighted these recurring issues, the second part takes these themes and principles and illustrates them by using case studies sourced from archival material from the Pickerill Collection at the University of Otago Hocken Library and School of Dentistry archives. The case studies have been selected to illustrate key areas of surgery for face and jaw surgeons. Each case study is presented and discussed and, where possible, case matches from Afghanistan have been used to compare similar injuries and contrast differences in surgical management. Although photographs and line drawings (drawn by Captain James Turner of the NZ Section and the fourth BDS graduate of the University of Otago Dental School in 1912) are used with the case studies, this part differs from Sandy Callister's work as it does not focus on imagery but rather uses it to illustrate the surgical art and technical innovations that were influenced by working on war injuries specific to the face and jaws. The final part of the thesis uses evidence-based systematic reviews of selected topics pertinent to the modern military surgeon building upon the principles and surgical developments from the previous section. The first review deals with why surgeons should know more about face and jaw war injuries, followed by a review of initial management of jaw fractures outside of the hospital environment and culminates with a third systematic review aimed at specialist level on damage control surgery of the face and jaws. These topics follow a progression from generalist to specialist surgical issues and looks towards the future for further research and developments of ideas.

**Structure of the thesis**

This thesis is structured into five chapters corresponding to an introduction, historical review, cases studies, evidence-based systematic reviews and a conclusion. The second chapter is sub-divided into six sections which follows the historical development of war surgery of the face and jaws over several centuries of war and conflict, starting from antiquity through to current military operations in Afghanistan. Perhaps a little different is the inclusion of urban combat, namely Northern Ireland, while not a war zone in a conventional military sense, nonetheless produced horrific injuries due to explosive devices and other ballistic injuries from gunshot wounds and rubber bullets.

The third chapter introduces the man regarded as the father of modern plastic surgery, Sir Harold Gillies and his remarkable contribution to the field of plastic and maxillofacial surgery. Among his contemporaries was Henry Pickerill, the first Dean of the dental school at the University of Otago who, along with other surgeons from the Dominions, worked alongside Gillies at the Queen's Hospital at Sidcup during the First World War. Pickerill returned from the war with surgical experiences that only war can provide as well as records of his surgeries on wounded soldiers. It is from this archival material held at the Hocken Library as well as a collection donated to the school of dentistry by the family of Captain Tommy Rhind, Pickerill's surgical assistant, that five case studies have been selected illustrating aspects of face and jaw surgery dealt with by Pickerill and other face and jaw surgeons including Gillies. This chapter is divided into 8 sections, the first two describing the contributions of Gillies and Pickerill and the next five sections presenting case studies and illustrating surgical concepts with case comparisons between wounded soldiers during the First World War and clinical material from Afghanistan. Chapter three concludes with the last section which presents a summary of the lessons learned and updates Gillies' sixteen surgical principles from *The Principles and Art of Plastic Surgery* (Gillies and Millard 1957).

Chapter four provides evidence-based systematic reviews aimed at providing the modern military surgeon with potential guidelines for best practice and future research directions. This chapter has five sections including the context for systematic reviews, three reviews covering contemporary aspects of war surgery of the face and jaws and an overview discussing strategic planning in modern military surgery and highlights the need for surgeons with face and jaw surgery expertise to be included in surgical teams deployed to support current military operations in response to the proportional increase in facial wounds seen among combatants in Iraq and Afghanistan.

The fifth and last chapter gives a summary of the thesis findings, conclusions and recommendations for future research and planning.

The terminology used in this thesis - "face and jaw" is in keeping with historical literature and may be used interchangeably with "maxillofacial" as it relates to the anatomical region for surgery and distribution of injuries. If this region is expanded to include the skull above and the neck below, "head, face and neck" becomes more appropriate and supports current literature which proposes that this should be the preferred terminology reflecting the injury patterns seen in Afghanistan and Iraq. Oral and Maxillofacial surgery is defined by the American Dental Association as "*as the specialty of dentistry which includes the diagnosis, surgical and adjunctive treatment of diseases, injuries and defects involving both the functional and esthetic aspects of the* *bone and soft tissues of the oral and maxillofacial region".* In the United Kingdom and New Zealand, the specialty of oral and maxillofacial surgery is also recognised as a vocational surgical speciality in medicine as well as dentistry, separate from plastic and reconstructive surgery and otolaryngology – head and neck surgery. There is overlap in certain areas such as trauma and reconstructive surgery of the face and jaws between the three specialties. This thesis limits the surgical discussion to the scope of practice typical of an oral and maxillofacial surgeon and by no means tries to portray the specialty as anything else than what it is.

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# CHAPTER TWO

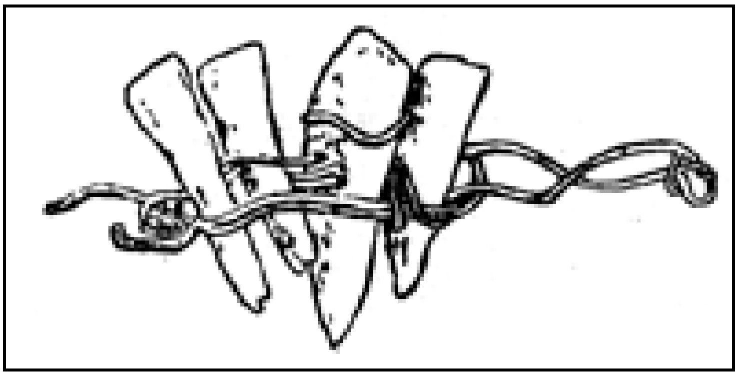
# THE DEVELOPMENT OF FACE AND JAW WAR SURGERY

## 2.1 The Management of Maxillofacial Injuries prior to the First World War

The orthopaedic management of bony fractures follows a dogma of anatomical reduction, rigid fixation, immobilisation of the joints above and below the fracture and functional rehabilitation. While elements of these principles have been known for centuries, the ability to actually execute these concepts was limited to the science and technology of the time, especially when dealing with the face and jaws. The Edwin Smith papyrus dating back to 1600 BC Egypt makes mention of reducing dislocated mandibles by pushing down on the jaw with thumbs inside the mouth and fingers outside supporting the chin (virtually the same technique is still employed today) and treating simple fractures of the mandible by bandaging with dressings soaked in egg white and honey for stiffening (Thoma 1944, Rowe 1971, Siegert and Weerda 1990). Comminuted fractures of the mandible however were regarded as beyond simple treatments and reference is made to not actively treat such an ailment that causes fever – perhaps a clinical descriptor for systemic infection or sepsis. Presumably the fracture was left to heal over time assuming the patient survived potential sepsis. A basic technique of immobilising fractured segments of the mandible is to wire together the teeth adjacent to the fracture site thereby using the teeth as splints and as a guide to anatomical reduction of the jaws (Figure 2.1a). This technique was described as early as 400 B.C. by Hippocrates in his works on surgery and medicine. In his volume *On the articulations*, he describes wiring as many teeth together as possible with gold wire and using Carthaginian leather glued to the chin and bandaged around the head to stabilise bony fragments. Without the benefit of histological examination he also described the formation of a bony callus prior to bony consolidation.[4]

**Figure 2.1a**

Line drawing of Greek artefact dating back to circa4th century BC showing teeth splinted together by gold wire. This illustration may be showing the management of periodontally involved teeth or the application of a wire splint for a fractured jaw in a manner described by Hippocrates.



(adapted from Clawson D (1934). Phoenician dental art. Berytus Archaeological Studies.
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Similar treatises can be found in other texts of antiquity from iconic figures of medicine such as Celsus, and Galen and ancient medical texts from China and India which describe similar techniques of wiring and splinting (Ring 1985, Mukerji 2006). Surgery, however, reached its lowest point during the "Dark Ages" when afflictions were seen to be a result of a transgression towards God rather than by a disease process. The example of Job and his afflictions also reminded people that illness and disease could also be a test of faith as well. Traditionally, the medical and surgical needs of the populace were performed by monastic orders, the most famous being that of the Knight's Hospitallers of St John of Jerusalem, the monks and nuns of whom administering to the physical and spiritual health needs of pilgrims to the Holy Lands during the crusades. But this service

[4] http://classics.mit.edu/Hipprocrates/artic.33.33.html. Accessed 07 Jan 2009.

was dealt a mortal blow during the pontificate of Pope Alexander III, when the Council of Tours in 1163 AD decreed that *"The Church does not shed blood"* which literally overnight effectively banned any monk or religious brother from performing surgery.[5] Furthermore, the Council was concerned that monks and secular priests were leaving their cloisters to attend public lectures in medicine and law and thereby violating their obligations of residence. Earlier church edicts had also prohibited secular clerics from attending lectures at Universities on medicine and law should "*... spiritual men be again plunged into world cares"* (Cressman 2001). In doing so, minor surgical procedures such as bloodletting, lancing boils and abscesses and cutting for stone were left to the auspices of barbers, bath keepers and hangmen. It is from this inauspicious background that surgery owes its foundation and is apocryphally why to this day, surgeons have the courtesy title of "Mister" rather than "Doctor" which was earned from a university and denoted a more learned medical (non-surgical or tradesman apprentice) background. In England, after the dissolution of the monasteries between 1536 and 1539, surgery was partially "legitimised" by Henry VIII uniting the Company of Barbers and the Guild of Surgeons by an Act of Parliament in 1540 (Figure 2.1b) thus forming The Company of Barber-Surgeons, a direct ancestor to the current Royal College of Surgeons of England (Cope 1959).

[5] http://www.newadvent.org/cathen/10142a.htm, Medicine and Canon Law. Accessed 10 Jan 2009.

**Figure 2.1b**

Henry VIII and the Barber Surgeons by Hans Holbein the Younger.
Henry VIII is handing a document uniting the Company of Barbers and the Guild of Surgeons to Thomas Vicary, Master of the Company of Barber-Surgeons.

(Hans Holbein the Younger, circa 1543. Henry VIII and the Barber Surgeons. The Royal College of Surgeons of England).

The contribution made by barber-surgeons during this period from the Middles ages to the 17$^{th}$ century was immense and in some ways fortuitous owing to the demise of the Church in such matters.

The link, therefore, between surgery and dentistry (in its most primitive form of "tooth pulling") lay in the surgical scope of practice of the barber-surgeons, using basic surgical skills and limited dental knowledge to produce startling developments in managing facial injuries – as evidenced by, perhaps the most brilliant of barber-surgeons, Ambroise Paré (Figure 2.1c).

**Figure 2.1c**

Ambroise Paré (?1517-1590). Paré was surgeon-in-ordinary to four Kings of France and wrote extensively on surgical techniques and appliances including those used in jaw injuries.

(Etienne Delauline (1518-1595).
Ambroise Paré. Bibliotheque Nationale, Paris)

Ambroise Paré (?1517-1590) was a barber-surgeon who rose to eminence as surgeon-in-ordinary to four Kings of France by his own skill and universal respect rather than personal favour and intrigue (Lyons 1987, Bishop 1995). His *Ten Books of Surgery* covered an extensive range of topics including gunshot wounds, amputations, dental treatment including the use of gold ligatures to stabilise fractures of the mandible, early dental and maxillofacial prostheses and the use of an obturator for defects of the palate due to syphilis (Rowe 1971, Ring 1985). It was Paré who advocated ligation of vessels after amputation and dressing gunshot wounds rather than cauterisation with boiling oil which resulted in patients who were " *…feverish with great pain and tumour* (swelling) *about the edges of their wounds…"* (Bishop1995). Paré is rightly described as the father of surgery and his skills and insight were years ahead of his time. By the 18$^{th}$ century, surgery had become less of a trade and more of a profession, enhanced in part by a world-wide phenomenon of scientific research in medicine and surgery and better understanding of the human organism. Scientific writing became more common and the world became smaller in terms of sharing of knowledge and cross-fertilization of ideas. With research comes understanding and some of the traditional methods of treatment were challenged such as simple wiring of teeth and bandage support for fractures of the jaws which did not provide rigid fixation crucial for bony union. Designs were made for fixation devices that were applied over the dentition to rigidly immobilize bony fragments of the jaws and perhaps the best examples of these were the Kingsley's apparatus (which had external bars attached for bandaging) and splints designed by Hayward and Gunning in the 19th century (Mukerji 2006). Perhaps Hayward's design was most innovative in terms of fracture reduction – his method involved taking an impression or mould of the mouth including the fractured segments of the jaws and producing a plaster cast. The cast would be cut through the fracture site and the segments realigned onto which a dental splint would be made. The splint would then be placed into the patient's mouth and the segments forced into the correct anatomical position, effectively reducing the fracture. This technique is still a valid treatment option for mandibular fractures, particularly in children.

Similarly, the concept of a Gunning splint may still have its uses today especially with comminuted fractures of the jaws in an edentulous patient. Thomas Gunning was an American dentist who devised a splint made of vulcanite (vulcanised rubber) which was moulded around the existing dentition and kept in place by suction around the teeth (Gunning 1866; Romm 1986). The splint consisted of dental tray which could be used to maintain the fractured jaw after manual reduction and could be secured by way of wires or screws. If reduction of the fracture was difficult, a one piece splint consisting of an upper and lower dental tray fixed together but leaving space for fluid intake and secretions, could be used not only for maintaining the fracture reduction but also used as a form of intermaxillary fixation for immobilising the fracture (Figure 2.1d). Gunning would reach everlasting fame for his treatment of William Seward, Secretary of State in 1864 after the unfortunate Seward fell and broke his arm and lower jaw. Gunning used a modified one-piece splint to accommodate an edentulous maxilla and a dentate mandible, proving the adaptability of his design.

**Figure 2.1d**

An example of a Gunning Splint made for an edentulous patient, the upper and lower trays acting as denture bases.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

These inventive designs were made to rectify problems and poor outcomes associated with traditional methods of fracture management of the jaws and introduce a fundamental concept in the healing of bony fractures: that a successful bony union and healing occurs when fracture segments are anatomically reduced and held in position long enough for bony repair to occur. From anecdotal experience, wire ligatures around teeth adjacent to the fracture site were not sufficient to prevent mobility of the fracture segments, which most likely would have led to malunion or worse, bony necrosis and sequestration and possibly sepsis and death.

Little is written about the management of fractures of the midface and this could be in part attributed to two major factors: accurate diagnosis of the injury and adequate fixation of the bones of the face as opposed to the single bone of the mandible. However, as sophistication and expertise grew with the use of dental appliances, some were attached to the upper dentition and held in place with external frames usually bandaged to the head. Examples of this type of external frame fixations would become more common during the First World War. Attempts to wire the bony fragments together directly were no more successful than using the teeth to stabilize the bony fracture. It is likely that this early attempt of osseous wiring (current terminology) failed due to the primitive state of aseptic operating technique, the contaminated nature of the oral cavity due to the millions of micro-organisms resident in the mouth and the absence of suitable antibiotics which had not yet been discovered. Poor surgical outcomes from the Russo-Japanese War (1904-1905) and the Balkans War (1912-1913) using direct bony wiring techniques and simple dental "trough" appliances resulted in the condemnation of these methods in a battle field environment due to the severe nature of the injuries created by high velocity modern fire arms. It was noted that local infection was common and in some cases bony healing did not occur until the wires themselves were actually removed from the surgical site. An Austrian surgeon writing about his experiences during the Balkans War stated that "*Surgical wiring of the bone is not to be recommended in peace time, still less on the battle-field"* (Dolamore 1916). Certainly by the First World War, German maxillofacial surgeons were advocating more sophisticated dental appliances and worked closely with their dental colleagues in special face and jaw units – a relationship that would be found in many face and jaw units of various nations during the First World War.

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## 2.2 Pioneering a Specialty

In the Herbert Moran Memorial lecture at the 2002 Annual Scientific Congress of the Royal Australasian College of Surgeons, it was stated that the development of craniomaxillofacial surgery (surgery of the face, jaws *and* skull), could also be traced back to origins in the First World War (Simpson 2004). Particular mention was given to Harold Gillies and his role in the development of Plastic and Maxillofacial Surgery and also to the American Harvey Cushing and the development of neurosurgery as a specialty. It was further mentioned that British military surgeons of the time were more prepared for the First World War than their continental counterparts due to their involvement in the South African or Boer War (1899-1902), but the statement is a gross generalisation as it is anecdotal and unsubstantiated as no nation was truly prepared for the sheer scale of the carnage to come in terms of numbers and severity. The Boer War was a vicious conflict that introduced the world to truly high velocity missile wounds caused by jacketed rifle ammunition fed by magazines. The Boers used the German designed Mauser rifle with a calibre of 0.315 inches and a 5-round magazine (Wolfe 2007). The 5-round magazine concept proved so effective, the British adopted this system and rapidly modified their single-shot 0.303 inch Lee-Metford and Lee-Enfield rifles to a similar standard. The Boer War also saw the use of the British copy of the Maxim Automatic Machine Gun in 0.303 inch calibre. For those familiar with military history and small arms development, the Mauser and Lee-Enfield rifles will reappear again during the First World War as would more lethal developments of the Maxim Machine Gun, namely the Vickers Mk.I. Despite the experiences of the Boer War and to an even more limited degree, the Russo-Japanese War and the Balkans War, no country (including Great Britain) was truly ready for the sheer numbers and severity of battlefield casualties soon to become legendary that helped define the sense of human suffering in the First World War.

During the early stages of the First World War, the acknowledged leaders in the infant field of maxillofacial surgery were Germany and France. No doubt as a result of observations by German medical authorities of the mostly unsuccessful outcomes of face and jaw injuries from recent conflicts like the Balkans War, hospitals in Berlin, Strasbourg, Hanover and Düsseldorf were already prepared to receive face and jaw injuries by 1914 (Dolamore 1916a). Among the more eminent maxillofacial surgeons of the time were Professor Christian Bruhn and Dr August Lindemann at the Düsseldorf Hospital and Hippolyte Morestin at the Val de Grâce Hospital in Paris. Lindemann had written a short text on the treatment of facial injuries, which was freely available to the medical services of both allies and central powers alike. Serendipity had a part to play it seems in launching one of the greatest surgical careers of the 20th century. An American dentist by the name of "Bobs" Roberts, serving with the American Ambulance at Neuilly (American involvement was strictly voluntary at this stage as the United States did not enter into the war until 1917) had a copy of a book on facial surgery and lent it to a promising young New Zealand-born British surgeon, remarking "*why don't you take up this work?"* (Pound 1964). The young surgeon was of course Harold Gillies, serving at the time as a volunteer with the Red Cross in France and who subsequently wrote *"I felt I had not done enough to help the wounded and that I must bestir myself"* and *"I realised that I had struck a branch of surgery that was of intense interest to me. My first inspiration came form the few pictures in that German Book"* (Pound 1964). The "German book" mentioned by Gillies, may have been written by Lindemann, however there is anecdotal evidence that this may have been a French book on rhinoplasty (Bamji, personal comm.). The remarkable contributions and developments made by Gillies will be examined in a later section and no one man may lay better claim to being the founder of modern plastic (and maxillofacial) surgery than Harold Gillies[6].

The mechanical aspects of treating injuries involving the maxillofacial skeleton, in comparison with soft tissue injuries and reconstruction, were relatively well established by 1914. Simple dental wiring techniques were clearly inadequate to effectively immobilise fractured bone segments and direct osseous wiring constantly failed due to local infection. Numerous dental appliances and techniques were developed and modified over the course of the war to deal with injuries that had not been encountered before. By 1916, the dental appliances available to treat bony injuries, especially those of the lower jaw, was at a stage of development that would remain basically unchanged until after the Second World War, and only then with minor alterations. Among the appliances available were dental splints which were cemented over the remaining dentition with various methods of spanning defects of the jaw, including expansion screws for gradual widening, heavy wire springs and a solid metal bar; cap splints with soldered hooks for inter-maxillary fixation and appliances with extra-oral extensions to allow bandages or extra-oral traction to help immobilise the fractured bone segments (Frey 1916, Hopson 1916, Piperno 1916, Dolamore 1917a, Mendleson 1918, Parrott 1918).

It is interesting to read contemporary medical and dental literature of the time. It would seem that the hard lessons of war surgery of the face and jaws were being taught by the

[6] The terms plastic surgery and maxillofacial surgery are used interchangeably at this stage as the specialty fields had yet to gain recognition among the surgical fraternity. Gillies himself used "face and jaw" surgery as an umbrella description that would cover soft and hard tissue surgery that would eventually separate into plastic and reconstructive surgery and oral and maxillofacial surgery based on training backgrounds rather than technical skill.

numerous casualties coming through into the hospitals but also the extent and severity of the injuries themselves necessitating innovation and creativeness on the part of the plastic surgeon, dental surgeon and dental technician. With the advent of trench warfare on the Western Front, injuries to the head and face became more common as this was often the most exposed part of the soldier. At sea, the main concern was burns to the face and hands. Unlike the rather haphazard observations from previous conflicts, here now are practiced teams of clinicians who were sharing their experiences through journal publications. A recurring set of basic principles now emerges from the medical and dental literature in dealing with bony injuries of the jaws:

1. Reduction of displaced bony fragments
2. Maintenance of the fragments during healing
3. Restoration of normal occlusion (termed *orthognathy*)
4. Stretching of cicatricial (scar) tissue and remoulding of facial contours
5. Prosthetic replacement of defects and restoration of function
6. Rehabilitation of the face and jaws through dynamic exercises

The concepts of anatomical reduction, immobilisation and functional rehabilitation are well defined, the missing concept being that of direct fixation of the fracture segments, which at this stage of development relied on external splinting rather than direct fixation of the bone. It is also noteworthy that emphasis had been placed on reproducing a normal occlusion by manipulation of the bony fragments back into their original position, which was termed *orthognathy* (Gk. Straight jaws), a descriptor still used today (*orthognathic*) to denote realignment of malpositioned jaws. This reinforces the principle of using the dentition as a guide to normal anatomical relationship of the jaws and using teeth themselves to help reduce the fracture segments when dental appliances are used. In the restoration of the mandible after gunshot injuries, the restoration of intraoral health in order to wear a denture and to regain some form of pre-morbid range of movement post-operatively were additional considerations in the management of jaw injuries (Kelsey Fry 1918).

The problem of scar contracture was a particular problem when both soft and hard tissue defects were sustained concurrently. In order to maintain the position of bony segments, external forces had to be minimised as the bone fragments, although reduced, were not rigidly fixed together thereby allowing the bony segments to move out of alignment. Contractures of soft tissue scars could place enough pressure over time to cause shifting of the fractured bone segments with resultant malunion or even non-union of the fracture (Sebileau 1917). Surgeons of the day sought to prevent scar contracture by two main methods. The first would be to anatomically reduce the fractured jaws in order for normal bony contours to be re-established and the covering soft tissues to be repaired over this restoration of bony form. When this was not possible and the soft tissue injury had healed, expansion of the newly formed scar (cicatrix) was undertaken, the timing of which was critical as stretching a newly healed scar or cicatricial tissue too early may cause wound breakdown whereas leaving the scar too long would lead to maturation making stretching more difficult due to the relative inelasticity of fibrous connective tissue. According to Mummery (1916) newly formed scar tissue had an "*almost infinite capacity for dilatation, and, containing but a few elastic fibres, has very little tendency to retract afterwards*". Unfortunately, we now understand that the reality of scar tissue biology is different – scar tissue has a tendency to contract and in some individuals, hypertrophic scarring or keloid formation may also arise producing a poor aesthetic result. Over time, even Mummery would have been disappointed with some of his patients' long term results. A simple method of slowly expanding a newly formed scar was to add successive layers of vulcanite to a dental prosthesis thereby stretching the soft tissues outwards from an intraoral device (Hopson 1916).

Combination appliances of cast cap splints with a jack screw have been described, the screw being turned on a daily basis allowing distraction of the bony segments and stretching of the soft tissues meanwhile providing cross arch splinting of the dentition (Dolamore 1916b). It may be interesting to the modern reader to note the significance of a device that allows the slow expansion of bony segments – the forerunner perhaps of the modern day helix palatal expansion device used by orthodontists or distraction osteogenesis devices used in craniomaxillofacial surgery. These technical examples illustrate how biomechanical knowledge of the dentition and jaws could provide the dental surgeon and plastic surgeon (the former working closely with the dental technician) with the means to treat soft and hard tissue injuries of the face and jaws. The complementary nature of the dental surgeon and plastic surgeon cannot be underestimated - the plastic surgeon’s skill base lies in soft tissue reconstruction but the underlying foundation of the soft tissue drape lies in the facial skeleton providing the correct proportion and symmetry over which the soft tissues are reconstructed. The key to re-establishing facial proportions, projection and symmetry is to correctly position the teeth and align the occlusion.

This concept is seen as an emerging theme in contemporary literature during the First World War and is still a fundamental precept when managing pan-facial fractures in contemporary maxillofacial surgery: establish mandibular continuity, relate the maxilla to the mandible using the dentition and placing the patient into the correct dental occlusal relationship using maxillo-mandibular fixation, re-establish the correct transverse proportions from midline to lateral structures then repair the cavities (such as the orbits or nose). The concept of "inside–out and bottom-up" management of maxillofacial injuries was elegantly discussed in a paper presented at the 1970 Annual Meeting of the Association of Military Surgeons of the United States and highlighted a philosophical difference of opinion between plastic surgeons and oral surgeons (the descendants of war time "dental" surgeons and fore-runners of today's oral and maxillofacial surgeons) (Small 1971). Oral and maxillofacial surgery has traditionally been seen as a dental specialty with obvious importance being placed on dental occlusion in the management of maxillofacial injuries. The boundaries have become somewhat blurred now with many countries (including New Zealand) requiring both medical and dental qualifications in order to become a specialist in oral and maxillofacial surgery. The move towards dual qualification reflects the importance and complexities of maxillofacial surgery which encompasses both dental and medical fields, a fact well pointed by Anson in his history of the New Zealand Dental Corps during the Second World War: *"The infinite variety of injuries ranging from the simple mandibular fracture to the destruction of half the face makes it is impossible to label a case as purely medical or purely dental"* . (Anson 1960). Dual qualification is not a new concept either: Sir William Kelsey Fry (Gillie's partner in crime during the First World War) was both medically and dentally trained and prior to working with Gillies, held the position of medical officer, 1st Battalion, The Royal Welch Fusiliers[7]. It was Kelsey Fry who suggested to Gillies *"I'll take the hard tissues. You take the soft"* and as Pound wrote in Gillies' biography: *"the partnership between the two branches of*

[7] History is full of strange events that seemingly are unrelated but later become bound together by a common thread. Siegfried Sassoon won the first of his Military Cross awards after a dangerous but unsuccessful raid on a German trench during the Somme in 1916 while serving with the 1st Bn Royal Welch Fusiliers. When the award was promulgated afterwards, the battalion medical officer took his own Military Cross ribbon and sewed it on to Sassoon's tunic. The medical officer in question was none other than Captain William Kelsey Fry. Http://www.191418.co.uk/sassoon/Bois%20Francais%202%20frame.htm. Accessed 18 Feb 2009.

*surgery was decisively confirmed by the arrival on the scene of Captain William Kelsey Fry MC…"* (Pound 1964).

However, dental prostheses and appliances cannot replace biological tissue, whether it be soft or hard tissue. Free soft tissue grafts were relatively straightforward to perform compared to bone grafts – the issues of infection, bone graft stability and potential loss of graft being key factors in the complexity of this surgery. This was the period before antibiotics were discovered and liberal use of topical antiseptics was the mainstay of aseptic technique. That notwithstanding, bone grafting procedures were performed during the First World War with varying degrees of success; autogenous bone already being shown as superior to alloplastic or heterogeneous grafting materials (Dolamore 1917a). The Germans were particularly innovative in this area with Lindemann at the Düsseldorf Hospital being recognised as a world leader by virtue of his large case series. Lindemann provided bone grafts to 97 patients, of which primary union of the bony segments was achieved in 86 patients: almost a 90% success rate (primary bony union achieved) which, given the severity of injuries, the state of the patient and lack of antibiotics, is nothing short of astonishing (Dolamore 1917a, b). The largest defect grafted in his series was 12cm in length and healed with a small defect of ¾ inch. The main cause of bone graft failure was invariably infection due to issues of aseptic technique, oral contamination and mobility of the bone graft (Dolamore 1917a, Sebileau 1917). By this stage of the war, shortages of manpower and materials were beginning to have an effect on the management of maxillofacial injuries as well as the sheer numbers of casualties. Efforts to decrease the surgical workload, especially for the dental surgeons and technicians lead to new developments such wire splints. Once again, the German surgeons proved themselves innovative and leaders in technology and a system of splints made from 1-2mm silver wire were manufactured which included fastening of the splint to the labial or buccal surfaces of the teeth by ligature wires and split rings acting as washers (Harrison 1917). This was a primitive form of arch bar and maxillo-mandibular fixation resulting in a greatly reduced need for castings, solder and bulky appliances. By 1918, the management of mandibular injuries was well advanced as illustrated in a paper by H.P. Pickerill (first Dean of the Dental School, University of Otago, Dunedin) who described stabilising bony segments of the mandible using an external frame attached by screws placed directly into bone (Pickerill 1918). The management of midfacial trauma was also evolving as the First World War dragged on. In this period where there was a lack of suitable internal fixation devices, the midfacial skeleton was reduced and stabilised using the maxillary dentition and frames either attached to the skull by way of a head bandage, plaster of Paris skull cap, or by straps similar to those used in orthodontics. Compared to the techniques in managing mandibular injuries, midfacial trauma did not receive the same degree of innovation and advancement, perhaps in part due to the lack of suitable diagnostic imaging but definitely hampered by the lack of suitable skeletal fixation. The relative scarcity of contemporary literature during the First World War specifically dealing with midfacial skeletal fixation compared to mandibular trauma reflects this disparity and the limits of technology at that time. The use of external frames for midfacial trauma would continue beyond the Second World War as the mainstay of surgical management. Problems of stabilisation of the midface and maxilla were noted especially against masticatory forces (Kazanjian 1918). Dental knowledge was crucial in overcoming some of these issues and getting the most out of the technology available at the time and once again, required the combined skills of dental surgeon and technician. An example of a sophisticated dentally-anchored traction device for midface trauma is shown in Figures 2.2a to 2.2c.

This soldier received mid -facial injuries resulting in a concave and slightly elongated appearance of the middle third of the facial skeleton. The likely differential diagnoses based on the clinical photographs are bilateral zygoma fractures, Le Fort II or Le Fort III pattern fractures of the midface or combinations of these injuries[8]. Having no adequate means of anatomical reduction and internal fixation of the mid-facial fractures, an external appliance was the only viable option available. By gradually winding out the four anterior square nuts, the springs of the traction device slowly distracted the midface into a more correct anatomical relationship (Figure 2.2d). The craftsmanship of the custom-made appliance is remarkable and bears great testimony of the skill of the dental technicians and the integral part they played in a multidisciplinary team (Figure 2.2e).

**Figure 2.2a**

Mid-face traction device in situ. The upper parts of the framework is attached to a broad metal band against the forehead used as anchorage. The poor quality of the images are due to the original photos being out of focus.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

[8] Le Fort R (1901). Experimental study of fractures of the upper jaw – Parts I-III. *Rev Chir de Paris* 23: 479-507. In this classic study, Le Fort described patterns of injuries to the facial skeleton after trauma using cadaveric skulls. Three distinct patterns of injury were described: Le Fort I involving the maxilla only; Le Fort II involving fracture of the maxilla but also extending upwards across the nasal bridge area in a triangular shapeand Le Fort III in which the entire facial skeleton is discontinuous with the base of the skull through the orbits and nasal bridge. Due to the degree of midface retrusion on the photographs the likelihood for at least a Le Fort II pattern injury is strongly suspected.

**Figure 2.2b**

Same device and patient showing connectors from the intraoral appliances to the external frame.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

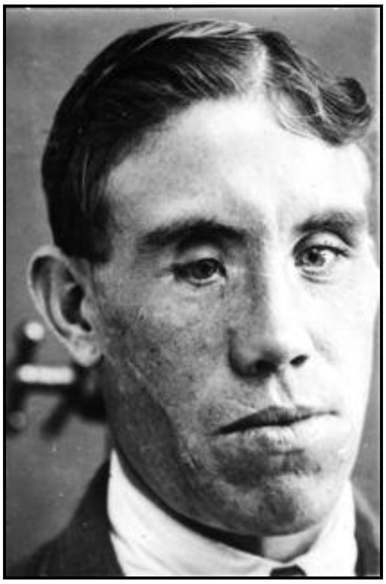


**Figure 2.2c**

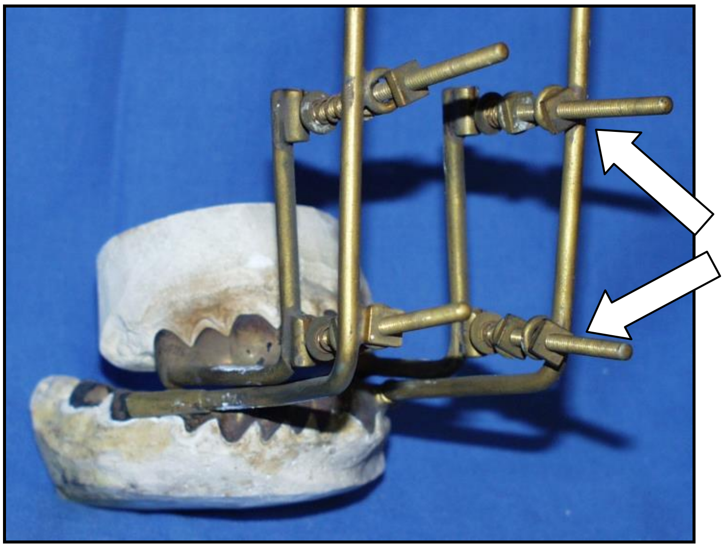
An acceptable final result given the technology of the time.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

Previous reference to Simpson's statement that the First World War was the genesis of craniomaxillofacial surgery is correct but can be further expanded by saying that the First World War was the genesis of many specialties including plastic surgery, neurosurgery and oral and maxillofacial surgery. The two specialties of oral and maxillofacial surgery and plastic surgery work towards a common goal of restoring facial form and function although their respective philosophical approaches may be different, the former being occluso-centric, reflecting its dental heritage. In civilian practice when public demand of services may be less, inevitable rivalries may arise, however, the close relationship between plastic surgery and dentistry that was established during the First World War should not be overlooked. There is great truth in the Hippocratic dictum that war is the greatest school of surgery.

**Figure 2.2d**

Detail of perhaps a second apparatus but for the same patient. By winding out the square nuts (arrowed) the mobile mid-face could be gradually pulled forward using the upper teeth.



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 2.2e**

An example of the craftsmanship involved with this custom-made appliance. Each threaded screw extension has a ball and slot arrangement allowing removal or replacement of the individual extensions. The appliance is in full working order over 90- years after it was made.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

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### 2.3 Maxillofacial Surgery in the Second World War

After the First World War, the future of plastic and maxillofacial surgery was by no means a certainty. Surgeons were warned not to rely solely on plastic surgery as a means of income and it was with some trepidation that Gillies himself finally took a leap of faith to restrict his practice to plastic and reconstructive surgery after the war (Pound, 1964). Many surgeons attached to the face and jaw units during the First World War did not continue on in the field and chose to return to their former practices. The inter-war years saw little movement in terms of advancing knowledge in the fledgling specialty despite numerous patients receiving ongoing treatment from war injuries in military and civilian hospitals. In 1921 there were still 15 patients “left over” from the war at the Queen’s Hospital in Sidcup and some of these patients were still receiving follow up in 1928. Both Pickerill and Gillies published textbooks on their surgical experiences and there was at least a growing recognition and respect among the medical and dental professions for this type of surgery. Perhaps “official” recognition of the specialty came when The Cartwright Medal and Prize for 1916-1920 was awarded to William Kelsey Fry for his essay on the treatment of jaw injuries, an indirect acknowledgment and validation by The Royal College of Surgeons of England and senior surgeons who still viewed plastic surgery with some suspicion. Further *kudos* was afforded to Gillies when he was granted permission by Buckingham Palace to dedicate his textbook *Plastic Surgery of the Face* to Queen Mary, wife of the reigning monarch King George V (Gillies 1920).

When Great Britain declared on Germany in 1939 the Ministry of Health had sought advice from Gillies and Kelsey Fry to help establish specialist centres for maxillofacial injuries under the auspices of the Emergency Medical Service. The planning arrangements made by the two surgeons were based on an expectation of 30,000 air raid casualties occurring immediately after declaration of war. However, despite the fame and reputation of Gillies and Kelsey Fry in the establishment of a maxillofacial unit at Sidcup, there was almost a sense of denial that the horrific facial injuries that were seen during the First World War would be repeated. The thought that the static type of trench warfare would be replaced by a war of movement and mobility in the coming conflict lead to a belief that the numbers of face and jaw casualties would be much less and according to a memorandum issued by the War Office of the day, dated 12 September 1939: "*the formation of an Army Maxillofacial Hospital will be undertaken when the incidence of maxillofacial wounds among army personnel justifies such a step*" (Pound 1964). It would appear at first that those in the War Office had forgotten lessons learnt from the previous conflict, but their perceptions seemed justified today as the overall incidence of maxillofacial injuries during the Second World War was only four percent compared to sixteen percent from the First World War (Dobson et al. 1989). The Army Medical Services was no better; the Directorate having no understanding or appreciation that plastic surgery had moved beyond the anatomical boundary of the face and jaws and now included the rest of the body; in particular the hands. At the outbreak of the Second World War there were only four recognised full time specialists in plastic surgery in the United Kingdom: Sir Harold Gillies, Tommy Kilner, Archibald McIndoe and Rainsford Mowlem – collectively known as the "Big Four" (Figure 2.3a).

**Figure 2.3a**

Plastic surgeons (clockwise): Gillies, Mowlem, McIndoe and Kilner – known as the "Big Four". Although UK-based, Gillies, Mowlem and McIndoe were originally from New Zealand.

Gillies and Mowlem (Author's personal collection, original source unknown)
McIndoe (public domain image courtesy of www.amref.org/who-we-are/archie-mcindoe)
Kilner (public domain image courtesy of calder.med.miami.edu/Ralph_Millard/aesthetic.html)

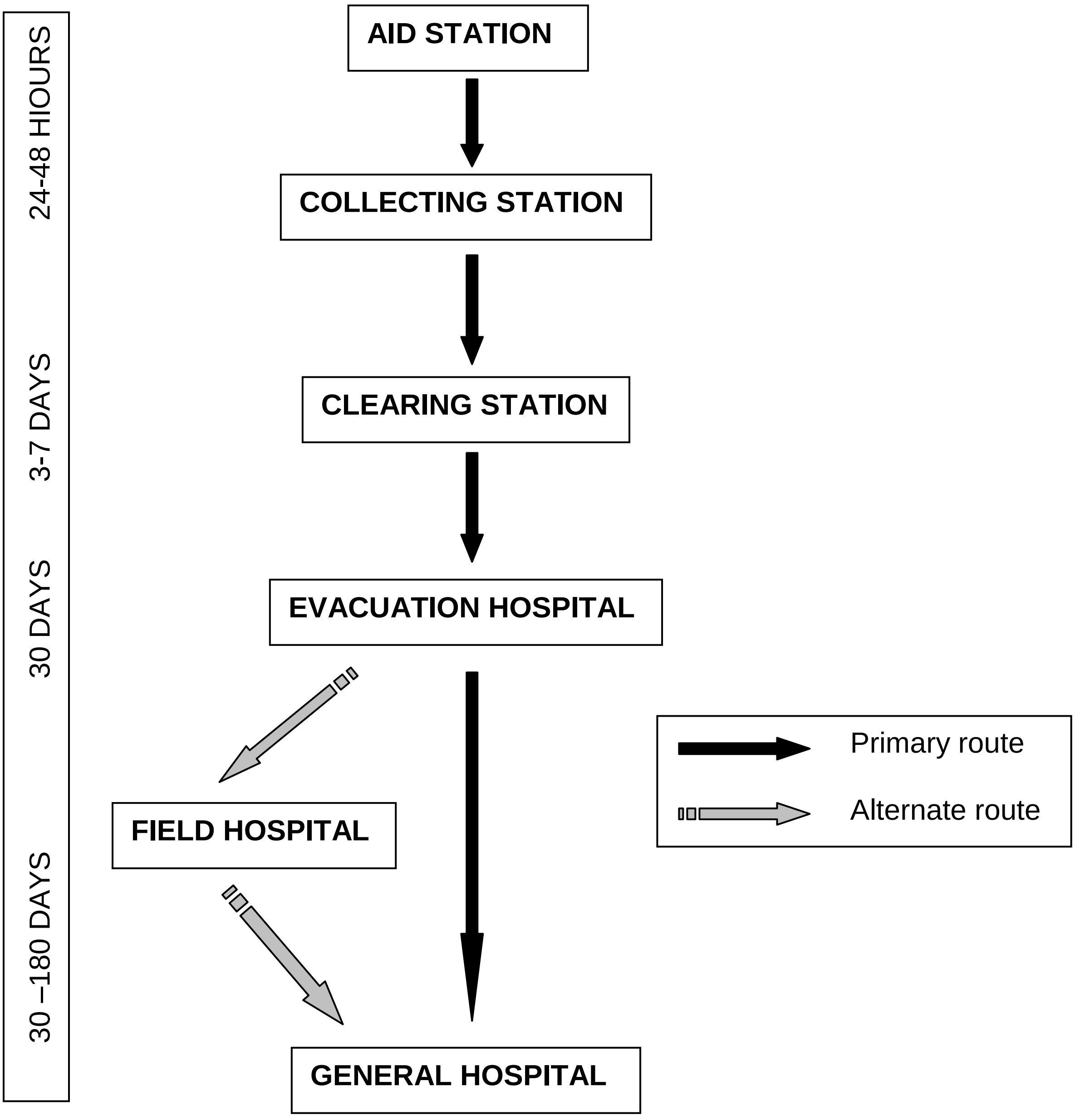
Three of the big four had connections with New Zealand: Gillies and McIndoe were both born in Dunedin with McIndoe and Mowlem both qualifying MBChB from the University of Otago (Meikle 2006, Tong et al. 2008). Kilner had been Gillies' assistant during the interwar years and had moved on in 1929 and later became the Nuffield Professor of Plastic Surgery at Oxford. Gillies, McIndoe and Mowlem were in partnership leading up to the Second World War and when war was imminent; Gillies wound up his private practice for the time being and became a consultant advisor to the Ministry of Health. Kilner was appointed the civilian consultant at Roehampton, Mowlem seconded to St. Albans, McIndoe becoming the civilian consultant to the Royal Air Force at East Grinstead and Gillies returning to Basingstoke having relinquished his position as the primary civilian consultant to the Royal Air Force in favour of McIndoe, in hindsight an exceptionally generous move on the elder statesman’s part, especially in light of McIndoe’s meteoric rise in fame and reputation during and after the Second World War in part due to his groundbreaking surgery and management of severely burnt British aircrew – members of the famous Guinea Pig Club.

The successful working relationship between plastic surgeon and dentist was once again re-established in the Second World War by allied forces, no doubt modelled after one of the greatest partnerships in the history of medicine and surgery: Gillies and Kelsey Fry. Many of the techniques and principles performed by First World War maxillofacial teams would be used once again in a global conflict, however particular emphasis was placed on a team approach of surgeon and dentist (as in the previous conflict) from the outset and treating maxillofacial patients at designated specialist hospitals (White 1943, CDC 1944, Paletta 1981, Strother 2003). The plastic surgeon, however, was always seen as the senior medical officer with the dental officer subordinate (but not subservient) to the plastic surgeon. This may be in part due to general medical responsibilities and the overall medical management of the patient, which lay outside of the dental surgery training. For example, Canadian soldiers with jaw injuries were considered the responsibility of the medical corps. During the hospitalisation phase, however, the treatment of jaw injuries involving the design, manufacture and insertion of fixation appliances was strictly the domain of the dental corps (orig. comm. BDJ, 1944).

The evacuation chain was improved to facilitate the rearward movement of these patients for definitive care and rehabilitation. For example, a US soldier with maxillofacial injuries could expect to be initially treated by a combat medic rendering first aid management, who would then send the patient rearward to a clearing station where a dental surgeon would manage haemorrhage, treat shock and if able, provide temporary immobilisation of the facial fractures. The patient would then be sent to an evacuation hospital where the wounds would be debrided, drains inserted and the fractures immobilised prior to evacuation to an area General Hospital for definitive management of the facial injuries (Figure 2.3b). In most instances the US soldier would then be transferred to the continental United States for further rehabilitation at one of the military hospitals (AAOMS 1989). This model of rearward evacuation of an injured soldier to progressively better resourced facilities and ultimately repatriation home differs only slightly from our modern contemporary model in that the injured combat soldier is stabilised at a Forward Surgical Team (FST) facility (with limited holding capacity and surgical resources) and priority for evacuation to a general hospital for definitive care is given, often within 48 hours (weather and airframe availability permitting).

**Figure 2.3b**

Evacuation and hospitalisation organisation in World War Two
(US Army model)



The principles of management of maxillofacial injuries essentially remained unchanged since the First World War and the armamentarium available still relied heavily on dental appliances and prostheses, which had become more refined and practical in nature. For example, the silver cast cap splint was still a mainstay in stabilising jaw fractures but had now become a two part or segmental system, allowing the splint to be applied to the separate segments, which were then manipulated and reduced before the splinted segments were fixed together by wires, cement or locking plates (Gilbert 1942, Graham 1944). This could only be done with adequate technical support and was not advocated for initial or emergency management of jaw fractures. The manufacture of these custom appliances required equal measures of technical science and art form. Figures 2.3c -2.3f illustrate what is now a lost art.

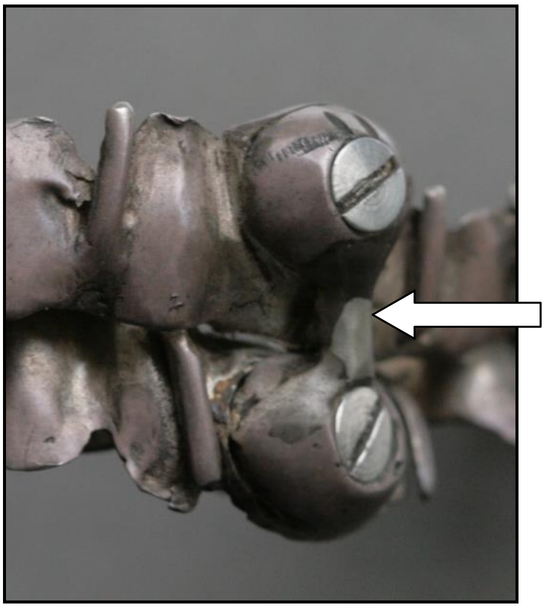
**Figure 2.3c**

A silver cast cap splint with precision locking plates and hook for wire ligatures to provide a secure method of intermaxillary fixation after cementation of the splint on to the existing dentition.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 2.3d**

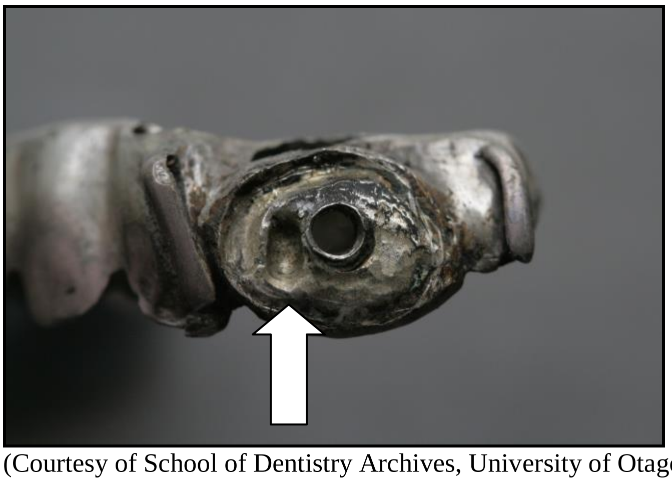
Close up view of the precision locking plate showing the screw placement and connecting bar (arrowed).



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 2.3e**

Precision locking plate removed showing the position where the plate is located onto the cast cap splint. Note the recess for positive guidance of the plate (arrowed).



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 2.3f**

Detail of precision locking plate and screws.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

The technique of producing these cast cap splints and various methods of connection is well illustrated in Kelsey Fry and Ward's textbook *The Dental Treatment of Maxillofacial Injuries* and illustrates how advanced the treatment of maxillofacial injuries had become since the First World War (Kelsey Fry and Ward 1942). In this textbook (and subsequent revised editions), chapters on wound healing, antibiotics, surgical nutrition and a "guest" contribution by Sir Archibald McIndoe on midface fractures are included. Maxillofacial surgery was no longer an *ad hoc* affair but had become a science as well as surgical speciality in its own right. Articles appearing in the *British Dental Journal* on bone pathology and healing, a retrospective review of 400 cases of high velocity missile wounding and Mowlem's work on bone grafting using cortico-cancellous bone chips were indicative of a move towards a scientific approach to maxillofacial surgery, examining patterns of injury and biologic processes rather than descriptions of techniques (Fish 1941, Mowlem 1944, Holland 1945a, Mowlem 1963).

The same issues of shock, sepsis and restoring lost tissue still confronted military surgeons in this later conflict, but at least formalised training had been developed between the wars and there was a cadre of older, experienced surgeons, who from their own time during the First World War, could provide invaluable advice and direction. Contemporary literature during the Second World War discussed recurring themes from the First World War, namely stabilisation of fractures, fixation devices and initial management of maxillofacial injuries. Inter-dental wiring as a method of temporary immobilisation of fractures was becoming more popular and various methods were published, utilising modified designs seen in the previous war (Walker 1940, Buxton 1941, Kamrin 1943). The reliability of external pin fixation methods had also been established as part of the armamentarium offered to maxillofacial surgeons. Stainless steel or vitallium[9] pins would be inserted into the bone on either side of the fracture and rigidly connected with a series of cross bars and adjustable connectors (Gillies 1941, Mowlem 1941, Bigelow 1943, Clouston 1943, Waldron 1943, Toomey 1944, Rushton 1945). This arrangement is often referred to as a biphasic system as it allows anatomical reduction and fixation of the fracture but was more prone to leaving external scars, infection and potential neurovascular injury (Alpert 1990).

The majority of papers dealing with skeletal fixation appear to involve mandibular injuries rather than the midface. The diagnosis of maxillary and midfacial injuries could be established clinically and radiographically but the issue of how to adequately stabilise midfacial fractures especially those involving more than one bone still relied heavily on First World War techniques and appliance design. The arrangement of a maxillary dental appliance with extensions to attach to some form of head gear was still in use; however, modifications were now being described in the surgical literature but tended to illustrate new techniques and designs in the application of existing hardware rather than making any innovative progress in the stability of the fractured facial

[9] Vitallium is the trademark name for an alloy consisting of cobalt, chromium and molybdenum often used in dentistry in the fabrication of metal partial dentures

skeleton (McIndoe 1941, Thoma 1942, Waldron and Balkin 1942, Parker 1943, MacGregor 1944, Holland 1945b). In terms of the maxillofacial reconstruction, the pioneering techniques of Gillies et al were well learned and surgeons such as Kazanjian (described as the "miracle man" of the western Front, who started off as a dentist but then qualified in medicine after the First World War) produced remarkable results utilising dental and plastic surgical skills in managing large defects (Kazanjian 1943). Techniques and principles first described in the previous war appear to be established treatment options such as the tube pedicle, intraosseous wiring, pin fixation and various flaps and grafting techniques – a trend to more invasive and "open" techniques of surgery made possible by the use of systemic antibiotics such as sulphonamide and penicillin (Kazanjian 1943, Converse 1945, Parker 1945). The use of early antibiotics enabled open procedures to be performed without inevitable infection and sepsis. Direct intraosseous wiring of adjacent bone segments was now an accepted form of treating mandibular fractures but as little as 30 years previously; this surgical technique was avoided due to its high complication and failure rate mainly due to sepsis. Direct wiring techniques were also being described for the treatment of midface and maxillary fractures as well but these practises were still in their early days and it was emphasised that these techniques could only be achieved in conjunction with the use of systemic antibiotics to prevent infection (Adams 1942, Peer 1943). Wires were not only used to reduce fracture segments together directly but also used to treat fractures indirectly by skeletal fixation. Thoma described a new method of managing a fracture of the edentulous maxilla by passing a wire through the anterior nasal spine intraorally by making local incisions into the mucosa and using this wire to attain intermaxillary fixation with an upper denture in place against lower natural dentition with an archbar (Thoma 1943). Remarkable for the time was an article appearing in 1945 describing the use of a tantalum plate and screws to bridge a defect of the mandible providing a level of rigidity that was not achievable with simple wiring. With increased rigidity the fracture is allowed to heal with optimum stability and offers a more rapid progress of recovery in both form and function. This early example of the use of a metal plate and screws to directly fix a fracture after reduction was a harbinger of the current typical technique of open reduction, internal fixation (ORIF) for treating a mandibular fracture (Christiansen 1945).

**Maxillofacial Surgery and the 2nd New Zealand Expeditionary Force**

Without entering into any disagreements of which nation was more surgically advanced than the other, the numerous maxillofacial units of the allied nations during the Second World War all employed similar techniques and adhered to basic principles well founded over years of hard earned experience. New Zealand was very much a proud member of the British Empire and still looked towards Great Britain as “home”. Certainly in medical circles, specialty training invariably lead to a long pilgrimage to the United Kingdom with attempts to gain a coveted Fellowship from one of the Royal Colleges of Surgeons in the United Kingdom, or Ireland, at the end of their clinical studies. Not only was the Fellowship seen as the benchmark of completion of surgical training but also a recognition among more senior surgical colleagues as being “one of them”. The maxillofacial units of the 2nd New Zealand Expeditionary Force (2NZEF) were typical of any other British and Empire maxillofacial units of the time. With similar basic philosophies and training (invariably UK based) the maxillofacial units attached to 2NZEF serve as suitable illustrations to describe the typical developments of maxillofacial units during the Second World War (at least from a British and Empire standpoint) outlined above. The core of a British maxillofacial unit in the Second World

War typically consisted of a team (or if lucky, teams) of a plastic surgeon, a dental surgeon trained specifically to manage maxillofacial injuries and a dental mechanic (technician) with either a dedicated general duties orderly or if attached a general hospital, nursing staff and other personnel on an *ad hoc* basis. At the beginning of the Second World War, specialist maxillofacial centres had been established in the United Kingdom which catered for both military and civilian casualties. A military maxillofacial section was based in Burwood near Christchurch but due to limited numbers of military patients, services were also to civilian patients as well. Plastic surgery was still very much an infant specialty in NZ at the time despite the strong kiwi connection of Gillies and Pickerill in pioneering the specialty. Following on from his experience and success during the First World War, Pickerill continued to practice plastic and maxillofacial surgery alongside his other numerous duties as the Dean of the Dental School. When he retired as Dean in 1927, he was at that time the only plastic surgeon in NZ (Brown 2007). In October 1940 while the second echelon of 2NZEF was training in England, the Assistant Director of Medical Services (ADMS) was instructed by the Director General of Medical Services (DGMS) in New Zealand to discuss with Sir Harold Gillies (no doubt using the Kiwi connection to its fullest advantage) the possibility of forming a New Zealand plastic and maxillofacial unit, similar to the successful predecessor under Major H. P. Pickerill during the First World War (Anson 1960). The discussion was obviously fruitful as medical and dental officers from 2NZEF remained in England and received training in plastic and maxillofacial surgery over a twelve month period. As this arrangement became more formalised, medical and dental officers were seconded from New Zealand and rotated through England along with dental technicians for twelve months at a time. New Zealanders were attached to Basingstoke, St. Albans and East Grinstead perhaps by no coincidence, as these were the specialist units run by none other than Gillies, Mowlem and McIndoe respectively, who having made the United Kingdom their home, no doubt a nostalgic connection would have been kept up with trainees from “down-under”. Indeed, Mowlem was described as “being very kind” to his Australian and New Zealand trainees rotating through the St. Albans unit in the post-war years despite never returning to New Zealand (Dawson 1987). These centres were not only open to New Zealanders but other nationalities as well, reminiscent of the heady days at the Queen’s Hospital in Sidcup where the New Zealand Section, Australian section and Canadian Section worked closely together with Gillies during the First World War. East Grinstead in 1941 boasted 118 dental officers from the Royal Navy, Army, Royal Air Force, Australia and New Zealand. The following year the numbers increased to 234 now including dental officers from Canada, The US and Norway. It was suggested even then, perhaps in prophecy, that East Grinstead should look to the future and establish itself as a postgraduate centre of education (Correspondent 1943). It soon became apparent that the number of maxillofacial cases sustained during this war was much less than anticipated from figures sustained during the First World War and as a result, the secondment of valuable medical and dental officers from more pressing general duties for specialist training in maxillofacial surgery was reviewed. If the relatively small number of maxillofacial cases were indicative of the current war then perhaps the continued training of medical and dental officers could not be justified. The main differences in figures between the two world wars were attributed to the change from trench warfare to mobile warfare (especially in the Western Desert) and the increased destructive nature of missiles causing outright fatality rather than injury. One may argue that near miss from a First World War British 18-pounder would be equally as destructive but the disparity in numbers was obvious. Also contributory perhaps was the unlikely survival of seriously injured soldiers left behind enemy lines or in prisoner of war camps. When British and Empire forces were forced to withdraw first from Greece then from Crete, many soldiers with maxillofacial injuries did not survive the ordeal and the true incidence of these injuries is largely unknown (Anson 1960)

The management of maxillofacial injuries in the field became quite systematic and the content of literature discussing this initial management appears quite familiar today as the fundamentals of what is now known as the primary survey were highlighted and discussed. Airway management, haemorrhage control, pharyngeal injuries and copious wound toilet are only some of the fundamentals preached by front line military surgeons prior to surgical care (Clarkson 1944). The management of shock, resuscitation and conservative debridement of wounds in the field environment were advocated as necessary prerequisites before evacuation to a general hospital for definitive surgery (Fuller 1945). Publications on the initial management of maxillofacial trauma by Major E.P. Pickerill (son of H.P.Pickerill) and Captain N.E. Wickham were so comprehensive and concise, they were included by the Assistant Director of Dental Services (ADDS) as an appendix to his *Notes and Instructions to Dental Officers* as a guide to future dental officers in the field. (Pickerill 1945, Wickham 1945).

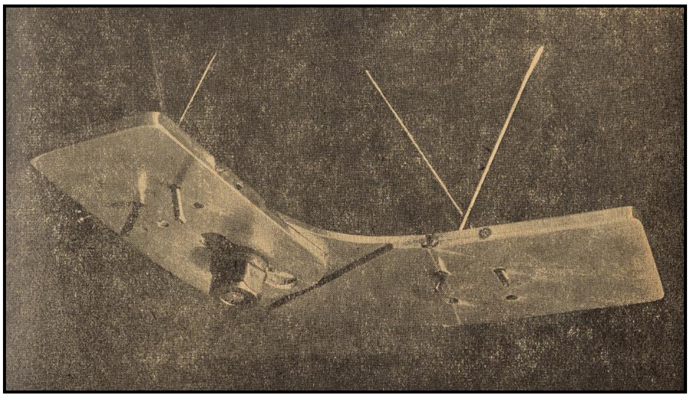
Necessity is often the mother of invention, especially when resources are scarce but not necessarily innovation and adaptability (hallmarks of the New Zealand soldier or “digger”). Anson makes specific mention of an unusual situation of a patient treated by Major Hutter and Captain Brebner which is worth repeating here as it illustrates several points: the nature of injuries sustained; the nature of the tactical environment; the initiative of the surgeons and adaptability of resources. The patient was a New Zealand soldier injured in the Libyan campaign in 1941 having sustained the following injuries: a compound fracture of the right humerus; neck lacerations and a displaced angle fracture of the right mandible. The main dressing station had at that stage been overrun and captured by enemy forces and the ambulance in which this soldier was transported, escaped capture reportedly by the narrowest margins. The soldier was driven to a NZ Casualty Clearing Station (CCS) but due to the tactical situation further evacuation to a higher level facility was not possible by which time his physical condition began to deteriorate. Now some weeks after the initial injuries were sustained, the patient finally reached an advanced New Zealand Hospital (probably 2 General Hospital (NZ) at Helwan as this was the only NZ hospital operating in Egypt at the time), his general condition was so poor that unless his displaced mandibular fracture could be repaired, his chances of survival were grim due to malnutrition and sepsis. His intraoral soft tissue wounds prevented the use of gunning splints (the patient was edentulous) and the correct method available was to use external pin fixation, only recently adopted by the British Forces. Without the necessary available equipment, Captain Brebner sought the assistance of a nearby Royal Air Force repair and salvage unit. Using a cardboard template of the mandible, metal parts from an airplane were used to fabricate an improvised extra-oral appliance (Figures 2.3g and 2.3h). With some satisfaction it was reported that the patient recovered remarkably well within three days with decreased pain and swelling in the jaw and a gradual recovery from sepsis. As Anson points out, this was perhaps the first time that an improvised pin fixation system was used in the field (Anson 1960, NZDC 1943).

This account serves to illustrate key factors common to war surgery: the severe nature of the injuries sustained; the fluid and often perilous tactical environment which at times lead to untimely delays in the evacuation of patients; the limited or total lack of resources available and the innovation of the surgeons, who faced with considerable adversity found often ingenious methods to get around the problems at hand.

When hostilities ceased in 1945 both in Europe and the Pacific, the maxillofacial units were demobilised along with the rest of the New Zealand expeditionary forces. Like the First World War, many surgeons and dentists returned to their former practices and did not continue on within the specialty but experience had shown once again that maxillofacial surgery was an area requiring particular expertise and training and required close cooperation between dentist and surgeon. Anson has the last word regarding keeping these skills and professional knowledge alive during peacetime when clinicians return to their civilian practices: *"The time to train for war is in peace"* (Anson 1960). In the next section, we shall see how prophetic that comment was to become as maxillofacial surgeons once again answered the call to treat facial injuries in so called "peacetime" conflicts around the world.

**Figure 2.3g**

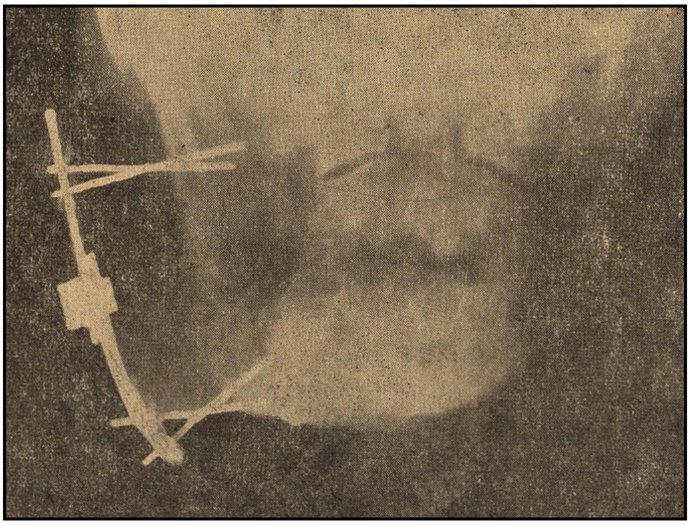
Improvised external fixation device manufactured from spare aviation parts during the North African campaign.



(adapted from The New Zealand Dental Corps (1943).
Three cases of major jaw injuries. *NZ Dental Journal* 39: 194-200).

**Figure 2.3h**

Radiograph of external fixation device in situ.



(adapted from The New Zealand Dental Corps (1943).
Three cases of major jaw injuries. *New Zealand Dental Journal* 39: 194-200).

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## 2.4 Modern Surgery for Modern Warfare

The surrender of Nazi Germany and Japan may have marked the end of the Second World War in Europe and the Pacific respectively, but by no means did it ensure world peace. Although not on the same global scale, conflicts since 1945 have not been any less bloody or horrific, especially when civilians continue to be involved in human rights abuses such as starvation, mass murder or genocide. To include every conflict since the Second World War would be inappropriately lengthy and pointless, therefore four conflicts have been chosen as representative of warfare since 1945: Korea, the American involvement in Vietnam, The Falklands, and the Balkan conflicts during the 1990s. These conflicts have been chosen not because of their scale or political impact but due to the manner in which war surgery was conducted during those conflicts, often in the face of extreme adversity and personal risk to medical staff.

These four conflicts spanning over the last half of the twentieth century offers a good overview of developments in the management of not only face and jaw injuries but also military surgery in general, from initial triage and evacuation to surgical procedures to the design of combat body armour and helmets in protecting the soldier from ballistic injury. As different nations are involved, their respective training philosophies and resources may be compared and an appreciation of how far plastic and maxillofacial surgery has come since the time of Gillies and Pickerill at Sidcup. The historical and political preamble to these conflicts are kept brief as it is not the intention to provide an in-depth analysis of the conflict itself but rather to provide a background against which the aspects of surgery can be appreciated.

**The Korean War 1950-1953**

Often dubbed “the forgotten war”, the Korean War was fought at a time when the world was still recovering from six years of global conflict and many nations, particularly in Europe, were still rebuilding their infrastructure and a way of life that was rudely interrupted by another devastating world war. Although the spectre of fascism was defeated, communism was now the latest threat to the free world ushering in the Cold War period. For many groups, the ideals of communism represented a new way of life, free from an autocratic ruling class or marauding nobility. For two global population giants, namely the Union of Soviet Socialist Republics (USSR) and China, communism was an effective means of centralised control of the people. When Soviet forces accepted the surrender of the occupying Japanese Imperial Forces on the Korean peninsula, the country became divided into North and South along the 38$^{th}$ parallel, with the North under communist control and the South under the control of the United States. The failure to hold free-elections, failed re-unification talks and continued border clashes between North and South fuelled tensions to breaking point. On 25 June 1950, North Korean forces invaded South Korea scoring notable early successes against their South Korean and US opponents and starting the first global conflict of the Cold War period (Hastings 1987). Despite being confined to the Korean peninsula, the conflict had the very real potential of drawing the United States and the USSR into a nuclear war and many feared an escalation into a third world war. Whereas Vietnam has in some ways become iconic due to Hollywood movies and a generation of great music and anti-war protesters, the Korean War to this day remains largely unknown and what exposure is given, is often portrayed in a biased fashion. For example, it is understandable (but perhaps unforgivable) to think that the Korean War was an American-only affair, especially when popular television shows such as *M*A*S*H* conditioned viewers into thinking that it was the one and only facility that operated in Korea. Judging from the combat casualties seen through the fabled 4077th Mobile Army Surgical Hospital, only US soldiers and Marines were involved. During the course of the Korean War, the armed forces of twenty countries were represented in the conflict ranging from the heavy weights such as the United States, China and the USSR to smaller countries such as the Philippines, Luxembourg, Belgium and of course New Zealand. Interestingly, this perception was not perpetuated in the original book by Richard Hooker who describes a particularly heavy period of casualty influx over a two week period during which a number of other nation's soldiers were operated on by the primary characters and surgeons Hawkeye Pierce, Duke Forrest and Trapper John McIntyre - soldiers from China, Puerto Rico, the Netherlands, Canada and Australia being mentioned (Hooker 1971). Medical support units from India, Denmark, Italy, Norway and Sweden were deployed during the conflict, the common policy being the deployment of medical support but not combat troops by the respective governments. The 60th Indian Field Ambulance and Surgical Unit attached to the Commonwealth Division was a good example of this non-combatant policy. Not wishing to align his country with one side or the other, the Indian Prime Minister at the time, Jawaharlal Nehru, opposed sending combat troops in what he saw was conflict between the United States and the USSR, but instead offered a medical support unit which remained politically neutral and served with distinction, gaining a reputation second to none treating friend and foe alike. The 60th Indian Field Ambulance performed over 2300 surgical operations and 5000 dental examinations from December 1950 to February 1954, seeing in excess of 200,000 patients during their deployment. Their professionalism and non-partisan attitude earned the unit great warmth and respect from UN forces and the civilian population (Carew 1970, Schafer 1995).

The Commonwealth Division was supported by 3 Field Ambulances: 25 Canadian Field Ambulance, 26 Field Ambulance (UK) and 60th Indian Field Ambulance and Surgical Unit. Each Field Ambulance had a Field Surgical Team (FST), a Field Transfusion Team (FTT) and the UK and Canadian units having additional elements of a Motor Ambulance Convoy (Bricknell 2003). The FSTs were often incorporated with the larger US Army MASH units and evacuation of Commonwealth casualties was through the US 121 Evacuation Hospital near Seoul and then on to Japan. Face and jaw surgeons during the Korean War used techniques learnt from their Second World War counterparts, just as those surgeons had consolidated lessons from their predecessors from the First World War. The Second World War introduced antibiotics into routine surgical treatment allowing the primary closure of wounds which would have been left open to prevent infection, the excellent blood supply to the face also being an important variable in allowing wound closure at an earlier stage. Adjunctive antibiotic therapy also allowed the routine use of intra-osseous wires in fracture management of both the mandible and midface, with open reduction of mandible fractures to visualise the bony injuries performed more frequently (Adams 1942, Peer 1943, Kazanjian 1955, Rowe 1971). The mainstay of immobilising jaw fractures remained wire intermaxillary fixation, with external fixation being utilised for both mandible and midfacial fractures using frames. In essence, the surgical techniques of Korean war face and jaw surgeons were no different from those on the latter parts of the Second World War but the outcome was improved due to antibiotics and earlier access to surgery, which would be the key legacies of the Korean War: the use of helicopters for casualty evacuation and the implementation of the Mobile Army Surgical Hospital (MASH) where major definitive surgery was performed in the field as opposed to evacuation to a continental general hospital facility (Figures 2.4a and 2.4b) (Triplett and Kelly 1977, Driscoll 2001, Bricknall 2003, Woodard 2003, King 2005). The use of the helicopter allowed faster casualty evacuation (CASEVAC) and in part mitigated the need for medical units to be sited near airstrips, although for strategic medical evacuation (STRATEVAC) to Europe, the continental United States and Japan, a usable airfield was still required. However, the overall importance of helicopters was disproportionally exaggerated, perhaps mainly due to their novelty at the time. CASEVAC helicopters only carried approximately 4% of all hospital admissions during the Korean War, the bulk of casualties being evacuated by the overburdened motor ambulance convoys or by railway. The main impact was minimising time delays in CASEVAC situations and the use of helicopters in CASEVAC would not become routine until the Viet Nam War (Cowdrey 1995).

MASH units were originally intended to provide support at divisional level with one MASH unit per division. As more nations contributed combat troops during the course of the war, MASH units were soon supporting a number of divisions with some units receiving up to 400 patients in a single 24-hour period (King 2005). The combination of rapid CASEVAC by helicopter and a forward deployed surgical unit such as a MASH unit undoubtedly saved many lives which in the previous world wars would have been lost due to the time delay between evacuation and surgical intervention.

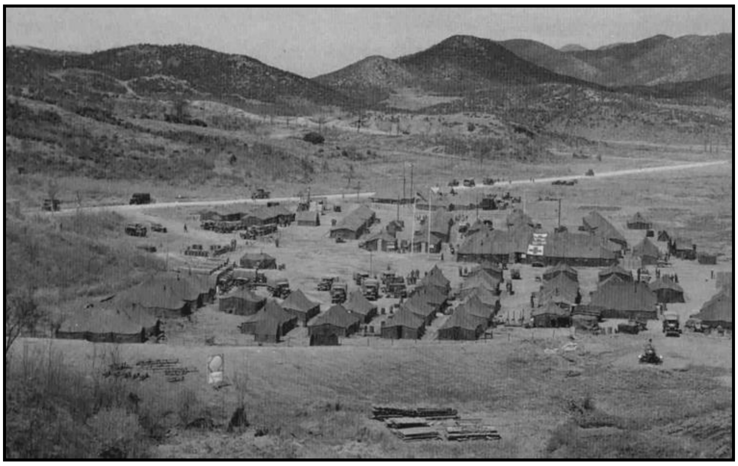
**Figure 2.4a**

Iconic: aeromedical evacuation by helicopter during the Korean War

(Public domain image courtesy of www.bell47helicopterassociation.org)

**Figure 2.4b**

US 8055th MASH, Korea 1951.
The fictional 4077th MASH was loosely based on this real unit along with its main characters.



(Public domain image courtesy of www.koreanwar-educator.org)

A subtle evolutionary step was also made during this period in terms of the specialty of face and jaw surgery. Plastic surgery remained the senior partner but dentists with surgical training for the face and jaws were now recognised as “oral surgeons” as opposed to “dental surgeons” in previous conflicts. The change may have been subtle, but in terms of recognition and acknowledgment that a dental specialty had a primary role in the surgical management of face and jaw trauma (Erich and Austin 1944), the change in name also reflected a change in status, the creation of the American Board of Oral Surgery in 1946 being one such example of increased stature, incorporating education, training and professional aspects under one organisation (AAOMS 1989). In time the specialty would undergo another evolutionary name change in keeping with the scope of practice beyond the oral cavity – that of Oral and Maxillofacial Surgery. For those performing surgery in the combat zone however, quasi-political name changes are largely irrelevant and meaningless if the quality of the surgery and the professionalism of the surgeons are not maintained. Oral surgeons in the Korean War were confronted with face and jaw injuries as horrendous and devastating as those seen in previous conflicts. Two contemporary papers published in the surgical literature show some outstanding results. It is interesting to note that both soft and hard tissue repair was performed by the oral surgeon (Cook 1951, Kwapis 1954). Oral surgeons were also more likely to be deployed to forward surgical units and treating injuries at a much earlier stage than their plastics counterparts, who by nature of their more lengthy reconstructive procedures were more appropriately based at a general hospital facility. This is still the case today with oral and maxillofacial surgeons being deployed within the combat zone in level III facilities alongside general surgeons, orthopaedic surgeons and neurosurgeons (Burris et al. 2004).

**US Military involvement in Vietnam 1955-1975**

The spectre of military failure in Vietnam continued to haunt the US military decades after US troops were officially withdrawn in 1975. Senior Commanders who, having been junior officers during that conflict, were well aware of the political and military fall-out resulting from the Vietnam War. So powerful were the after-effects that military commanders such as General H. Norman Schwarzkopf, (Commander-in-Chief of Coalition Forces during the Gulf War of 1991) made continued reference to the political and military mistakes of the Vietnam War and was determined not to repeat the same mistakes during Operation Desert Storm (Schwarzkopf 1992). The Vietnam War has become symbolic of how military forces, no matter how powerful or well resourced, if not supported by its government or its people, has two battles to fight – one locally and the other at home. As General William Westmoreland, former Commander, US Military Assistance Command, Vietnam stated: *"No nation should put the burden of war on its military forces alone"* (Bonds 1988). Ho Chi Minh, the venerable leader of the North Vietnamese continually exhorted his troops to bear their losses and hardships because they would ultimately win, not because of superior military tactics, but because the resolve of the American people would not be sustained. "Uncle Ho" had summarised the war in a nutshell. The communist strategy of supporting small wars of "national liberation" in South East Asia was not only confined to Vietnam. An earlier communist supported terror campaign began in Malaya (1949-1960) and the Indonesian-Malaysian conflict over Borneo (1962-1966) while strictly speaking was not a war of liberation, was a confrontation with communist support within Indonesia at the time (Vader 1971, Cross 1986, Pugsley et al. 2008). US military involvement started in 1955 when 300 military advisors were sent by President Eisenhower on request from the South Vietnamese government to help train members of the Army of The Republic of Viet Nam (ARVN). Following North Vietnamese attacks on US warships (Gulf of Tonkin incident) and US military installations, President Lyndon B. Johnson received authorisation to allow US troops to retaliate against any further attacks by the North Vietnamese armed forces, this corresponding with an exponential increase in troop numbers. In 1962, there were 4000 US military personnel in country, this number increasing to 23,000 by the end of 1964; 184,000 by 1965 and reaching almost 500,000 military personnel by the end of 1967 (Bonds 1988, Thomson 2000). By the time Saigon surrendered to the North Vietnamese Army (NVA) in 1975, the Vietnam War had already been lost on the US home front and veterans from that era still bear the scars of humiliation and betrayal felt when they went home – often to public derision if not outright ostracism. The Vietnam War had had also become the yardstick against which other "unwinnable" wars were measured, most notably the Soviet Invasion of Afghanistan from 1979-1989 being referred to as a "Russian Vietnam". Critics of the current military operations in Afghanistan by US and Coalition Forces continue to draw parallels with the Vietnam conflict much to the detriment of the personnel involved.

Following on from experience gained in the Korean War, US military medical services once again deployed MASH units. However, the major difference between the Korean War and Vietnam was that relatively well defined "battlefronts" were evident in Korea but not so in Vietnam, the main enemy tactic being guerrilla insurgencies with the occasional pitched battle and in part, this influenced the need for a mobile surgical unit which would set up in accordance to where the front line was situated at the time. Therefore a more permanent facility was introduced – the MUST or Medical Unit, Self-Contained, Transportable (as only the military could describe in such imaginative terminology) with expandable, mobile shelters and additional inflatable add-on sections replacing traditional tented structures. However, after repeated mortar attacks on these semi-permanent facilities, these units were ordered to become more mobile and essentially trained as MASH units in all but name (King 2005). The use of helicopters in the Korean War was further refined and exploited during the Vietnam War - in combat as well as medical evacuation (MEDEVAC)[10] roles – and would gain its iconic status as one of the recognisable symbols of the war (Figure 2.4c).

**Figure 2.4c**

Unidentified Australian soldier being loaded onto a US medevac helicopter during the Vietnam War

(Reference Number COL/67/0140/VN: Australian War Museum)

[10] The differences between CASEVAC and MEDEVAC is primarily MEDEVAC uses a standardised system of dedicated vehicles or aircraft for the purpose of evacuating patients, whereas CASEVAC uses non-standardised and non-dedicated transport to fulfil evacuation requirements. In Korea, the helicopter was initially used as an observation platform or for supply drop-off but became adapted for evacuating the wounded. In Vietnam, dedicated vehicles were available for this service hence the appropriate use of MEDEVAC in this context.

Medical resuscitation would improve dramatically compared to Korean War standards with advancements such as intravenous fluids in plastic bags (as opposed to glass bottles), improved critical care monitoring, earlier blood product replacement therapy and improved burns management, all contributed to better outcomes for war casualties with the additional windfall of these techniques also improving trauma survival in civilian practise as well.

A review by Phillips (1970) of 128 maxillofacial casualties seen at a forward surgical hospital in South Vietnam describes many of these advances as a background to improved surgical care in maxillofacial war injuries. In particular, Phillips pointed out that the basic principles of maxillofacial war surgery remained unchanged from previous conflicts (one would assume the Second World War and Korea) - but with the advent of rapid and consistently available helicopter MEDEVAC services, casualties were seen much earlier allowing a more conservative approach to wound management, a principle that Phillips advocated. Once casualty resuscitation and fracture stabilisation using the tried and true method of wire intermaxillary fixation had occurred, the wounded were then transferred to larger hospitals either in country, to hospital ships, or evacuated out of theatre depending on whether the soldier would be able to return to duties within 30 days or not. Similar to Korean War experiences, minimising time delays in evacuation of the wounded played a critical role in improved survivability and wound management (Haacker 1969). The incidence of maxillofacial injuries from the period 1965 to 1973 was estimated at 10-15% or in raw numbers between 30,365 to 45,457 casualties (Tinder et al. 1969, Kelly 1977).

The basic general principles of thorough wound toilet and debridement, adequate volume resuscitation and early haemorrhage control were still as pertinent during Vietnam as it was in Flanders during the First World War. Due to excellent MEDEVAC services maxillofacial injuries did not require definitive management at a forward surgical hospital and routine antibiotics, intermaxillary fixation, skeletal fixation and suspension with wires and the continued use of dental appliances were the mainstay of treatment in the early stages of wound management. Similarly, local rotational flaps and the tube-pedicle, the latter described and used to great effect by Gillies in the First World War were still used in late-stage reconstructive procedures again a testimony to the skills and principles based on hard won experience developed by the pioneers in the field of face and jaw surgery (Carson et al. 1970). Surgeons in Vietnam found that the majority of penetrating facial injuries were caused by fragments from explosive devices such as rockets, mines, booby traps and grenades rather than gunshot wounds, and that the mandible was the most commonly injured anatomical site on the face. Almost all wounds were drained[11] after surgical procedures in order to decrease soft tissue dead space and prevent haematoma formation as well as allowing irrigation of the wound if necessary (Andrews 1968, Morgan and Szmyd 1968, Irby 1969, Terry 1969). This pattern of injury relating to blast fragment wounds mirrors patterns seen today in Israel, Iraq and Afghanistan.

Just as the helicopter had revolutionised medical evacuation in the combat zone, one particular innovation was beginning to make its presence felt that would equally revolutionise the management of maxillofacial trauma – the use of metal plates or mesh

[11] A surgical drain is a form rubber tubing that is inserted into a surgical wound coming out through the skin after surgery. In its most simple form, it allows the wound to collapse in on itself as the drain is slowly withdrawn thereby preventing dead space or “voids” in the soft tissue where infection or haematoma formation could arise. More modern drains may also be attached to a suction device such as a vacuum bulb again to decrease dead space but also remove excess fluid build up under the skin.

in the rigid internal fixation of facial fractures. Early reports of using metal plates fixed to the bone by screws alone appear to be in the context of providing rigidity to defects of the mandible that could not be adequately stabilised by wire fixation and included the use of early metal alloys of tantalum or vitallium (Christiansen 1945, Freeman 1948). The principle of open reduction, internal fixation (ORIF) take advantage of the biological process of bone healing by fixing the fracture in such a way that the bone ends have minimal separation between them and the bony fragments held rigidly in place to prevent shifting, allowing bone healing to occur in a shorter time period (Ellis 2004). In the 1950's orthopaedic surgeons were observing the benefits of this type of fracture management in long bones, but it was not until the late 1960s that these orthopaedic principles were applied to the mandible by Luhr (Luhr 1968, Buchbinder 1990). Originally using stainless steel finger plates (the smallest available plates at the time), mandibular fractures were fixed using the orthopaedic principles of compressing the bone ends to together to attain maximal bone to bone contact for healing (Brons and Boering 1970). However, this often required larger surgical access often involving an incision to be made on the outside of the jaw in order to plate the lower border of the mandible. Further developments in biomechanics and mathematical models of fracture behaviour occurred in the 1970s pioneered by Michelet et al in 1973 and Champy et al in 1978 (Michelet et al. 1973, Champy et al. 1978), culminating in the use of mini-plates and screws applied to the specific areas of the mandible and midface that give structural strength to the facial skeleton. One main advantage with this system was that the plates could be applied through incisions inside the mouth or smaller incisions outside thereby improving the post-surgical aesthetics. Wiring the jaws together to help align the fracture segments was still advocated but many surgeons elected to keep their patients wired together even when the fracture had been plated. The potential for definitive fracture management of the facial skeleton could be performed at time of primary surgery was now an achievable goal in a combat environment. In parallel development of titanium plates and screws for the maxillofacial region was the development of a semi-rigid adaptable titanium mesh and this was first used in Vietnam in the early 1960s. Despite advantages of physical adaptability and the flexibility of where the mesh can be placed on the bone, titanium mesh never gained the popularity of mini-plate fixation and is only used infrequently today for trauma management (Patel and Langdon 1991). The management of maxillofacial injuries during the Vietnam War was literally at a cross-road where basic principles learnt over the previous sixty years of war surgery were being augmented with newer technologies such as metal plates and screws and more conservative approaches to the facial skeleton. These fundamental basics are what surgeons rely on and go back to time and time again in times of adversity or when resources are primitive and/or scarce, typical of many situations during war surgery and so graphically illustrated during Bosnia and Kosovo in the 1990s.

Summarising data and lessons learned from clinical experience by oral and maxillofacial surgeons in the US Navy during Vietnam, a study of maxillofacial war injuries identified key areas that required further research and investigation in order to improve the care of patients with craniofacial injuries (Kelly 1977). These areas bear remarkable resemblance to the problems that vexed face and jaw surgeons during the First World War, namely the issues of preventing fibrosis and scar contracture; the healing of bony fractures, biomaterials and the need for rehabilitation – both physically and psycho-socially. Emphasis, however, was on the biological processes of healing (in particular the molecular biology of bone healing) and the biomechanical and bioengineering aspects of skeletal fixation, healthy indicators that the field of maxillofacial surgery was indeed more than a technical discipline and quite correctly, a surgical *science*.

**The Falklands War 1982**

Without being unkind, the Falklands War was not a major conflict in global terms of troop numbers, casualty figures and geopolitical boundary changes. It was however, an interesting war in terms of political intrigue, last minute negotiations, historical rivalry, military pride and prejudice and the last vestiges of imperial colonialism reminiscent of a by-gone age. From a military aspect the Falklands was a great proving ground for weapons and technology, with unfortunate results for the Royal Navy and many Argentine aircraft. The Sea Harrier, Exocet missile and the superiority of the AIM-7L sidewinder air to air missile (AAM) over its earlier cousins (improved heat seeking capability and a proximity fuse for warhead detonation) all made their mark during the Falklands much to the interest of militaries and armament manufacturers the world over. The Falklands War also seemed to validate the British system of a small but highly professional volunteer army when compared to the larger and mainly conscripted army of Argentina.

The Falklands consist of two main islands (East and West Falkland) and 778 smaller islands located in the South Atlantic, some 650km south of the South American continent and 1400km north of the Antarctic Circle[12]. The Falklands have been under French, Spanish, Argentinean and British administration at one point or another during its 250 year history. It is named after Viscount Falkland by the Captain of *HMS Welfare*

[12] The Islands: Location. The Falkland Island Government website www.falklands.gov.fk/Location.html Accessed 28 Jan 2010

in 1690.The first settlers however were French, having established themselves on East Falkland in 1746, followed later by a British expedition who having established themselves on West Falkland and claimed the Islands for Great Britain, were totally unaware of the presence of the French settlers. France was considered an ally of Spain at the time and the French settlement was bought out by the Spanish. After sending a small fleet from Buenos Aires the Spanish evicted the British. In 1826 the newly established country of Argentina claimed sovereignty control and occupied the islands but following an incident with a US seal-hunting party, the Argentinean colonists were evicted by the master of the warship *USS Lexington*, the place ransacked and the islands declared free of all government, allowing Great Britain to return for a third time and claim the islands in 1833. With this rather chequered history of occupation, eviction and re-occupation by Argentina and Great Britain, the Falkland Islands (*Islas Malvinas*) have been hotly contested between the two countries ever since, especially by Argentina (Hastings and Jenkins 1983, Way 1983, Middlebrook 1987). In 02 April 1982, under the direction of a new military Junta, Argentina invaded the Falkland Islands and claimed the *Malvinas* as Argentinean territory. After a brief fire fight, the small garrison of Royal Marine Commandos were obliged to surrender to overwhelming numbers on orders from the Governor General to prevent further bloodshed. The photographs of Royal Marines being made to lie face down on the ground galvanised calls for action in Great Britain, but after budget cuts in defence, Great Britain found itself in an awkward situation, weighing up the costs between a military response or allowing the Falkland Islands to be handed over to Argentina.

In the end, Prime Minister Margaret Thatcher authorised a military response to the surprise of Argentina (and the rest of the world) and the largest Royal Navy task force assembled since the Second World War found itself steaming to the South Atlantic.

After an amphibious landing during the night of 21 May 1982, British troops secured a beach head at San Carlos and the ground phase of he Falklands War began in earnest. Over the next few months the battle honours of Goose Green, Wireless Ridge, Mount Longdon and Tumbledown would be added to some of Britain's finest regiments.

The Argentinean Commander General Menendez formally surrendered to Major General Jeremy Moore on 14 June 1982 at Port Stanley, ending a war that lasted 74 days and with an enormous cost of men and materiel.

British casualty figures were 255 dead and 777 wounded. Of the 255 combat deaths, 217 were a result of direct action with Argentinean Forces. Argentinean casualty figures were less precise numbering between 650 – 750 dead and between 1100 - 1200 sick or wounded (Middlebrook 1985)[13].

Both sides established military field hospitals during the conflict and had access to either converted or dedicated hospital ships. The main British field hospital was established at Ajax Bay in a deserted meat works factory (Jolly 1983, Batty 1999). As it was co-located with military stores including ammunition, the hospital could not be identified by a Red Cross symbol under the rules of the Geneva Convention. Some cynics have observed that it would have been a moot point anyway as Argentina was not a signatory of the convention at the time. Working under extreme conditions, the surgical teams faced freezing temperatures; fatigue; lack of resources (including basic

[13] Middlebrook gives figures of 746 dead and 1105 sick or wounded according to Argentinean figures collected three weeks after the war. An Argentinean newspaper article published in 1998 to commemorate the fallen heroes of the Malvinas gives a figure of 649 dead (source: ***Ley nacional 24.950/98 - Declaración de "Héroes nacionales" a los combatientesargentinos fallecidos en la guerra de las Malvinas***, accessed 29 Jan 2010)

laboratory and radiology services) and the constant threat of serious injury of death due to the presence of two unexploded bombs after an air attack on the area. Extreme weather conditions, difficult terrain and intense enemy fire also meant delays in the evacuation of combat casualties by helicopter or other means. As a consequence a relatively high number of infected wounds were seen, mainly attributed to the delay in the goal of receiving surgical treatment within 6-hours from time of injury as per medical doctrine (Jackson 1984, Batty 1999).

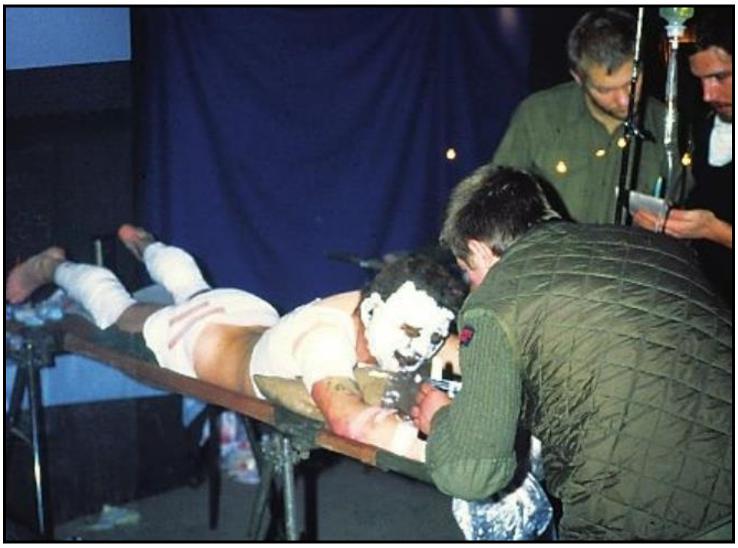
In spite of these difficulties, by the end of the campaign, 233 British and Argentinean surgical patients were treated at the Field Hospital - dubbed the Red and Green Life Machine by its officer-commanding, Surgeon Commander Rick Jolly in reference to medical teams being drawn from the Parachute Regiment (red or maroon berets) and the Royal Marine Commandos (green berets). The fact that there were only three intra-operative or postoperative deaths reflect a remarkable achievement and bear testimony to the training and skill of the staff at Ajax Bay (Jackson et al.1983, Batty 1999). Data collected by the UK military Hostile Action Casualty System (HACS) on head and neck injuries sustained during the Falklands included burns, smoke inhalation and cold-related injuries which may have distorted numbers giving a relatively high incidence of 29% (Dobson et al. 1989). One study, however, reported 36 cases of head and neck injury constituting only 14% of all injuries which is more in keeping with other conflicts (Jackson et al. 1983).

One major lesson from the Falklands War was the management of burn injuries following the bombing of the *Sir Galahad* on 08 June 1982. The Royal Fleet Auxiliary ship *Sir Galahad* was at anchor in Fitzroy Bay when it was attacked by Argentinean A4

Skyhawks, one bomb exploding in the aft section setting of secondary explosions of munitions and stores in the ship where men of the First Battalion, Welsh Guards (1 Welsh Gds) were awaiting disembarkation and suffered severe losses. This one incident alone produced 179 casualties including 33 Welsh Guardsmen and approximately 18 other soldiers and sailors killed (Hastings and Jenkins 1983). Numbers vary according to sources but between 78-83 soldiers received burns of varying degrees and were evacuated to the Field Hospital at Ajax Bay, the hospital ship *SS Uganda* or other smaller hospital ships prior to the UK (Marsh 1983 Chapman 1984). The liberal use of flamazine cream® (silver sulfadiazine, Smith and Nephew, Hull, United Kingdom, HU3 4DJ), saline-soaked field dressings, occlusive plastic bags on hands and escharotomies (the careful cutting of burnt tissue to allow for swelling so as not to cut off the blood supply to the tissue from oedema) were the mainstay of initial treatment. Faces were left exposed but liberally coated with flamazine (Figure 2.4d). These casualties, some suffering up to 20-45% burns, were treated according to best practices at the time and 25 years on, with better understanding of burn injury biology and evidence-based practice, some of these patients would have been managed differently today but the Sir Galahad bombing remains a singular lesson in triage and initial management of burns in a combat zone with limited resources (Kay 2007).

**Figure 2.4d**

Flamazine covers the face of a burnt British soldier following the air attack on the *Sir Galahad*, 1982.



(Adapted from Jolly R (1983). *The Red and Green Life Machine- A diary of the Falklands Field Hospital*. London: Century Publishing)

One Welsh Guardsman horribly burnt in the *Sir Galahad* was to literally become the public "face" of that catastrophic event, suffering 46% burns including his face. Weston endured more than 70 operations including numerous skin grafts to rebuild his eyelids and nose and has become an ambassador for burns victims and the needs of ex-military veterans, in part recognised with a richly deserved OBE in 1992. Simon Weston symbolises the bravery of all soldiers who have survived combat injury only to go through difficult times back home, some physical, but for others more psychological as they relive the nightmare of their injury or the loss of their mates (Nichol and Rennell 2009). Facial disfigurement continues to elicit a level of repulsion and horror that in essence has not changed since the days of the Somme or Ypres almost a century ago.

**The Balkan Conflicts 1991-2001**

The Balkan states have been an extremely volatile region of Europe for most of the twentieth century with constant clashes between the various states prior to the First World War and following the dissolution of the Austro-Hungarian Empire. It was in Sarajevo that Gavrilo Princip, a Bosnian nationalist, assassinated the Archduke Franz

Ferdinand and started off a chain of events culminating in the First World War. Bismarck once remarked that “some damned foolish thing in the Balkans” would ignite a major war (Winter and Baggett 1996). It is not known if Bismarck was predicting a global conflict or was referring to something more regional, but his apocryphal remark was borne out in 1912 when war broke out in the Balkan states. In an effort to wrest Macedonia away from Turkish control, the Russian supported Balkan League consisting of Serbia, Bulgaria, Greece and Montenegro declared war on Turkey on 08 October 1912. After a string of defeats, Turkey was obliged to sue for peace and an armistice was concluded on 03 December 1912 with a peace conference organised in London. However, after a coup by the Young Turks, a nationalist movement seeking reforms in the crumbling Ottoman Empire, peace talks faltered with hostilities being resumed by both sides in January 1913. Further victories gained by the Balkan League resulted in the Ottoman Empire signing a peace treaty in May 1913 but only after losing most of its territories in Europe, with Macedonia being divided among the Balkan League nations and Albania gaining full independence but leaving behind a deep sense of mistrust that would continue on into the last decade of the twentieth century (Miller 1997). This war although relatively minor, had a significant impact on the development of face and jaw surgery as Germany had sent medical observers to the conflict and although unimpressed by the surgical techniques and standards observed, the concept of having dedicated face and jaw units as part of military medical services was adopted by the German military medical authorities so that by 1914, maxillofacial departments in four hospital in Germany were already functional and ready to receive casualties (Dolamore 1916a).

The Balkan conflicts of 1991-2001, also referred to as the Wars of Yugoslav Secession or the War in (the former) Yugoslavia, was and remains a confusing period of fighting because of the complex mix of different ethnic groups within the former Yugoslavia.

Against a back drop of the fall of communism and the dissolution of the Union of Socialist Soviet Republics, tensions increased between the six Yugoslavian constituent republics, the largest and most powerful being Serbia under Slobodan Milosevic. In 1991, Slovenia, Croatia and Bosnia-Herzegovina declared national independence breaking away from the Serbian majority government leading to bitter fighting between the republics and later fighting between Bosnian Serbs and Bosnian Croats fuelling ethnic hatred which resulted in the loss of many lives and numerous human rights abuses on a scale not seen since the Second World War. During the Bosnian War from 1991-1995, ethnic cleansing, mass rape and murder and the whole sale destruction of property was to become a legacy that shocked the world. The images of the Olympic Village in Sarajevo being shelled and its venues turned into battlegrounds with sniping alleys not safe for man, woman or child are haunting reminders of the savagery encountered during the siege of Sarajevo from April 1992 to February 1996. Eye witness accounts of heroic surgeries being performed under the most primitive conditions are harrowing with medical teams literally risking life and limb just by moving within the hospital due to sniper activity and artillery fire (Villar 1998). NATO ground and air forces were deployed to bring about security in the region and Bosnian Serbs were forced to negotiate a ceasefire, resulting in the creation of a Muslim-Croat federation and a Bosnian Serb entity within the country (Jackson 2007).

In 1999 ethnic Albanians began fighting for an autonomous Kosovo province within Serbia leading to yet another period of fighting in the troubled area with almost one third of the population of Kosovo fleeing to nearby Macedonia, Albania and

Montenegro. Up to a quarter of a million refugees were living in tents under NATO protection with great fears of disease and death with the coming winter (Jackson 2007). The Kosovo conflict ended with the withdrawal of Yugoslav forces from Kosovo after an 11-week air campaign by NATO forces. An excellent timeline of events is available from the Washington Post online website (http://www.washingtonpost.com/wp-srv/inatl/longterm/balkans/timeline.htm)[14]

During the conflicts in Croatia and Bosnia, the incidence of maxillofacial injuries ranged between 5-19% of war casualties including both soldiers and civilians (Jović et al. 1997, Prgomet et al. 1998). The main causes of maxillofacial injuries were due to explosive fragments or small arms fire, with fragment injuries appearing to be more dominant in casualties who sustained their injuries while involved in military operations and a higher number of gunshot wounds among civilian casualties either due to sniper fire, self-inflicted gunshot wounds or accidental gunshot wounds among the predominantly young male population (Jović et al. 1997, Puzović et al. 2004). This pattern of injury may be more representative of the fighting in Bosnia with particular relevance to civilian casualties during the siege of Sarajevo as one case series during the earlier Croatian war reported no difference in incidence, severity and patterns of maxillofacial injuries between civilians and military personnel (Aljinović-Ratković et al. 1995). The presence of sniper activity in built-up areas in Sarajevo created "no-go" zones similar to "no-man's land" between the trenches during the First World War. These so-called "sniping alleys" restricted movement within the city and civilians and soldiers alike were targets of opportunity with one case series from 1991-1994 reporting

[14] The Washington Post Online http://www.washingtonpost.com/wpsrv/inatl/longterm/balkans/timeline.htm, accessed 30 Jan 2010

that over a sixth of perforating (through and through) injuries of the upper face and head (fronto-ethmoidal) region were caused by sniper bullets (Ivanović et al. 1996).

A common theme of desperation arises from the surgical literature depicting the violence in the former Yugoslav states. Desperation resulted from too many casualties for too few medical staff and a limited and dwindling supply of equipment and resources set in a back drop of a civilian population fighting for survival from indiscriminate violence. The use of common kitchen utensils as surgical retractors and otherwise disposable endotracheal tubes and urinary catheters being sterilised and re-used illustrates the conditions in which often heroic measures were taken to treat sick and wounded (Hoxha et al. 2008). In these circumstances the precedence of saving life, limb or eyesight is further reduced by necessity to saving lives only, often at the expense of a limb or an eye. This brutal reality is brought home in a passage from Richard Hooker's apocryphal *M*A*S*H* where the war-weary Hawkeye explains the differences between war surgery and "text-book" surgery to a newly arrived junior surgeon who is yet to be initiated to war: *"... sometimes we deliberately sacrifice a limb in order to save a life, if the other wounds are more important. In fact, now and then we may lose a leg because, if we spent an extra hour trying to save it, another guy in the preop ward could die from being operated on too late"* (Hooker 1971). Hooker wrote with good authority having served as a general surgeon under his real name H. Richard Hornberger in the 8055th MASH, his experiences are still being shared in the field surgical hospitals of Kandahar, Camp Bastion and Baghdad today.

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## 2.5 Maxillofacial Injuries and Urban Guerrilla Warfare

The Taliban and Al-Qaeda do not hold exclusive rights to terrorist activity, although in the aftermath of "9/11" it would be difficult to change our current public perception of such activities. Forty years ago a similar public perception also existed but terrorism and urban guerrilla warfare then was synonymous with activities in Northern Ireland and Israel instead. That is not to say that terrorist activity did not occur in other countries - South Africa, India, Pakistan and Sri Lanka have had frequent terrorist attacks in the last few decades but in the popular media, Northern Ireland and Israel have become quintessential examples of urban guerrilla warfare and constant terrorist activity targeting a population group. A sense of déjà vu arises with reports of bombings in Kabul or Baghdad, when not so long ago similar events were happening on the streets of Belfast or in disputed Israeli territories. The intended targets may have been military and paramilitary forces but frequently the civilian population suffered "collateral damage" as a result of these acts of violence. Furthermore, there is a vast difference between the opposing forces especially in terms of weaponry and mode of operation. The term *asymmetric warfare* is used to describe this difference. It has been applied to current military operations in Afghanistan and Iraq where a large conventionally armed, organised military force is opposed by a determined but relatively poorly equipped force using irregular tactics (Hinsley et al. 2005). Professional military and paramilitary forces are typically well armed, better protected and have an infrastructure that allows for a more reliable resupply and operational support system. Their training may be more standardised and arguably more rigorous but perhaps the most crucial difference is one of rules of engagement – the parameters of which may be restrictive to the point of absurdity but designed to minimise the potential for misconduct by military or paramilitary personnel. Therefore the term asymmetric warfare is equally as appropriate to describe experiences in Northern Ireland and Israel as much as it is for Afghanistan and Iraq. Israel in particular has endured ongoing terrorist activity ever since its establishment in 1948 with escalations into outright war with her Arab neighbours on several occasions (Miller 1997). The Hippocratic dictum that war is the greatest school of surgery is well exemplified by the numerous trauma studies that have been published from Israeli sources; the authors as a group having a wealth of experience in constant combat trauma situations which make them quite a unique authority in this area. Arguably, Israeli Defence Force (IDF) personnel were among the most experienced soldiers in the world operating in an urban combat environment, the only rivals perhaps being the British Army in Northern Ireland. Often, the lessons learned by one military may be adapted for another; one example being the decision of the regimental medical officer (RMO) of 2$^{nd}$ Battalion, The Parachute Regiment (2 Para) during the Falklands War to make each soldier carry a bag of intravenous fluid for volume resuscitation, this recommendation being based on Israeli practise at the time (Hughes 1985, Nichol and Rennell 2009). Local trauma surgeons in Northern Ireland, South Africa and Israel are among some of the most experienced in the world in dealing with ballistic injuries and anecdotally it is no wonder that many young Commonwealth surgeons seeking experience in ballistic trauma were directed towards Belfast as a place to learn their trade during the 1970s and 1980s and later to Johannesburg, home town of South Africa’s largest hospital Baragwanath. In this section different mechanisms of injury to the maxillofacial region in the context of urban guerrilla warfare are discussed with particular emphasis on the use of non-lethal rounds for crowd control and smaller IEDs such as the pipe bomb as these two aspects serve as important illustrations of the differences between urban guerrilla warfare and conventional military operations between opposing uniformed armed forces.

**The Terrorist Threat**

Terrorism may be defined as a use of violence and threats to intimidate or coerce especially for political purposes[15], the net effect being a disruption of normal activities as a result of fear. The opposing forces may have different political ideologies, religious beliefs, cultural differences or grievances that often cannot be resolved by diplomatic means and the issue separating them are often deeply historical and bewildering to outsiders. In Northern Ireland the armed campaign between loyalist and republican paramilitary groups (known as "the Troubles") lasted almost thirty years from 1969 to 1997, ending with the Belfast Agreement in 1998 which continues on in an uneasy truce marred by sporadic events of violence that threaten to undermine the relatively peace that currently exists. It was also a period where the British Army, deployed to bolster the local authorities, was tested in many ways, the initial deployments being particularly harrowing for the soldiers with ambiguous rules of engagement, often faulty intelligence and a general sense of not knowing how to deal with "their own people" as opposed to foreign nationals (Parker 2002). As a scene of bitter sectarian violence, every conceivable type of weapon has been used, ranging from fists to bricks to high velocity rifles and explosive devices resulting in a full spectrum of traumatic injury including death (Whitlock and Kendrick 1994). This pattern of violence however, is not unique to the streets of Belfast; similar incidents are commonly reported in India, Pakistan, South Africa and Israel with the population seemingly inured to the situation.

Kapur et al. (2005) reported 36,110 bombing incidents in the United States of America from 1983 to 2002, an average of over 1800 incidents per year over a twenty year period and includes high profile incidents such as the World Trade Center bombing in 1993, the Oklahoma City bombing in 1995 and a bombing incident at the Olympic

[15] http://dictionary.reference.com/browse/terrorism

Games in Atlanta in 1996. The Bureau of Alcohol, Tobacco and Firearms (ATF) maintains a data base for such incidents and has not included the World Trade Center attacks in 2001 as a bombing incident as such, although Kapur and co-authors have argued that the use of an airliner technically can be classified as a fuel-air explosive device. There are similarities and differences between the US experience and other places. According to the ATF, explosive bombing incidents with known motives were mainly due to homicide whereas incendiary bombings (often involving a lesser magnitude of explosive) were mainly due to revenge or extortion (Kapur et al. 2005). The motives of homicide and revenge killings may also apply to Northern Ireland and South Africa whereas an underlying political agenda can be attributed to other areas such as Israel and India for example. Regardless of the motive, the injuries produced may range from minor wounds such as simple lacerations to more significant injuries, which may be fatal in nature. This level of trauma will stretch civilian medical emergency teams to the limits of their skills and resources, especially when mass casualties are produced from an incident. The crucial elements of timely medical evacuation, appropriate triage and resuscitative surgery are as equally important in this civilian context as it is on the battlefield. A major difference with incidents in urban centres however is the close proximity of tertiary level medical care facilities - often casualties arriving to an emergency department within a short period of time after the incident, for example the average time between injury and transfer to a medical facility was 15-20 minutes in Belfast compared to 40 minutes during Vietnam and six hours during Korea (Melsom et al. 1975). Two different concepts of trauma patient transfer have been suggested; the first being labelled “scoop and shoot” whereby the casualty is transferred to appropriate medical care in the shortest time frame possible with minimal resuscitative care en route and the second method involving more comprehensive stabilisation of the patient before transfer (Saraswa, 2009). The first method of "scoop and shoot" is only viable if advanced medical care is nearby – the situation found in most urban centres; whereas the second method is more suited to situations where potentially lengthy transfer times due to terrain, weather or the tactical situation occur.

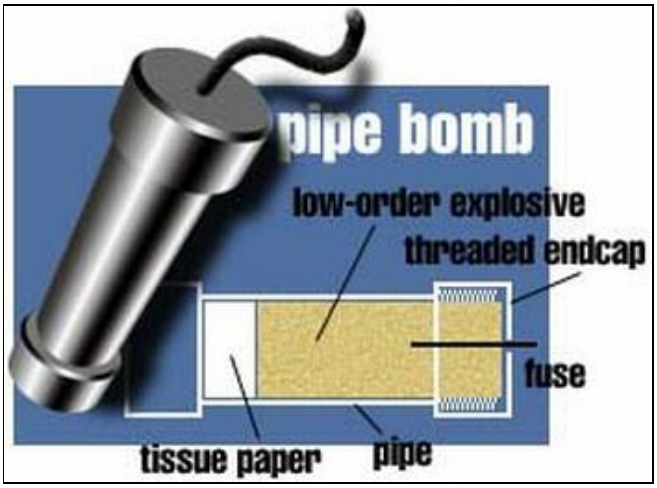
Trauma surgeons at the Royal Victoria Hospital in Belfast dealt with a variety of injuries including penetrating injuries as well as blast injuries not too dissimilar to those found among the civilian population in Iraq and Afghanistan – civilians who sustain grievous bodily injuries from highly destructive weaponry without the benefit of body armour. The severity and range of injuries seen over such a sustained period of time has allowed many protocols to be developed to the benefit of trauma victims not only in Belfast but also worldwide. Due to the nature of the conflict, sometimes literally involving neighbours, the psychological impact was seen as important as the physical impact of the injury and great emphasis was placed on victim support for families and for the injured individuals themselves, a key acknowledgement that trauma is not always physical in nature (Kendrick 1990, Whitlock and Kendrick 1994). The missiles causing injuries ranged from non-lethal rounds such as rubber bullets to high velocity rifle rounds and fragments, the latter including masonry, ball bearings, nails, nuts and bolts as well as anti-personnel mines and incendiary devices (Boyd 1975, Whitlock and Kendrick 1994). The injuries sustained to the head, face and neck (HFN) region from high velocity missile rounds, both gunshot and fragments, were managed no differently from those seen in conventional military combat situations, requiring the same level of expert surgical care but perhaps having the luxury of better resources closer to hand and definitely shorter evacuation times to a trauma centre. Differences in evacuation timings and tactical environments aside, the standard of surgical care for the injured patient should not be compromised.

**Improvised Explosive Devices**

The term Improvised Explosive Device or IED was first coined by the British Army to describe a homemade bomb, often using readily available store bought products, but used in a manner outside of a conventional military context. IEDs range from small pipe bombs to large vehicle-borne IEDs (VBIEDs) - more commonly known as car-bombs. It is somewhat disturbing to find references on the internet to the partial manufacture if not full instructions on how to construct a pipe-bomb (Figure 2.5a). Pipe-bombs are cheap and simple to make and can be modified to be anti-personnel or simply an explosive device (Gibbons et al. 2003). Pipe-bombs have been used in the United States of America, Israel, Northern Ireland and South Africa.  Karmy-Jones et al. reported 12,216 bombing incidents in the United States of America between 1980 and 1990, the majority of which involved pipe-bombs (Karmy-Jones et al. 1994). The authors describe a combination of thermal, penetrating and blast injuries that pose a special challenge in surgical management of these patients.

**Figure 2.5a**

The basic elements of a pipe bomb.




(Public domain image courtesy blottered.com)

Furthermore, these injuries do not only occur among the intended victims of the attack, as pipe-bombs or any home-made IED have the potential to be unstable and may result in the injury or death of the bomb-maker themselves which may pose difficulties in balancing immediate surgical management of the patient and the need for further information to be obtained by law enforcement agencies (Karmy-Jones et al. 1994, Lucas and Crane 2008). Larger IEDs involving the use of agricultural fertiliser or plastic explosives produce more severe injury patterns that include penetrating injuries as well as major blast injuries and traumatic amputations. Hadden et al. (1978) studied 1532 consecutive patients injured by bombing incidents between August 1969 and June 1972 seen at the Royal Victoria Hospital in Belfast and noted that the predominant sites of injury were to the head, face, neck (HFN) followed by the extremities. In this study penetrating injuries to the trunk was relatively low, the authors suggesting that clothing provided a degree of protection.

Among the bony injuries sustained in the HFN region, skull fractures were reported in eleven patients and a further eleven patients were treated for maxillofacial fractures. The majority of HFN injuries were soft tissue lacerations and contusions including ten patients with ocular injuries and up to 67 patients with initial deafness from the blast incident. In another study of bombing incidents in Northern Ireland from 1969 to 1977, HFN injuries predominate with 51% of patients in the study having skull fractures and 31% sustaining facial fractures. The combination of skull fracture and intracranial injury was the most commonly observed pattern of injury among the fatally wounded (Hill 1979). Note that these patients were predominantly civilians who did not have the benefit of helmets or other protective equipment available to military or paramilitary forces at the time, but even then there are still issues of adequate protection. Combat Body Armour (CBA) and helmets worn by both IDF and British army personnel have undoubtedly saved many of lives by preventing lethal penetrating injuries to the chest and abdomen. However, the areas that remain exposed are the upper and lower extremities and the face and neck regions, a familiar pattern of injury already observed in Northern Ireland and to be repeated in subsequent conflicts in Iraq and Afghanistan (Figure 2.5b).

**Figure 2.5b**

Combat Body Armour in Afghanistan. Note the overall bulk of the equipment and the exposed areas of the upper and lower limbs and the face.

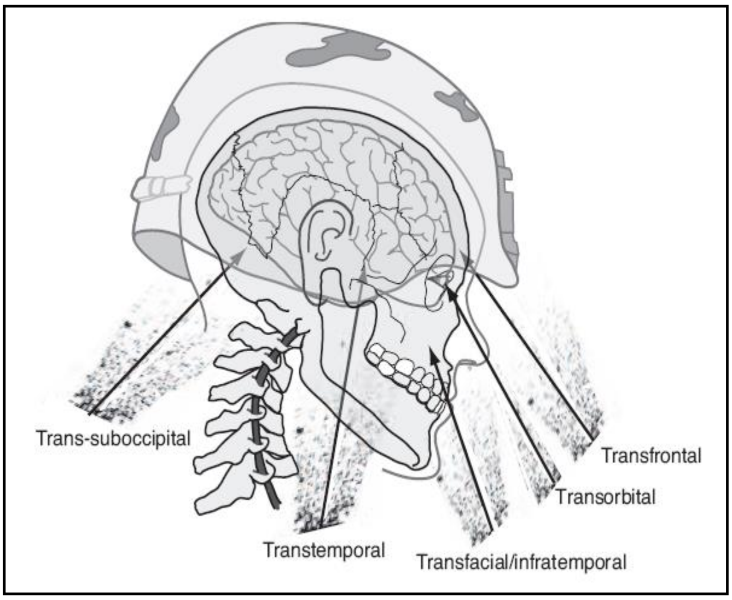
(DT Personal Collection)

Similar to the ATF, the Israel National Trauma Registry is a central repository for data involving injuries sustained by military personnel and civilians. It is an invaluable tool in analysing trauma patterns that may exist over a period of time, especially those involving IDF personnel after an operation or series of operations. One such analysis involving the Israel National Trauma Registry studied data from 2000-2002 with the objective to characterise and compare terror related injuries due to gunshot wounds and explosive devices, the outcomes being used to help better management of resources and training in potential mass casualty situations (Peleg et al. 2004). In this study the authors reported that injuries due to explosions were more common than gunshot wounds (GSWs) although a larger proportion of GSW victims died during the first day from their injuries. Furthermore, the injuries due to explosion tended to be polarised with minor injuries at one end and critical to fatal injuries at the other.

Lakstein and Blumenfeld (2005) focussed on injury patterns in Israeli soldiers during the fighting in the West Bank, the Gaza Strip and Northern Israel in 2000 and found that GSWs were more common than blast fragment injuries among Israeli Army personnel. This is perhaps indicative of the nature of that particular type of conflict where individual soldiers are targeted rather than an indiscriminate bombing in a built up area. The most common sites of injury were the HFN region and the extremities, the authors suggesting that the current style of combat body armour may need to be redesigned or modified to offer greater protection to the exposed areas of the face, neck and limbs. Similar suggestions were raised by Gofrit et al. (1996) who studied the injury patterns 164 Israeli soldiers that were killed in action during the 1982 Lebanon War and found that the face was the most vulnerable part of the body exposed to penetrating injuries, some of which were lethal due to fragments entering the brain following penetration of facial structures (Figure 2.5c). The dilemma of protection versus the ability to fight and manoeuvre continues to be problematic, limited by the materials available and the physical limits of the human body. Increased protection due to increased bulk and weight is at the expense of mobility and no soldier in combat wishes to be a sedentary target.

Saraswat (2009) described the injury patterns of 418 security force personnel in India involved with low intensity conflicts in an area prone to militant violence reporting GSW injuries being slightly more common than fragment injuries. Almost three quarters (73.9%) of these casualties sustained at least one limb injury and 23% received HFN injuries with almost half of these patients sustaining closed head injury. Despite CBA being worn, the HFN region and the extremities remain at risk from penetrating trauma and do not protect against primary blast injury barotrauma. The issues of CBA and injuries to the HFN region will be explored in greater detail in later section of this thesis.

**Figure 2.5c** Common entry points of penetrating brain injury below the protective areas of the helmet




(adapted from Burris DG, Dougherty PJ, Elliot DC et al. (editors): Emergency War Surgery, 3rd US edition, p15.2. Washington DC: Borden Institute, 2004.)

**Non-Lethal Rounds**

Conventional military warfare does not require the use of non-lethal rounds but in a situation necessitating civilian crowd control, non-lethal rounds are highly desirable to limit potentially fatal injuries. Non-lethal bullets were a feature of urban riot control in Northern Ireland and in some ways have become somewhat iconic of “the Troubles” but in a perverse way. These rounds were not designed to kill but could still nonetheless result in serious injuries especially when the head and face were involved. Rubber bullets were introduced by the British Army in Northern Ireland as a means of riot control and saw much action in the streets of Belfast and Londonderry during the 1970s. The idea was to aim at the ground and ricochet the rubber bullet into the legs of rioters as a painful deterrent. These rounds are referred to as “baton rounds” by military and paramilitary forces and are made of solid rubber (Figure 2.5d). Because the bullet fits poorly inside the barrel of the riot gun, it has poor flight characteristics making them inaccurate above a range of about twenty metres. The rounds are not designed to penetrate soft tissue but can cause significant contusions and often will leave an imprint of where the bullet struck the skin for some time after the initial injury (Whitlock and Kendrick 1994). Millar et al. reviewed 90 patients with rubber bullet injuries from 1970 to 1972 and found that over fifty percent of the injuries involved the head and neck region and approximately twenty percent involved the chest (Millar et al. 1975). Of the 90 patients, 35 individuals sustained concomitant facial fractures (almost 40%) and over one quarter of the patients sustained eye injuries. The malar and nasal bones were most affected, as often the round would strike the individual on the side of the face, striking the individual as they were turning away perhaps. Although the authors state that the fractures themselves were no different from any other fractures sustained from blunt trauma, the high percentage identified from the study meant that a higher index of suspicion was required when examining patients with rubber bullet injuries to the maxillofacial region in relation to the more obvious and often distracting soft tissue injuries.

**Figure 2.5d**

Non-lethal ammunition.
A rubber bullet is shown on the left and a plastic bullet is shown on the right of this photograph. Note the absence of the conical head on the plastic bullet.

(Public domain image courtesy of www.trsikelle.eu)

Issues concerning the poor flight characteristics and tendency of the rubber bullet to tumble in flight resulted in the need for a more accurate non-lethal round culminating in the introduction of the plastic bullet during the late 1970s. Whereas the rubber bullet measured 15cm in length and had a cono-cylindrical shape, the plastic bullet was 11cm in length and was blunt ended similar in appearance to a shotgun cartridge. However, solid rounds fired at close range can produce injuries as devastating as conventional rounds as illustrated in reports of casualties sustaining significant to severe facial fractures and facial soft tissue injuries, one extreme example being a man who was struck in the face by a plastic bullet at short range, resulting in a perforating eye injury, facial lacerations, a shattered left maxilla and fractures of the left zygoma, frontal bone and left mandibular condyle (Phillips 1977, Cohen 1985).

Despite being introduced as a "non-lethal" round, plastic bullets have been associated in a number of deaths, most notably in Northern Ireland and Israel (Metress and Metress 1987, Hiss et al. 1997). Analyses of the fatal injuries from both countries show that the main cause of death was from brain injury and that the rounds were fired at too close a range – distances well within the minimum recommended "safe" range of twenty metres, bringing into questions the level of training and intent of the security forces involved and allegations of abuse.

A significant number of ocular injuries either in isolation or as part of facial fractures appear to be associated with non-lethal ammunition. In an analysis of firearm injuries to the head and face from 1969-1977 in Belfast, Marshall reported that most of the fatalities as a result of gunshot wounds to the head and/or face were due to high velocity rounds (over 60%) and that a eye injuries were predominantly caused by shotgun pellets but rubber bullets were the cause of contusion or rupture in 20 eyes (Marshall 1986). A further case series of 42 patients with ocular injuries sustained from rubber bullets during civil unrest in Palestine in 2000 reported ruptured globes in almost 40% of these patients and that once the globe itself is hit by a rubber bullet it is rarely salvageable (Figure 2.5e) (Lavy and Abu Asleh 2003).

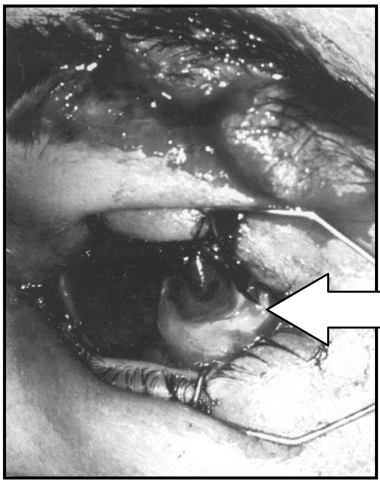


**Figure 2.5e**

Penetrating wound of the left eye with rubber bullet adjacent to the ruptured globe (arrowed)

(adapted from Lavy T, Abu Asleh S (2003). Ocular rubber bullet injuries. Eye 17: 821-824.)

**Conclusions**

Literature suggests that the injuries sustained in urban conflicts such as Northern Ireland and Israel can be as equally devastating as those sustained on the battlefield, perhaps more so due to the civilian population not having the benefit of protective combat body armour. Non-lethal rounds when fired at ranges too close to be deemed safe have resulted in fatalities due to intracranial injuries and even when not fatal, may cause severe facial fractures, disfigurement and blindness giving rise to questions about the use and safety of such ammunition. Terrorists have no such concerns in the use of improvised explosive devices, which when detonated in built up areas can cause massive collateral damage both in terms of injury and destruction of property. Blast and fragmentation injuries affecting the limbs and the head, face and neck regions predominate in bombing incidents – areas not protected by combat body armour and exposed to penetrating wounds. These experiences from Northern Ireland and Israel serve as timely reminders of the lessons learned as trauma teams and war fighters alike continue to struggle in Afghanistan and Iraq where the patterns of injury and the types of surgery performed seem all too familiar and reminiscent of similar injuries seen in the First World War.

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## 2.6 Current Operations: Maxillofacial trauma in Iraq and Afghanistan

Following the attack on the World Trade Center on 11 September 2001 ("9/11"), US security agencies determined that the attacks were perpetrated by terrorists belonging to Al-Qaeda, a militant Islamic group calling for a global jihad (literal translation meaning "struggle" but often misinterpreted to mean "holy war" by western society). Furthermore, communication intercepts were made by the FBI implicating Osama Bin-Laden as the primary suspect in planning this attack, Bin-Laden already a wanted man by the FBI for his involvement with other attacks on US installations in Africa. It was suspected that Bin-Laden and other high ranking Al-Qaeda operatives were hiding in Afghanistan and when an extradition request to the Taliban regime failed, a military option was taken with a US-led international military coalition, supported by Iraq's Northern Alliance, attacked Al-Qaeda and Taliban strongholds in October 2001 (OPERATION ENDURING FREEDOM). By December 2001 remnants of both organisations had sought refuge across the porous border into the tribal regions of Northern Pakistan (Connaughton 2008). Although several high ranking operatives were captured or killed during operations at that time, coalition forces were unable to find Bin-Laden until he was later located and killed by US Special Forces in May 2012. In 2003 as part of US President George W. Bush's "war on terror", US armed forces commenced military operations in Iraq on the premise that Iraq was in possession of weapons of mass destruction and was also harbouring wanted Al-Qaeda operatives. Many felt this to be an unnecessary diversion from military operations in Afghanistan and a mainly US-UK coalition force invaded Iraq embarking on an unpopular seven year conflict (OPERATION IRAQI FREEDOM). The political fallout from this invasion continues to rage, but in some ways has been diluted by ongoing events and issues in Afghanistan, now the main effort of coalition forces in the war on terror.

As previously discussed in the chapter on urban guerrilla warfare, literature from Northern Ireland and Israel described a tendency for blast and fragment injuries to produce multiple penetrating wounds to the extremities and the head, face and neck (HFN) regions. The use of modern combat body armour (CBA) especially utilising ceramic plate inserts, have reduced the numbers of lethal penetrating injuries to the chest and abdomen and increasing soldier survivability. In an analysis of injuries sustained by US Army Rangers and Special Forces in Somalia during the Battle of Mogadishu in 1993, the authors found that no rounds penetrated the ceramic plates of the CBA vest when worn by US Soldiers (Mabry 2000). Trauma experiences from Afghanistan and Iraq rival those seen in the First and Second World Wars, Korea and Vietnam. The severity of injuries sustained from GSW and explosions on current combat operations continue to challenge medical trauma services, perhaps even more so as the increased survivability of severely wounded soldiers poses issues in itself in terms of resuscitation, medical evacuation and rehabilitation back home (MacDonald 2010).

In some ways trauma surgery in Afghanistan and Iraq are reminiscent of the procedures performed during the First World War and indeed principles that were developed by surgeons almost a century ago are still applicable today and form the core teaching of many surgical specialties including oral and maxillofacial surgery. The key aspects of trauma surgery in Afghanistan and Iraq may be summarised as follows:

- The consistent use of CBA, helmets and ballistic eye wear protection among military coalition personnel

- The recognition of injury patterns unique to asymmetric warfare especially those involving blast and fragment injuries

- Emphasis on pre-deployment trauma training of personnel utilising lessons learnt, both current and from previous conflicts such as Vietnam and feedback from inured servicemen themselves, for example soldiers who have sustained traumatic amputations and how they were managed in the combat zone

- Timely medical evacuation procedures and availability of resources to transport severely injured military personnel to a Level IV medical facility (such as the NATO Hospital in Landstuhl, Germany)

- The location of and expertise available at Level II and III surgical facilities in theatre providing for life-saving resuscitative procedures

- The re-establishment of Damage Control Surgery as the appropriate means of care for severely wounded military personnel given the limited resources available and the relatively ready access to medical evacuation to a Level IV facility for definitive surgical care

- The availability and use of fresh whole blood and other blood products and new approaches to pre- and perioperative resuscitation

- Reliable data collection and analysis of combat related injuries coordinated by a central agency such as the US-based Joint Theater Trauma Registry (JTTR)

- Scientific publication of techniques, policies and guidelines pertinent for education, training and planning of medical resources based on data analysis and best practice rather than pure anecdote

(Beekley and Watts 2004, Beekley 2006, Holcomb et al. 2006, Parker 2006, Beekley et al. 2007, Butler et al. 2007, Cordts et al. 2008, Sakorafas and Pero 2008)

Whereas the above summary is not an exhaustive list of topics and lessons learnt from combat operations in Iraq and Afghanistan, it gives a good overview of the similarities and differences in terms of trauma management from previous major conflicts. The information given may further be summarised into the basics of performing life saving resuscitative procedures within the constraints of limited resources and prompt rearward medical evacuation for definitive surgical care with a commitment to learn from hard experience in the field of combat trauma surgery. The examples of battlefield amputations, Damage Control Surgery (DCS) –summarised by control of massive haemorrhage, wound toilet and patient resuscitation ready for rapid medical evacuation to a higher echelon of medical care, and the need to position surgical elements as far forward to the combat zone as possible are all concepts developed during the First World War, albeit without the technological advances but the principles governing the rationale behind these elements are essentially the same.

Despite advances in technology, equipment and therapeutic agents there are still barriers such as weather, terrain and the limits of human biology to sustain massive injury that cannot be changed. Another barrier is the perennial struggle between war fighters and medical specialists with the seemingly immovable emphasis placed on bullets and bombs. There is also a parallel struggle between the controllers of government funds and those on the ground – both combat and medical, prompting the UK Director General of Army Medical Services (DGAMS) in 2006 to ask in why there were no dedicated all-weather military helicopter evacuation platforms available to British soldiers fighting and getting injured in Helmand province during OPERATION HERRICK IV (Parker 2006).

The use of CBA and armoured vehicles by coalition soldiers has seen a decrease in lethal penetrating injuries to the chest and abdomen but injuries to the exposed areas of the body not protected by CBA – the extremities and the face and neck, have increased proportionately, in part due to the mechanisms involved (fragment and blast injuries more than GSW) but mainly due to the fact that severely wounded soldiers have a greater chance of survival and will require surgical management of limb and facial injuries, soldiers who in the past may not have survived long enough to have these wounds tended to (Patel et al. 2004, Xydakis et al. 2005, Belmont et al. 2010). The actual management of facial injuries especially facial reconstruction is, in essence, no different from the civilian setting in terms of biology and equipment with a readily available supply of plates and screws available for facial fracture management for example. The main differences relate to the tactical environment that affects not only the patient but the surgical team, because surgical care is provided in ways not readily apparent to civilian counterparts. For example, the combat soldier with severe facial injuries may have concomitant injuries of the head, neck or extremities. To some extent this is similar to patients with panfacial fractures sustained in motor vehicle accidents where over half of them according to one study also suffer from another injury or injuries such as intracranial haemorrhage, spinal injuries, internal organ damage and limb fractures (Follmar et al. 2007). These patients, however, suffer from blunt trauma injuries rather than penetrating or perforating injuries caused by fragments or bullets and the patients seen in combat trauma are typically young, healthy males but who may also be physically and mentally fatigued, dirty and undernourished – reminiscent of patients from the First and Second World War. During a mass casualty situation involving multiple patients from a single incident such as a car bomb explosion or enemy ambush, the surgeon may not have the luxury of time for the definitive treatment of the injury. Some facial reconstructions may take up to 6-10 hours (and sometimes longer) in a civilian trauma setting but this time frame is unrealistic in a combat trauma hospital where the order of the day is “life, limb or eyesight” and the greatest good for greatest number of patients. Surgical teams may also be exposed to enemy attack adding to the stress of the situation and a timely reminder for the need for expedient surgery and one’s own mortality.

Current concepts of HFN trauma in a combat zone are still evolving, in some ways mimicking the fluid nature of current combat in Afghanistan. On one hand, HFN trauma can be managed using the same principles as DCS with the emphasis on haemorrhage control and facial fracture stabilisation by means of intermaxillary fixation or external fixation devices (Breeze and Bryant 2010). From a doctrinal viewpoint, British soldiers with complex facial injuries were not typically treated in theatre (theatre of operations) but mobilised for medical evacuation and definitive repair at a higher echelon of care (which in 2009 either meant the Level III facility at Kandahar Air Field or evacuation back to the UK or Germany). In contrast, US literature has proposed that the definitive management of facial fractures is feasible but only by following a set of criteria which included an open fracture wound through soft tissue; treatment not delaying evacuation from theatre and treatment allowing the soldier to remain in theatre (Lopez and Arnholt 2007). The rationale for keeping and treating a soldier with an open fracture wound in theatre was to limit the potential spread of *acinetobacter baumannii* (an opportunistic human pathogen that is multi-drug resistant and has been found in war wounds in soldiers returning from Iraq and Afghanistan) back to the continental USA. However, a recent study found that the majority of wounded US soldiers returning from Iraq and Afghanistan do not have significant levels of *A. baumannii* but on going monitoring is recommended (Sheppard et al. 2010). If definitive treatment of facial fractures and other injuries is to be carried out in theatre, the technical procedures used are similar to that in a civilian setting in terms of equipment and surgical sequence. Panfacial fractures still require the establishment of mandibular continuity in order to relate the unstable maxilla to the mandible by way of intermaxillary fixation, followed by the re-establishment of other bony projections such as the zygomas and finally repairing defects such as orbital floor blow out fractures. Soft tissue wounds still require wound toilet and debridement and gentle tissue handling. In terms of wound toilet, however, the decontamination of these wounds is perhaps even more important in theatres of war due to general hygiene issues and the nature of the injuries with foreign bodies likely to be introduced and the higher likelihood of tissue necrosis necessitating aggressive surgical debridement. The management of jaw fractures, therefore, still follow the sequence of anatomical reduction, fixation, immobilisation and rehabilitation – principles published in 1916 almost a century ago (Hopson et al.1916)

It would seem that the principles used in modern maxillofacial war surgery have been well established and tested in many theatres of conflict and that the current state of surgical care has incorporated salient lessons learnt so far. Major innovations and discoveries from the past are being adapted to new situations. Perhaps the tenet of current military surgery is not so much breaking new ground but rather taking those lessons learnt and applying them well while finding news technologies or systems to implement them better. The use of blood product therapy, which was first introduced to the British Army by Canadians surgeons during the First World War and is still an essential part of trauma resuscitation (Pinkerton 2008, Spinella et al. 2009), provides an outstanding example. Technological advances in component therapy (such as recombinant Factor VIIa) and utilisation of different combinations of blood products such as an increased plasma to Red Blood Cell (RBC) ratio or a 1:1:1 ratio of fresh frozen plasma to red blood cells to platelets show positive outcomes for survival of combat-related injured soldiers (Beekley et al. 2007, Spinella et al. 2009). With a more developed trauma resuscitation system, antibiotics and rapid medical evacuation (when available) injured soldiers receive life and limb saving surgery much sooner with the need for definitive treatment limited by the resources available and military doctrine rather than by the skills and dedication of the surgeons themselves.

The next chapter will examine a set of principles developed from hard earned war experience by one of the greatest surgeons of the twentieth century - Sir Harold Gillies - using archival and contemporary case records to help illustrate these principles in graphic detail.

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## CHAPTER THREE

## ILLUSTRATING THE SURGICAL PRINCIPLES

### 3.1 The Surgical Legacy of Sir Harold Gillies

Sir Harold Gillies is often regarded as the father of modern plastic surgery and until eclipsed by his first cousin, Sir Archibald McIndoe in the Second World War, Gillies was the preeminent plastic surgeon of his time. Gillies was born in Dunedin on 17 June 1882, the son of a prominent land agent and member of the New Zealand House of Representatives, Robert Gillies. His mother, Emily Gillies (nee Street) was a descendent of Edward Lear who wrote a celebrated children's book entitled the *Book of Nonsense*. The house in which the Gillies family lived in on Park Street still exists and is listed by the New Zealand Historic Places Trust under the name Transit House (Figure 3.1a) – a name chosen by Robert Gillies (who was also an amateur astronomer) to commemorate his observation of the transit of Venus in December 1882 from an observatory built on the roof of his home (Figure 3.1a). Although the rest of the house has been almost fully restored the base of the revolving dome is the only part that remains of the observatory.


(DT personal collection)

**Figure 3.1a**

Transit House. The plaque reads:
"Named after the transit of Venus, 1882 and designed by JA Burnside for Robert and Emily Gillies. Family home of Sir Harold Gillies (1182-1960) the pioneer of plastic surgery".

Gillies was educated at Wanganui College (now Wanganui Collegiate School) and travelled to England where he qualified in medicine from Cambridge, gaining his Fellowship from the Royal College of Surgeons of England (FRCS) in 1910. He was a gifted sportsman representing Cambridge in rowing, a top-class amateur golfer, gifted artist (advantageous given the field in which Gillies was to make his mark in) and inveterate prankster (Pound 1960, Negus 1966, Bamji 1999, Bamji 2006, Martin 2006, Meikle 2006, Tong et al. 2008). It is not the intention to give a full biography of Gillies as there are many sources available both in written and electronic formats that cover his remarkable life and career in great depth, including a highly readable biography written by Reginald Pound (1960) which gives good insight into Gillies the man rather than focussing on his surgical achievements. Gillies' involvement with the head and neck region began not as a plastic surgeon but rather as an otolaryngologist or ear, nose and throat surgeon under the tutelage of Sir Milsom Rees (1866-1952). When the First World War broke out, Gillies enlisted with the Red Cross in 1915 (Figure 3.1b) and was posted to France where he met a French-American dentist named Auguste Valadier who had established a face and jaw unit at Wimereux.

**Figure 3.1b**

Gillies as a volunteer medical officer in the Red Cross, 1915

(by kind permission of Dr Andrew Bamji, Curator, Gillies Archives, Queen Mary's Hospital, Sidcup, UK)

Valadier was not medically qualified (there is some debate over whether he had any formal qualification at all) and could only operate on facial injuries under the supervision of a “real” doctor and an interest was sparked that soon ignited into a career choice for Gillies (Bamji 2006). Having made his decision to follow his fascination with facial reconstruction, Gillies persuaded the military authorities to allow him ward space specifically for wounded soldiers with face and jaw injuries at the Cambridge Military Hospital, Aldershot. However, when heavy numbers of casualties with facial injuries were received as a result of the Somme offensive in 1916, the unit was quickly overwhelmed. An acute need for larger premises arose and the unit eventually was moved to Sidcup, Kent in 1917, opening as the Queen’s Hospital in June 1917 and so becoming the literal birthplace of modern plastic surgery (Figure 3.1c).

**Figure 3.1c**

The Queen’s Hospital, Sidcup, County Kent. Note the horseshoe layout with various departments radiating from a central receiving area. The design is attributed to Gillies.

(by kind permission of Dr Andrew Bamji, Curator, Gillies Archives,Queen Mary’s Hospital, Sidcup, UK)

Gillies was later joined by other surgeons from Australia, Canada and New Zealand (Figure 3.1d), including Henry Pickerill, first Dean of the Faculty of Dentistry at the University of Otago. Although the primary responsibility of the various Dominion face and jaw sections was to their own injured soldiers, the sections often offered mutual support to each other.

**Figure 3.1d** Queen Alexandra with senior staff, the Queen's Hospital, Sidcup, 1917. Gillies is third from left in the back row and Pickerill is third from right)

(by kind permission of Dr Andrew Bamji, Curator, Gillies Archives,Queen Mary's Hospital, Sidcup, UK)

Gillies wrote *Plastic Surgery of the Face* (1920) which was received with much acclaim, and used material from his many cases during the war to illustrate techniques in facial repair. However, his magnum opus *The Principles and Art of Plastic Surgery* (co-written by American plastic surgeon D. Ralph Millard (born 1919) was published in 1957 and as reflected in the title, plastic surgery required more than just a technical skill demanding also a certain aesthetic awareness. In this two volume textbook, Gillies and Millard outlines a set of surgical principles that were developed over many years of experience spanning two world wars and the intervening years between. Millard had published Gillies' principles or his "Ten Commandments" earlier and added another six when this was incorporated into the textbook (Millard 1950). By this time plastic surgery had become a bona fide surgical specialty losing most if not all of the suspicion held by earlier conservative members of the surgical fraternity.

### Gillies' Surgical Principles

In *The Principles and Art of Plastic Surgery* Gillies and Millard (1957) describes a set of sixteen principles which is annotated with case illustrations, cartoons and anecdotes (Table 3.1). Millard had published what he described as Gillies' Ten Commandments. It is written more in the vernacular of an older colleague offering sage advice and wisdom rather than a pompous professorial consultant. What is perhaps striking from a clinician's standpoint is that these principles remain as fresh today as it was when first published and an excellent example of a common sense approach to basic surgery.

**Table 3.1 Gillies' Surgical Principles**

1. Observation is the basis of surgical diagnosis
2. Diagnose before you treat
3. Make a plan and a pattern for this plan
4. Make a record
5. The lifeboat (a reserve plan)
6. A good style will get you through
7. Replace what is normal in normal position and retain it there
8. Treat the primary defect first
9. Losses must be replaced in kind
10. Do something positive
11. Never throw anything away
12. Never let routine methods become your master
13. Consult other specialists
14. Speed in surgery consists of not doing the same thing twice
15. The after-care is as important as the planning
16. Never do today what can honourably be put off till tomorrow

(adapted from Gillies HG and Millard DR (1957) *The Principles and Art of Plastic Surgery*, London: Butterworth, pp49-54).

Some of these principles will appear quaint but we must bear in mind that these principles were written and formed during a time when technology was relatively basic compared to what is available for surgeons today, ranging from improved suture materials to vascularised free grafts and internal fixation using mini-plates.

The first five principles cover the pre-operative planning phase which includes examination, diagnosis and treatment planning. Gillies makes mention that a surgeon should learn observation from a physician and that a surgeon should not work in isolation which signifies a broad-minded approach to surgical management which may surprise those critical of surgeons stereotyped as arrogant and prima donnas. The next six principles relate to technical advice and are based on experiences gained from two world wars and sound surgical skills. The principle that "*a good style will get you through"* sounds rather superficial and generalised but the underlying lesson is that meticulous surgery is based on gentle technique, manual dexterity and complete hand-eye coordination. There is an apocryphal story about Tommy Kilner (later Professor Kilner) breaking a suture during an operation and when he asked the nursing sister whether this was the same material that Gillies used, she answered rather sharply "Yes – but think of his touch" (Pound 1964). Similarly *"do something positive"* is a rather unusual thing to say in relation to surgery as one would hope that any surgery that is undertaken would be a positive procedure, however Gillies describes "*doing something positive*" as taking the first step in executing the surgical plan. He uses the example of severe facial soft tissue injuries whereby identifying anatomical landmarks and repairing the readily identifiable structures becomes a positive step forward in executing the plan of surgical treatment. The remaining principles describe general aspects of surgical care and the fourteenth and fifteenth principles are particular pertinent to trainee surgeons who often mistake speed with hurried movements rather than efficiency and tend to regard the end of the procedure as the end of surgical management. Gillies' principles will be revisited in the next section and archival material from one of his surgical contemporaries – Henry Percy Pickerill, will be used to illustrate the management of combat related facial injuries according to these basic principles.

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### 3.2 Henry Pickerill and the Pickerill Collection

Gillies was the acknowledged leader in the field of face and jaw surgery at the Queen's Hospital in Sidcup, but he found he had to share aspects of his glory with some of his surgical contemporaries at this time.

One such contemporary was Major Henry Percy Pickerill, Head of the New Zealand Section at Sidcup and first Dean of the Dental School at the University of Otago. Certainly, Pickerill deserves recognition not only for his academic and research background but also his surgical skill and pioneering efforts to establish plastic and maxillofacial surgery in New Zealand and Australia after the First World War. Like Gillies, his transition into a practice solely based on plastic surgery was not easy but helped pave the way for others to follow a less rocky path.

Henry Percy Pickerill (1879-1956) was born in Hereford, England and was educated at the University of Birmingham gaining his Bachelor of Dental Surgery in 1904 and his Bachelor of Medicine and Bachelor of Surgery in 1905 (Meikle 2006). Following graduation he worked part time in private dental practice and part time at the Birmingham General Hospital as well as finding the time to lecture in dental pathology. In 1907 he was successfully appointed as the first Director of the newly built Dental School at the University of Otago at the tender age of 28. The distinguished career ahead of him would see Pickerill as an eminent dental researcher, teacher and gifted surgeon treating face and jaw injuries and congenital malformations such as cleft lip and palate. By 1911, Pickerill had gained higher academic degrees with a Master of Dental Surgery and Doctorate in Medicine. During this time Pickerill was active in the New Zealand Dental Association and was editor for the *New Zealand Dental Journal*, meanwhile still clinically active and keeping a keen and discerning eye on surgical developments from the Western Front that was being published (Brown 2007). It would appear that Pickerill was the ideal candidate to be appointed as a jaw specialist by the New Zealand government to be sent overseas for military service. Pickerill took a leave of absence from the University of Otago in 1916 and became the face and jaw surgeon to 2 NZ General Hospital based at Walton-on-Thames in Surrey with the rank of Major (Figure 3.2a). His task was to establish a face and jaw unit there and he found plenty of work to challenge his considerable expertise due to the severity of the injuries sustained by the soldiers and also the appalling conditions in which they suffered while on the front line. Pickerill established strict surgical routines and became proficient with bone grafting jaws, an area that was still fraught with complications and a high failure rate. Harold Gillies was keen to centralise all facial work at Sidcup (and had already agreed the transfer of the Australian and Canadian teams under Henry Newland and Carl Waldron respectively). Pickerill, however, was reluctant to follow suit and it was not until a visit to Walton-on-Thames by King George V and Queen Mary, when the latter firmly expressed her wish for Pickerill to go to Sidcup, that he acquiesced, thus forming the NZ Section.

**Figure 3.2a**

Major HP Pickerill, NZMC

(By kind permission of Dr Andrew Bamji, Curator, Gillies Archives,Queen Mary's Hospital, Sidcup, UK)

One can imagine with such a concentration of talent and surgical egos (as critics are quick to remind) there would inevitably be a degree of rivalry. Indeed this was actively encouraged in part by the Director of Medical Services, Sir William Arbuthnot Lane, who reasoned that specialist surgeons would vie with one another in advancing plastic surgery through their individual techniques (Neale 2011). Although Gillies was still the leading figure at Sidcup, Pickerill's advances in bone grafting, pedicle flap design and in particular his upper lip reconstruction earned him a reputation as a first rate plastic surgeon alongside Gillies himself which may have fuelled any perceived rivalry or jealousy between the two men, but apparently more so from Pickerill's side than Gillies who pays tribute to Pickerill's surgery in his book *Plastic Surgery of the Face* published after the war (Gillies 1920, Brown 2007, Tong et al. 2008, Bamji personal correspondence 2011). There was still much surgery to be done after the armistice had been declared and Pickerill left Sidcup in March 1919 returning to Dunedin and the Dental School as one of the leaders in the field of face and jaw surgery. Later that year, a face and jaw (maxillofacial) ward at Dunedin Hospital was established in order to continue the lengthy rehabilitation process of wounded servicemen. Pickerill was to become the first surgeon in Australasia to limit his practice to plastic and facial surgery and appeared to be highly regarded. Perhaps in part due to his unorthodox approach to his later surgical career and his lack of a Fellowship from one of the Colleges of Surgeons (anecdotally crucial for peer recognition among his peers), Pickerill has never been fully recognised as a pioneer in plastic surgery alongside his fellow New Zealanders, Gillies and McIndoe, despite his contributions to the field (Brown 2007, Tong et al. 2008).

Records of Pickerill's surgical work during the First World War currently forms part of the Gillies' Archive at the Queen's Hospital in Sidcup, County Kent, United Kingdom (Curator, Dr Andrew Bamji FRCP) as The Macalister Archives, named after the late Professor A D "Sandy" Macalister, Chair of Oral Surgery and Medicine at the University of Otago from 1972 to 1984. Professor Macalister was appointed as the Menzies Campbell Lecturer at the Royal College of Surgeons of England in 1987 and delivered a well-attended lecture on the Queen's Hospital as the foundation of British oral surgery. Professor MacAlister donated some 295 sets of case notes, including photographs, line drawings and radiographs, 100 watercolours and a life size wax model head and upper torso to the Queen's Hospital thereby reaffirming the New Zealand connection with the early development of plastic surgery of the face and jaws (MacAlister 1987; Bamji 1993). Many of the watercolours are attributed to Herbert Cole, a New Zealander who later painted under the pseudonym Rix Carlton and like his more illustrious British counterpart Henry Tonks and the Australian Daryl Lindsay (three of whose paintings are in the Sidcup archive), captured the gruesome reality of these injuries in art. Parts of Pickerill's original collection of New Zealand Section notes are in the Hocken Library and School of Dentistry at the University of Otago, Dunedin and it is primarily from these sources as well as the Captain Tommy Rhind's (Pickerill's surgical assistant) collection that illustrative material for the following case studies are drawn to help visualise the surgical principles that were developed from experiences from the First World War over 90 years ago.

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### 3.3 Case Illustration: The management of soft tissue injuries of the face

**General Considerations**

Soft tissue injuries may range from simple contusions and minor lacerations to significant loss of tissue (avulsive injuries) which not only pose a problem for the initial management of haemorrhage control and wound contamination but also has a profound impact on the repair and ultimate reconstruction of the wound from a functional and aesthetic perspective. The principle of observation as the basis of making a correct diagnosis advocated by Gillies (Gillies and Millard 1957) is important to help categorise the mechanism of injury and the resultant wound. A simple laceration to the face may be managed with relatively minimal intervention whereas high velocity missile injuries, from bullets or fragments, imparts high energy transfer into the tissues which may lead to a higher risk of tissue necrosis necessitating a more aggressive approach to surgical debridement and wound toilet. Haemorrhage control and identifying anatomical structures are key steps in the initial management of soft tissue wounds followed by wound toilet and appropriate debridement with the removal of any foreign objects and dead tissue. Overly aggressive debridement may lead to unnecessary loss of tissue and basic guidelines for the initial management of maxillofacial injuries disseminated by the American Expeditionary Forces during the First World War included the caveat of not removing any bone that was still attached to soft tissue (Schaeffer 1919, Strother 2003).

Wound coverage is facilitated by primary wound closure or dressings or a combination of both. The difficulty with avulsive injuries lies in finding enough tissue to replace that which is lost and this may involve the use of local or distant donor sites. Local flap reconstruction is only possible when there is a small defect and there is adequate tissue to rearrange to cover the defect. Free tissue transfers from distant sites have the disadvantage of not having an adequate blood supply to keep the graft vital whereas tissue flaps that remain attached to a blood supply have a better chance of survival. An example of this is the pedicle flap, the base of which remains attached at the donor site and the free end sutured into the wound defect. Longer flaps had a tendency of having the edges of the flap curl inwards and Gillies is attributed with the invention of the tube pedicle flap when he completed the inward curling by suturing the edges together forming a tube and decreasing the risk of infection (Pound 1964). Gillies' claim to inventing the tube pedicle was hotly disputed by his South African assistant surgeon, Captain J L Aymard with a degree of acrimony but it became a moot point when Gillies discovered that both of them were pre-empted by a Russian surgeon from Odessa, Dr Vladimir Filitov, who described the use of a tube pedicle in early 1917, some months before Gillies' revelation (Pound 1964).

The following case studies showing soft tissue injuries are sourced from the Pickerill Collection at the Hocken Library, copies of case notes and images from archives donated by Pickerill's surgical assistant Captain Tommy Rhind, New Zealand Medical Corps and the author's personal collection.

**Case Study One**

The first case study (Figure 3.3a) shows wound scarring and contracture, highlighting the problems described above when dealing with larger wounds with a degree of tissue avulsion. The obvious feature of photographs I and II is the avulsive nature of the soft tissue wound across the right side of the face. The mechanism of injury has not been

**Figure 3.3a** Case Study One


(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

The notes at the bottom of the photographs read:

"*Fracture of ascending ramus and deep gutter wound across cheek with loss of lobe of ear. III-IV shows the excision of scar after healing and the construction of a lobe from a horizontal flap from the neck, the end of the flap being twisted on itself to epithelialise its posterior surface.*"

recorded but sufficient force has been generated with the injury to produce a fracture of the ascending ramus of the mandible and significant loss of tissue.

From the pattern of injury observed, the missile or fragment that produced this injury was of high velocity and struck the face in a parallel trajectory to the skin surface as opposed to penetrating deep into the facial skeleton. Either a gunshot wound (GSW) or fragment injury from a blast could have produced this wounding pattern. Note the separation of the right ear at the inferior pole from the face due to the loss of the ear lobe on that side. Rhind's commentary describes the injury as a "deep gutter wound across the cheek" which gives the impression of tissue loss over a broad area rather than a simple laceration where the wound edges are maintained but are merely separated. In this wound, part of the skin and underlying soft tissues have been lost producing almost a gouge effect in the right side of the face. What is not readily apparent is the degree of neurologic damage sustained from the injury in relation to the right facial nerve as it exits the parotid region in front of the ear. It is also difficult to assess whether the noticeable scarring in pictures III and IV is due to excessive wound contracture or whether the soft tissue margins have been placed under too much tension or a combination of both with the neck flap used to construct the ear lobe creating tension and pulling of the scar while undergoing contracture. Note the terminology of "construction" rather than "reconstruction" – the former denoting forming or making something de novo as opposed to repairing something using existing structures or tissues. No further information is given about the fracture across the ascending ramus of the mandible and there is no knowing from the photographs whether an intraoral splint appliance has been fitted to aid with fracture management.

## Wound toilet and debridement

Knowing the tactical environment and mechanism of injury is important in order to plan for surgical treatment, for example, more aggressive exploration of the wound may be necessary when contaminants from the surrounding environment and particles introduced by the ballistic missile such as bits of clothing, dirt or masonry are expected or anticipated. In these situations wound toilet and surgical debridement of necrotic tissue is essential in the management of such wounds to prevent infection and wound breakdown. Wound toilet is not merely flushing with water or saline but also may necessitate physical scrubbing or scraping of tissues that may be imbedded with dirt or foreign bodies. Debridement is a French term that describes the removal of dead tissue from the wound in addition to wound toilet. High velocity soft tissue injuries, whether from GSW or blast fragments, produce significant amounts of tissue damage and tissue necrosis as a result of the energy transferred into the tissues associated with a pressure wave being formed (cavitation effect) (Holmes 2004). In these situations, extensive soft tissue debridement is often required and was of extreme importance prior to the era of systemic antibiotics when gas gangrene was a major risk factor leading to sepsis and death (Owen-Smith 1981). Despite routine antibiotic use in surgery, first developed during the Second World War and continued during the Korean War, studies of wounded US soldiers showed that inadequate wound debridement was the leading cause of wound infection perhaps emphasising the importance of physical decontamination of the wound rather than relying on antimicrobial therapy (Manring et al. 2009).

## Wound closure

The options for sutures in closing facial soft tissues that were routinely used by Pickerill and his contemporaries at the time were gut (a resorbable suture material derived from animal collagen) for suturing internal structures or mucosa and horse hair for skin. The suture material had to be threaded through the suture needle, a task usually left to the nursing sister assisting the surgeon in theatre. The modern day use of synthetic resorbable suture materials such as polyglactin 910 resorbable suture (Vicryl®, Ethicon Inc., Somerville, New Jersey, USA) may allow for better wound healing when compared to silk and surgical gut sutures due to their relatively inert properties in terms of inflammatory response. When compared to surgical gut and silk for closing wounds internally, Vicryl® was shown to elicit a minimal inflammatory response and resorbed completely by hydrolysis whereas surgical gut acted as a retained foreign body subject to removal by inflammatory cells (Conn et al. 1974, Breitenbach and Bergera 1986). As a general principle, deep layered closure of soft tissue wounds results in better re-approximation of tissues in their correct surgical planes, preventing a space where infection or haematoma formation may take place and allowing a more tension-free closure at skin level.

**Wound healing**

Soft tissue injuries heal by fibrous connective tissue repair and scar formation. When the wound edges are sutured in close approximation to each other (primary healing by first intention) the amount of scar contracture that results is minimised when compared to healing by second intention where the wound edges are left apart – typical of avulsive injuries (Kumar et al. 1997). Furthermore, scars are more noticeable when the wound crosses “against the grain” of the natural skin creases, known as resting skin tension lines (RSTL) – the areas where natural skin creases become wrinkles as we age, where for cosmetic reasons, incisions are intentionally made in order to hide the surgical incision.  Excessive scar contracture, hypertrophic scar and keloid formation all lead to unsatisfactory cosmetic results and to an extent are prevented by meticulous wound closure approximating tissue layers in such a way as to minimise the tension across the wound at skin level (Herford and Ghali 2004). Wounds closed under tension also have a tendency to pull part due to swelling and result in more scar tissue formation, essentially healing by "in-filling" or secondary intention.

Although the observation of scar contracture was noted in surgical literature during the First World War, Pickerill and his contemporaries would not have known the biological mechanism behind this, namely the healing of wounds due to the laying down of fibrous connective tissue, the formation of new blood vessels and the various tissue factors secreted by cells. In situations where the wound edges are far apart (as described above by Rhind as a "gutter") a greater amount of fibrous connective tissue is laid down by fibroblasts and contracture takes place due to myofibroblast activity (Kumar et al. 1997). During the First World War, surgeons had to deal with gross tissue contamination from the field, wounds that were potentially days old and patients not in peak physical condition due to the stresses of the combat environment, relying on physical means such as thoroughly cleaning the wound and meticulous surgical debridement. Today, surgeons still employ these physical aspects of wound management but with advances in molecular biology and greater understanding of biological processes, natural healing may one day be augmented by directly modifying the behaviour of cellular components in healing, using calcium nano-particles or cultured fibroblasts for example (Kawai et al. 2011, Sakrak et al. 2012) and potentially merging traditional surgical wound care with molecular technologies in the future.

A similar injury to that seen in Figure 3.3a to the right face is seen in Figure 3.3b, the result of fragment injuries from an improvised explosive device incident. Both patients have noticeable scars post-operatively as the wounds cross the RSTLs of the face; however the scarring is less noticeable in the contemporary patient post-operatively. This may be may be due to a number of reasons including the size of the fragment causing injury, the velocity of the fragment creating the wound, less missing tissue from the wound (compared to Pickerill's patient in Figure 3.3a) and the early presentation of the patient to the operating theatre – giving less time for tissue swelling to occur. The rapid evacuation to a surgical facility is a key factor in improving surgical outcome and unlike their First World War counterparts who sometimes waited days before evacuation, contemporary soldiers in Iraq and Afghanistan can be medical evacuated sometimes within hours instead.

**Summary of Surgical Principles relating to Case Study One**

1. Recognise the mechanism of injury and diagnose the wound appropriately
2. Delays in medical evacuation allow more time for tissues swelling and necrosis leading to a higher risk of infection
3. Wound toilet and debridement is critical to remove contaminants
4. Close the wound in layers with minimal tension at the skin level
5. Scars that cross the natural RSTLs of the face may be more noticeable
6. Inadequate soft tissue mobilisation leading to tension across the wound and infection contribute to adverse scarring and unsatisfactory cosmetic results
7. Systemic antibiotics are an adjunct and not a substitute for appropriate wound toilet and debridement.

**Figure 3.3b**

Contemporary patient seen in Afghanistan with similar facial injury showing (A) pre-operative and (B) post-operative views.


(DT personal collection)

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### 3.4 Case Illustration: The management of fractures of the mandible

**General Considerations**

Orthopaedic dogma for the management of bony fractures involves anatomical reduction of the bone segments; holding the fracture stable during healing and rehabilitation of the limb through appropriate exercise (Apley and Solomon 2001). These fundamental concepts are applicable to fractures of the mandible but with some modification due to the anatomical structure of the mandible itself (a complex shaped bone with different biomechanical properties) and the presence (or not) of teeth. Dental surgeons during the First World War were well aware of the need for stabilising fractures in order for healing to occur, though early attempts to wire bone ends directly often failed due to infection. As discussed in section 2.2, by 1916 dental surgeons appointed to specialist face and jaw units had innovative means at their disposal to reduce and stabilise fractured mandibles using intraoral and extraoral appliances that were attached to the existing dentition, the typical example being the use of cast cap splints that were cemented over the teeth and indirectly holding the reduction of the fractured mandible by a rigid metal structure. In grossly comminuted (fragmented) fractures, the small fragments had to be kept in position by the use of bolsters literally holding or sandwiching the fragments together, an example of which will shortly be described. Although functional, these appliances were often bulky and cumbersome and did not offer the surgeon a direct visualisation of the fracture itself, relying instead on closed reduction (no surgical opening of the fracture) which may not always results in the correct alignment of all the fragments of bone. By the end of the First World War however, face and jaw surgeons in the Empire and American forces were wiring the bone segments directly using an incision over the injury site in order to directly visualise the fracture (open reduction). Similar to soft tissue wound healing, bringing bone ends closely together by anatomical reduction minimises the gap across which new mineralised tissue is laid down by bone cells (Kumar et al. 1997). However, merely approximating the bone ends together is not enough as fractures heal better when there is minimal movement across the fracture site and the more rigid the means of fixation, the more stable the fracture becomes during the healing period (Chacon and Larsen 2004, Ellis 2004). By the end of the Second World War, the use of metal plates were being described as a superior means of fracture management in the mandible, developing into what is being used as standard practice today.

**Case Study Two**

The second case study shows line diagrams and clinical photographs of Soldier G who sustained a GSW to the mandible resulting in gross comminution (fragmentation) of the bone in the symphyseal region of the mandible. Although the general COA (condition on arrival) was good, the case notes report that the wound was infected with foul discharge being present both intraorally and extraorally (Figure 3.4a). Subsequent management of the mandibular fracture involved the use of a series of custom-made appliances, the first utilising an intraoral cast-cap splint arrangement with an external attachment that is clearly shown in Figure 3.4b. The use of an external bolster provided upward stability for the fragments at the inferior border of the mandible whereas the intraoral splint stabilised the fracture from a transverse or width dimension. Once the mandible was sufficiently healed, the external attachment was removed and a new intraoral appliance was fitted to provide further stabilisation until definitive healing had taken place.

**Figure 3.4a** Case Study Two. Case notes for Soldier G, 36 years of age.

9.8.18 G.S.W. face and neck.
15.8.18 Admitted to Queens Hospital, Sidcup
C.O.A. General condition good. Fracture of symphysis. Lower incisor teeth loose. Drainage below chin - slight foul smelling discharge. Mouth foul.
15.8.18 X Ray shows fracture of symphysis with many radiating lines of fracture involving the teeth.

Dental Treatment by Capt. Turner
22.8.18 Applied screw lever splint.

7.11.18 X Ray shows comminuted fragments are in good position at symphysi

Dental Treatment by Capt. Turner
8.11.18 Comminuted fragments now in good position at symphysis, during leave lower central incisors came away.
Screw lever attachment removed. Fragments braced together and lower metal cap splint cemented in position.
12.1.19 Removed $\overline{2/2}$ and braced fragments together and cemented on new metal cap splint.

16.1.19 Discharge stopped.

17.2.19 X Ray shows middle line fracture with loss. Approximation of fragments, but not united by bone.

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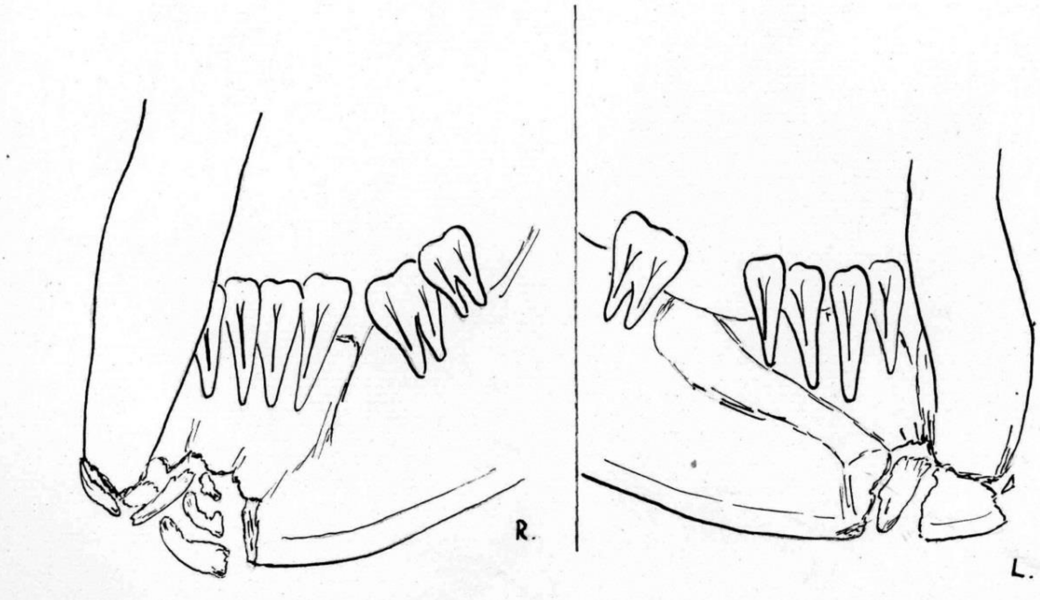
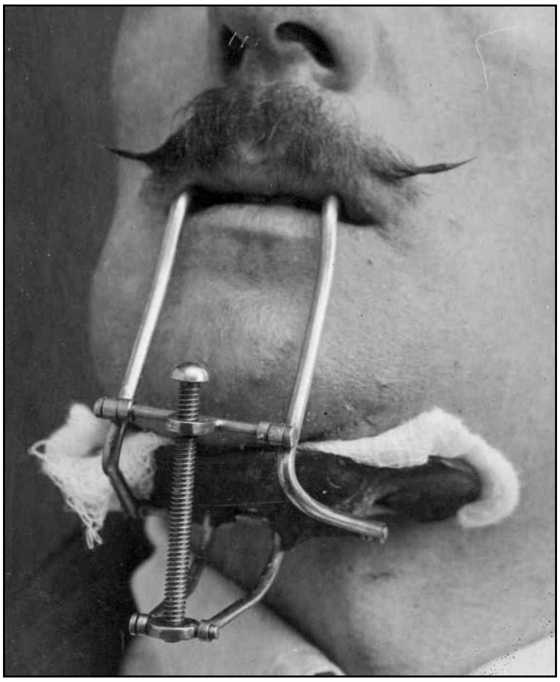



15.8.18 X Ray shows fracture of symphysis with many radiating lines of fracture involving the teeth.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 3.4b**
Photograph of Soldier G showing external attachment providing support to the inferior border of the mandible. The vertical screw was used to provide adjustments to the amount of pressure exerted onto the lower border of the chin.



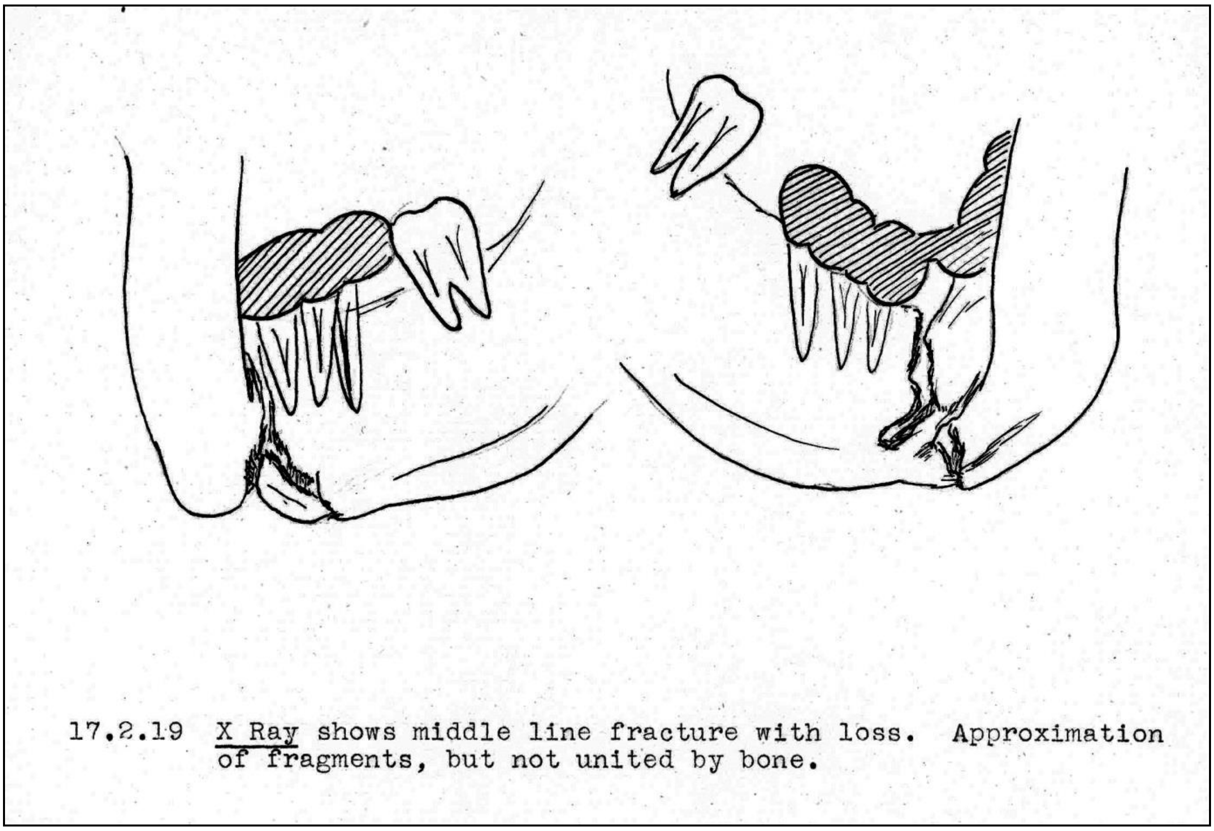
(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**The issue of infection**

The standard method of managing fractures of the mandible during the First World War was cementing an intraoral appliance directly over existing dentition. Once the fracture was reduced, the fragments were held in position using an intraoral appliance to promote bony union. This was done after "disinfecting" the wound with various irrigants such as saline, permanganate of potash and dilute sodium hypochlorite (Dalton 1916, Payne 1916, Piperno 1916). This type of disinfection was in conjunction with surgical wound toilet and tissue debridement. Residual necrotic tissue or tissue with compromised blood supply still posed a major source of infection prior to the advent of systemic antibiotics.There were distinct advantages in using an indirect method of fracture reduction given the surgical options at the time, namely minimising infection by not creating wounds inside the mouth allowing oral microbes to enter the wound; maintenance of anatomical dimensions (space maintenance) and the rigidity of the intraoral appliance providing good stability and immobilisation of the fracture. Early observations by German surgeons during the Balkan War of 1912-1913 discredited the use of direct osseous-wiring techniques as it was associated with poor surgical outcome and infection, perhaps due to oral bacterial contamination or insufficient rigid fixation of the fracture. Yet by the end of the First World War, reports of wiring fracture ends together and using wires to position bone grafts were being published, indicating perhaps operator skill and appropriate surgical facilities were key factors in successful outcome rather than the actual technique itself. The issue of infection in the context of Soldier G may have involved several factors which include wound contamination and inadequate wound toilet and debridement, inadequate fracture immobilisation, the presence of teeth in line of fracture and gross comminution of the bone, any of these factors in isolation or in combination could lead to wound infection and delayed healing especially in the absence of systemic antibiotics (Chacon and Larsen 2004).

There are no details of the appearance of the external wound for this patient however there is mention of drainage and foul smelling discharge from under the chin. As the GSW was sustained only 6 days prior to admission to the Queen's Hospital, it is more likely that wound breakdown due to infection was present rather than a draining sinus. Devitalised bone fragments and possibly non-vital teeth in line of fracture are the likely sources of infection and the case notes report the subsequent loss of anterior lower teeth and the fracture was approximated but showed no evidence of bony healing almost six months later (Figure 3.4c). Even with the use of a seemingly rigid intraoral appliance and an external bolster cradling the fracture from under the mandible, it would appear from the line drawings that the fracture fragments at the inferior border remained unattached and suggest fibrous tissue ingrowth rather than bony callus formation had taken place, preventing bony union of the fracture.

**Figure 3.4c** Line diagrams of radiograph of Soldier G taken 6 months after initial injury. The loss of bone and non-union of the fracture is noted.



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

### Fragmented mandible fractures

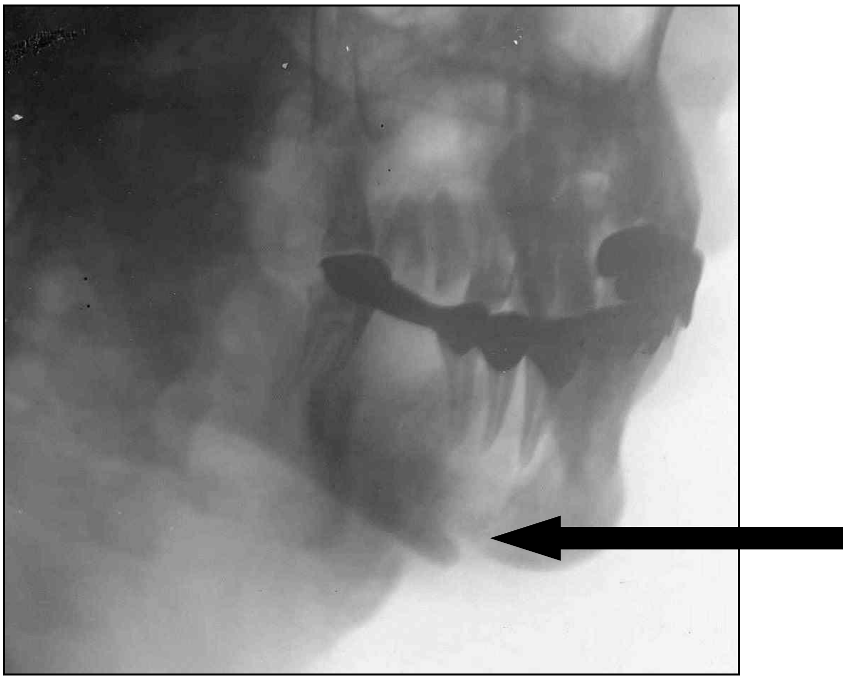
The problem of managing small fragments remains an issue with the surgeon being faced with the dilemma of trying to stabilise the area of comminution without compromising the blood supply to the area by stripping off the surrounding periosteal layer which carries the nutrient supply to bone. Pickerill commented on this issue in the *Lancet* (Pickerill 1918a) changing his initial management of removing these small fragments of bone to a more conservative approach provided that the comminuted area was adequately immobilised and free from pus. Grossly comminuted mandibular fractures may be managed by indirect methods of fixation such as intraoral appliances, wire intermaxillary fixation (wiring the teeth together as long as teeth are present to be utilised) and external pin fixation with a frame. External pin fixation was utilised more routinely during the Second World War and Korea and provides excellent rigidity but necessitated a longer healing period as well as the discomfort and inconvenience of wearing an external frame appliance for several weeks. Some modern day surgeons prefer to fix these fragments using open reduction and internal fixation techniques with mini-plates and screws however the risk of stripping off the periosteum and potentially devitalising the bone fragments leading to infection and loss of the bony fragment can be as high as 50% (Blinder and Taicher 1995). Because of this, it has been suggested that a conservative approach is more prudent and harks back to First World War practices but with the advantage of adjunctive systemic antibiotic therapy.

**Teeth in the line of fracture**

Teeth associated with the fracture line can be problematic. They can be a source of infection as they become non-vital and although important in aiding the anatomical reduction of fractures, if the tooth roots are fractured, exposed or prevent the bone ends from being reduced then they become a liability and their surgical removal is indicated (Shetty and Freymiller 1989, Chacon and Larsen 2004, Samson et al. 2010). Sometimes the infection from the teeth as they become non-vital might take several months to declare itself, by which time chronic low grade infection may lead to bone loss within the fracture site itself. The current recommended practice when teeth associated within a mandibular fracture line are retained is to regular monitor the vitality of these teeth over a period of 12 months with a view of treating these teeth endodontically by managing infection of the root canal system (Chrcanovic 2012). During the First World War the management of mandibular fractures relied on intraoral appliances cemented to the dentition and as a result, it was recommended that teeth were to be preserved wherever possible (Cole and Bubb 1916). Furthermore, Payne (1916) recommended the removal of teeth that were unable to be hygienically maintained, had septic roots or were in line of fracture in order to minimise delayed healing (presumably due to infection). However, once an intraoral appliance was cemented over the existing dentition, vitality testing and monitoring of the teeth themselves would have been impossible unless the appliance was removed first.

Figure 3.4d shows a radiograph of another First World War soldier (Soldier B) who sustained a GSW to the mandible. In the case notes for this soldier, three teeth in the fracture site were removed four months after initial injury, most likely due to mobility secondary to bone loss and infection. It is likely that the associated infection from the roots of the teeth would have contributed to the fracture failing to heal.

**Figure 3.4d** Radiograph of Soldier B showing area of bone loss secondary to infection from possible non-vital teeth in the line of fracture (arrowed).



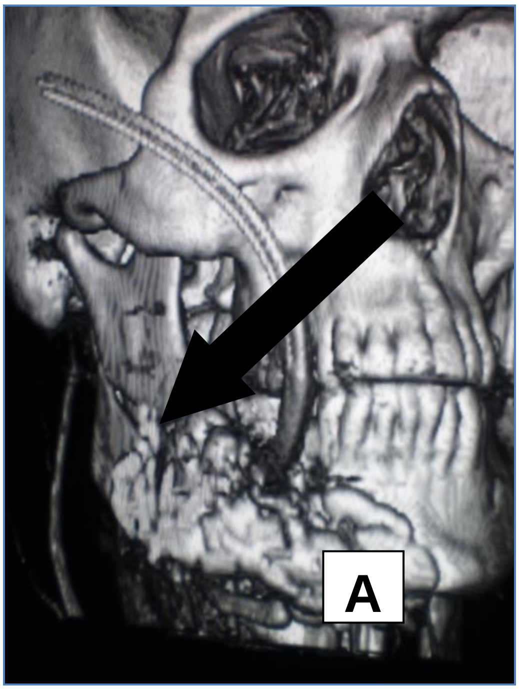
(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

### 21st Century management

The principles of fracture management remain extant but the means by which to achieve a successful outcome have evolved drastically. By 1918, Pickerill and his colleagues at Sidcup were performing direct osseous-wiring of mandible fractures, a technique that was regarded as unsound only five years prior by German surgeons from their observations from the Balkans conflict. By the latter years of the Second World War, open reduction and internal fixation using metal plates and screws were tentatively being performed but by no means regarded as routine treatment.

Figure 3.4e shows a pre-operative computerised tomography (CT) scan of a patient who sustained a high velocity GSW to the right mandible in April 2009 and presented to the NATO Role 3 Multinational Medical Unit (MMU) at Kandahar, Afghanistan.

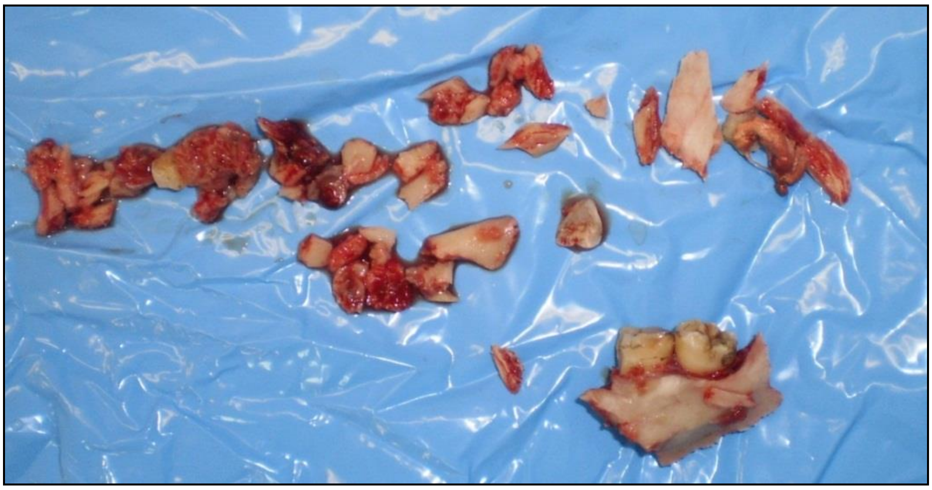
**Figure 3.4e** CT scan of patient with GSW to right mandible. The area labelled A shows grossly comminuted fragments which have been blended together on the 3-dimensional reconstruction of the CT images. Note the fracture across the ramus of the mandible in addition to the destroyed area in A (arrowed)




(DT personal collection)

Pre-operative plain radiographs were not taken as the patient required further CT scanning for other concomitant injuries sustained at the time of the GSW to the mandible. The patient was taken to the operating theatre where the GSW to the right mandible was treated by making an extraoral approach under his mandible to minimise contamination from inside the mouth. Copious wound toilet and debridement of non-vital fragments of bone and teeth was performed (in keeping with principles discussed in section 3.3) which if left in situ could develop into sources of wound infection. (Figure 3.4f).

**Figure 3.4f** Devitalised bone and teeth fragments removed during debridement of patient seen in Figure 3.4e



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As a result of the high energy transfer from the high velocity GSW to the right mandible, the bone was grossly comminuted (shattered into pieces) and following surgical debridement, a continuity defect of the mandible spanning from the right lower canine region of the mandible to the right angle of the mandible was established. The ramus fracture was fixed using smaller mini-plates but a large reconstruction plate was used to span the main bony defect of the right mandible (Figure 3.4g). The post-operative radiograph in Figure 3.4h shows the extent of the titanium hardware placed in the mandible, which has effectively united the mandible allowing early mobilisation of the jaws and oral intake of nutrition. The extent of mouth opening at 10 days post-operation is shown in Figure 3.4i which would not have been achievable during the First World War if intraoral appliances were used.  Although residual swelling from the injury and surgery is evident on the right side of the patient's face, the range of movement in the mandible was good. Primary bone grafting (bone grafting to reconstruct the mandible at time of initial surgery) was not performed primarily due to clinical time constraints but also due to other security-related issues at the time.

**Figure 3.4g** Intraoperative view showing reconstruction plate *in situ*

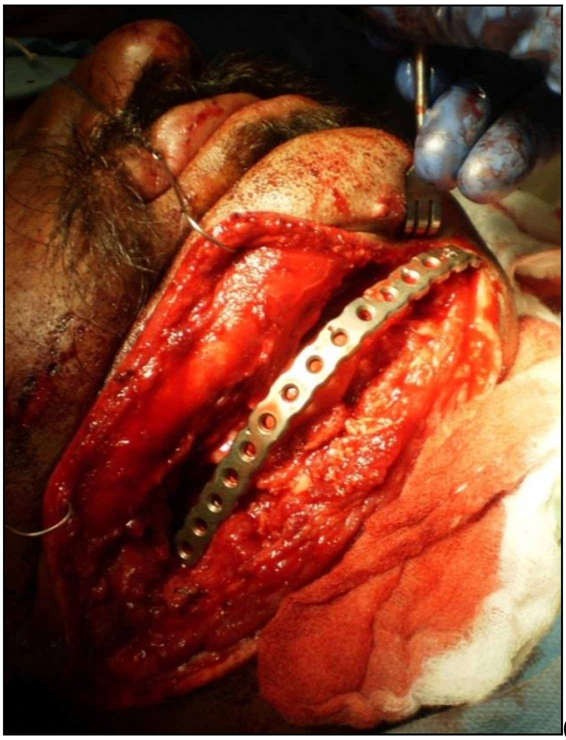
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**Figure 3.4h** Post-operative radiograph showing titanium plate reconstruction of the right mandible. The line of skin staples to close the incision is clearly shown on plain film.

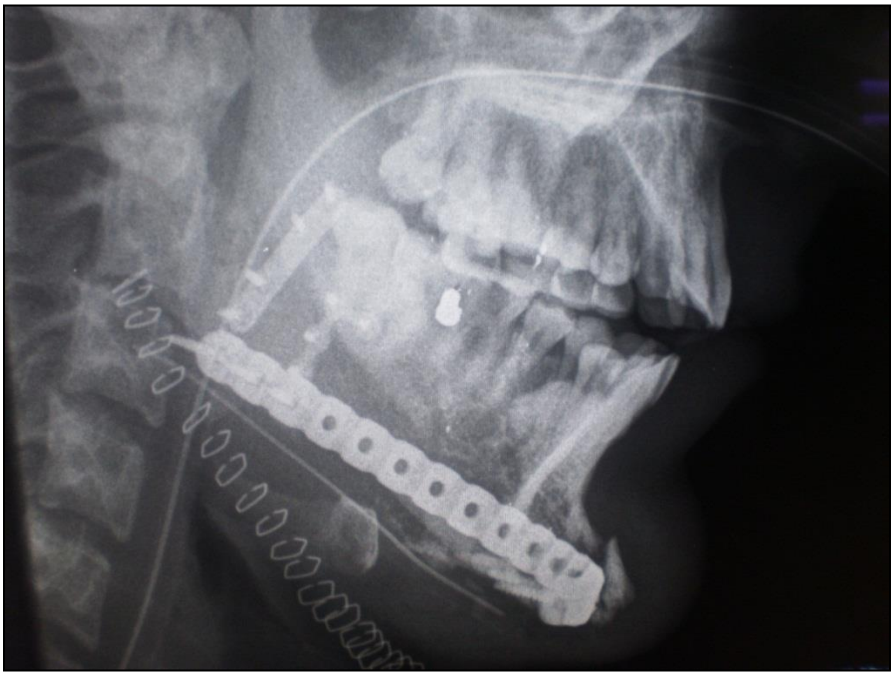

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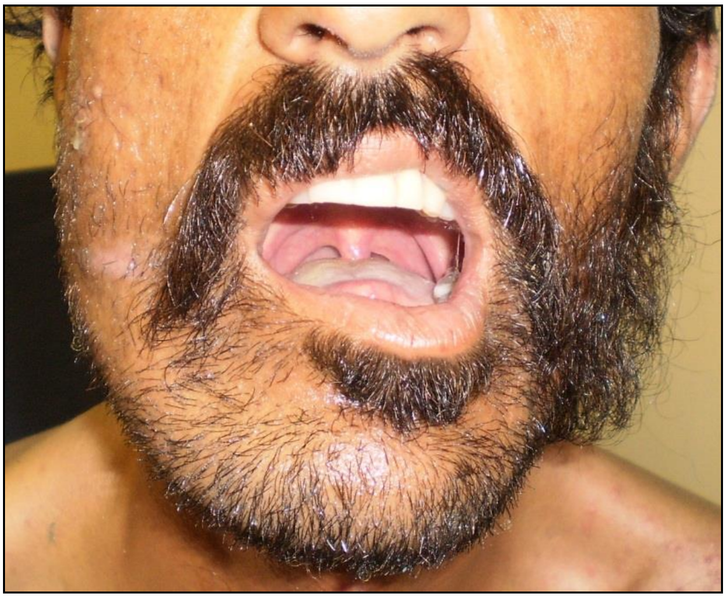
**Figure 3.4i** Extent of mouth opening ten days after surgery. The right side of the face is still swollen from the injury and surgery.



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**Skin staples versus sutures**

In this contemporary patient, the soft tissue wounds were closed in layers using resorbable sutures but skin staples rather than sutures were used to close the superficial layer of skin. Sutures may be classified into resorbable or non-resorbable materials or whether they are braided or non-braided. Typical examples of braided sutures include silk and vicryl® and non-braided or monofilamentous sutures include nylon and other related synthetic derivatives (Dunn 2005). There is some literature suggesting greater bacterial adherence to braided suture materials used to close wounds resulting in inflammation and superficial infections which may result in delayed healing and poor cosmetic result (Masini et al. 2011). However, randomised controlled trials comparing braided versus non-braided sutures used for closing skin (where cosmetic results are a major factor) show no evidence to support this view (Kundra et al. 2010). For larger wound closures such as those found in orthopaedic or general surgery procedures, stainless steel staples have been used to good effect. These staples essentially are non-braided metal "sutures" which approximate the skin edges together at a superficial level. There is a suggestion that skin staples give a superior cosmetic result in scalp wound closure and may be preferred over sutures in closing potentially contaminated wounds (Hochberg et al. 2009). Another advantage in using skin staples is the ease and speed of wound closure when compared to suturing, certainly a consideration for the contemporary patient discussed above as a pressing need for the operating theatre became more acute due to other patients requiring urgent surgery. Despite these apparent advantages, there is evidence from the orthopaedic literature to suggest that skin staples may actually increase the risk of wound infection and that this practice may need reviewing (Smith et al. 2010). The surgeon therefore must take into account all considerations including ease of closure, time constraints and infection risk, before choosing the appropriate material for wound closure.

**Internal Rigid Fixation**

The use of a large titanium reconstruction plate for rigid internal fixation is a distinct advantage over the use of an intraoral appliance typical of First World War management. Although a cast splint is very rigid, it relies on having teeth available to be cemented in place. Where there are no teeth available, fractures could not be held in anatomical reduction, such as the ramus fractures seen in the contemporary patient from Afghanistan in Figure 3.4e. The reconstruction plate was able to re-establish mandibular continuity and not only provided primary stability of the mandible but also provided reasonable anatomical contour as well as space maintenance so that the mandible did not become too narrow or deviated towards the right due to the discontinuity defect in the right body of the mandible. Early rehabilitation in jaw movement and oral intake was also possible as a result of this method of mandibular reconstruction. Literature suggests a three to ten percent incidence of plate fracture associated with mandibular reconstruction without bone grafting due to excessive plate bending during surgery or metal fatigue as a result from masticatory forces (Peacock et al. 2012) therefore the next surgical phase would have ideally involved bone grafting to replace the missing segment of mandible with a view to oral rehabilitation potentially with dental implants and an implant borne prosthesis (Guerrier et al. 2012). This patient was lost to follow up however and further reconstructive surgery was unable to be performed.

Despite the obvious technological advances in resuscitative trauma surgery and internal fixation systems, basic principles have still been observed when managing the wound at time of surgery which involve the prevention of infection by appropriate debridement of the wound of non-vital soft tissue and devitalised hard tissues such as bone and teeth, lessons learnt during the First World War. The principles of reducing the fracture, stabilising the fragments during the healing period, re-establishing dental relationships, dynamic jaw exercises and prosthetic oral rehabilitation are as important today as it was when these concepts were being shared between surgeons during the First World War, indicating perhaps that the principles remain the same but the means by which successful surgical outcomes are achieved are different due to developments in technology and biological understanding.

**Summary of Surgical Principles relating to Case Study Two**

1. Anatomical reduction of the mandible must be stabilised and adequately maintained during healing in order for bony union to occur
2. Wound toilet and debridement is critical to remove contamination and decrease wound infection which may also necessitate the removal of devitalised bone and non-vital teeth in line of fracture
3. Rigid internal fixation methods allows a more rapid recovery in terms of healing and functional rehabilitation
4. The management of small comminuted fragments is difficult and considerable clinical judgement is needed to decide whether or not to fix these fragments and risk devitalising these fragments by detaching them from their blood supply

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### 3.5 Case Illustration: Continuity defects of the mandible

**General Considerations**

No matter how much rigid fixation is applied, spontaneous bony healing cannot take place if the gap between the bone ends is too large (critical size defect) as a result from significant loss of bony tissue (Torroni 2008). The length of the critical size defect is not well described in humans but may be in the order of 2.5cm in non-human primates (Boyne et al. 2006). The best substitute for bone is bone itself and in particular bone harvested from the patient themselves (autogenous bone) which not only stimulates non-specialised host cells to become specialised in forming new bone (osteoinduction) but also provides a scaffold for bone-forming cells to lay down bone (osteoconduction) (Wilk 2004, De Long et al. 2007, Misch 2008). The importance of bone grafting is not the harvesting procedure but ensuring the survival of the bone graft once it has been taken from the donor site. With current plating systems, systemic antibiotics and oral rehabilitation, bone grafting of the jaws has become a routine procedure, but during the First World War problems of stabilising the bone graft and preventing sepsis made this a risky procedure and early attempts had a high failure rate perhaps in part due to poor patient selection, contaminated wounds and poor understanding of biological principles. Certainly by 1918, bone grafting of the jaws was more commonly performed with an increased success rate, the reasons perhaps due to the improvement of surgical technique and strict infection control. Pickerill wrote in 1917 that bone grafting could only be feasible when the wound was "healed perfectly" and no communication into the oral cavity was present, stating that it was an operation *"... requiring the most rigorous asepsis, and opinions are at present, I find, doubtful as to what is going to be the future of the method"* (Pickerill 1917a). This was a somewhat gloomy appreciation of bone grafting procedures, no doubt coloured by a high failure rate among bone-grafted patients. Nonetheless, Pickerill was more positive in a later piece of correspondence describing that he had several bone grafted jaws among his patients presumably at Walton-on-Thames and that a combination of harvesting bone from the tibia and rib cartilage seemed to be producing excellent results (Pickerill 1917b). The following case study from 1918 is of a soldier with a GSW to the mandible illustrates Pickerill's innovation and skill in reconstructive surgery.

**Case Study Three**

This third case study from the Pickerill Collection shows line diagrams, radiographs and clinical photographs of a 19-year old soldier who sustained a GSW to the right mandible and thigh. No reason is given as to why there was a considerable time delay between date of injury (20 September 1917) and transfer to the NZ section at Sidcup (08 February 1918) but the soldier had received some initial management and arrived at the NZ section with a lower intraoral appliance in situ (Figure 3.5a).

The GSW to the mandible had resulted in a sizeable bony defect in the right mandible and considerable scar tissue ingrowth into the defect had taken place over a period of six months from date of injury to the preparation of the site for future bone grafting (Figure 3.5b). The case notes state that Pickerill excised the scar tissue between the bone ends and used a full thickness soft tissue flap taken from the neck to obturate the defect. The use of hydrogen peroxide may have been used to provide haemostasis and a level of disinfection to the soft tissue bed but there is no further elaboration as to why it was used. A bone grafting procedure was performed approximately six months after soft tissue preparation of the site had healed and presumably after re-establishment of a good blood supply, the bone being taken from the tibia using a rotary instrument with a circular saw blade fitted. Note the interesting terminology of “bone screws” fashioned from the harvested tibial bone graft.

**Figure 3.5a** Case Study Three. Case notes for Soldier C, 19 years of age.

20.9.17 Wounded - G.S.W. lower jaw - right thigh.

25.9.17 Admitted to Queens Hospital, Sidcup

26.11.17 X Ray shows large gap between fragments - fracture right ramus. Much elevation of posterior fragment.

8.2.18 Taken over by N.Z.Section with lower splint and slide attachment. Dental Treatment by Major Rishworth

16.2.18 Removed lower splint and slide and inserted splintswith upper and lower slide attachment.
20.2.18 Immobilised mandible.
13.3.18 Operation by Major Pickerill to provide tissue bed for subsequent bone-graft. Scar excised and flap taken from neck to fill space previously occupied by scar.
X Ray taken about Feb. 1918 (see Fig. 2)
17.5.18 Re-cemented in position splint with flange.

3.10.18 X Ray (for record purposes, prior to bone graft) shows much elevation of posterior fragment.

Dental Treatment by Capt. Turner

4.10.18 Cemented in position Double Gunning Splint for bone graft with saddle on lower splint for posterior fragment.

5.10.18 Operation by Major Pickerill Bone graft.

3.11.18 X Ray shows no union as yet.

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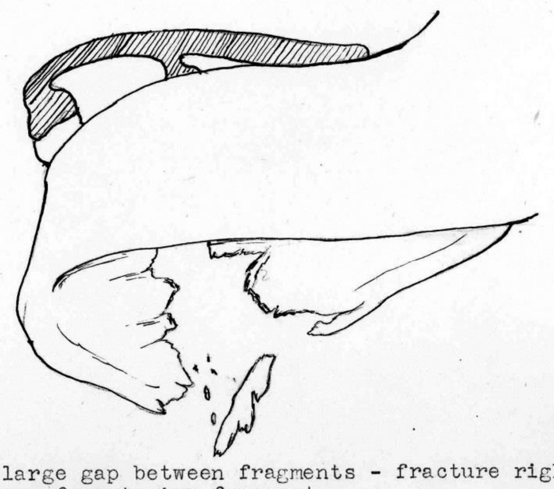


26.11.17 X Ray shows large gap between fragments - fracture right ramus. Much elevation of posterior fragment.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 3.5b** Operative findings for Soldier C.

CONDITION. Large wound over rt,angle,frac.rt.hor.ramus.

13-3-18 Operation by Major Pickerill to provide tissue bed for subsequent Bone-Graft.
Scar excised deeply removing fibrous tissue between bone ends which could not be excised,well scarified and H2 O2 rubbed in. Flap was taken from neck containing platysma and fat and swung upwards to fill space previously occupied by scar.

5-10-18 CONDITION. Loss of bone at right angle of jaw,for about 1½", with considerable elevation of the posterior fragment.

5-10-18 OPERATION by Major Pickerill.Curved incision along the angle of jaw extending as far up as possible.The anterior fragment was readily exposed,but in attempting to expose the posterior fragment,the padded margin of the splint was mistaken for it & cut down upon,thus opening into the mouth.This was at once sewn up with catgut sutures & tincture of iodine applied.The posterior was then exposed.Measurements having been taken,graft was cut from the tibia with circular saw in the motor,graft was then fitted in position,slots were cut in both fragments & the graft secured by means of bone screws,cut at the time from fresh tibial bone.The wound was closed by deep catgut sutures exerting pressure continuous horsehair skin sutures & drained

4-10-18 DENTAL by Capt.Turner. Cemented in D.G.splint for bpne graft with saddle on lower for post.fragment.

20-1-19 R.P.O. Owing to mouth having been opened bone graft suppurated.
OPERATION by Major Pickerill. Area opened up and curetted.

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

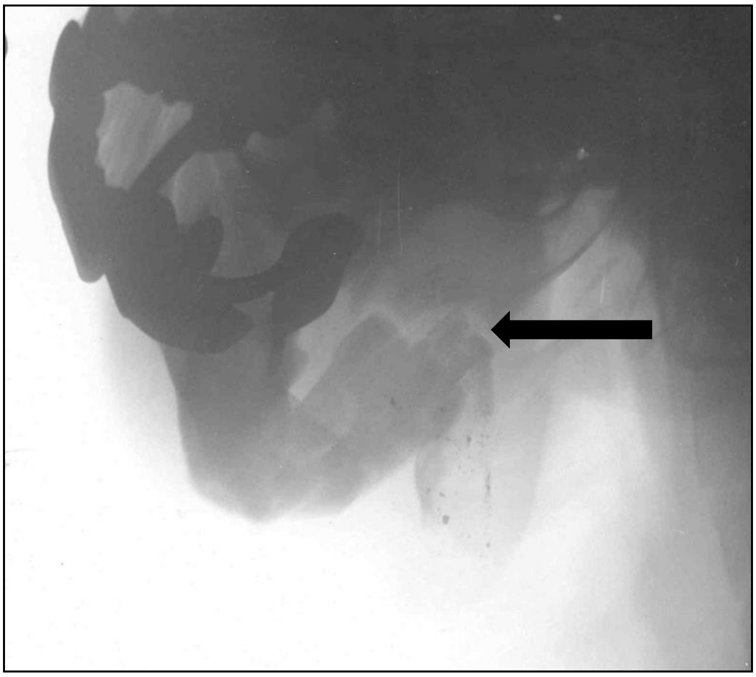
## Bone Screws

The operation note dated 05 October 1918 describes the use of "bone screws" cut from the tibia to secure the graft in the mandible (Figure 3.5b). This may be somewhat confusing to the modern reader as one would imagine some form of metal hardware allowing fixation of the bone graft to the existing mandible, such hardware being clearly absent in the radiographs (Figures 3.5c and d). The line diagrams clarify what Pickerill meant by "bone screws" and when comparing the line drawings with the post-operative radiograph, these bone screws (arrowed) become more apparent as struts of bone which were cut and morticed into the ends of the existing mandible, which was certainly an innovative approach for its time and conveniently avoided the use of direct intraosseous wires (Figure 3.5e). This requires a high level of technical skill in order to cut a preparation into the mandible to fit the struts of bone into. In retrospect, the bone struts may have provided some degree of initial stability but would have been at risk of resorption allowing unwanted movement across the fracture/graft site later on which may have led to the annotation “no bony union as yet” one month later on the radiographs. Unfortunately no further notes are available to follow up on whether this procedure was successful or not but two months after the bone graft procedure signs of infection were present and were attributed to possible contamination from oral organisms when communication of the surgical wound inadvertently was created with the oral cavity as described in the case notes in Figure 3.5b.

**Figure 3.5c** Pre-operative radiograph showing bony defect of the right mandible

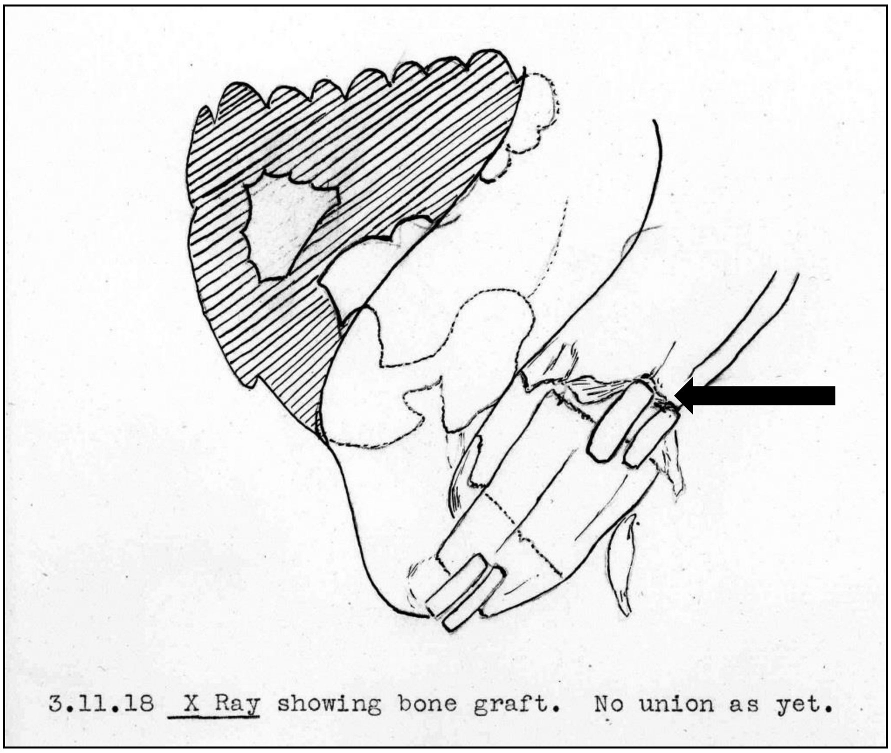
(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 3.5d** Post-operative radiograph showing bone graft in situ. Note the morticed bone struts described in the case notes as "bone screws" (arrowed).



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 3.5e** Line diagram illustrating the "bone screws". Compare this with the radiograph above in figure 3.4d




(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Hydrogen peroxide**

Pickerill's operation note dated 13 March 1918 (Figure 3.5b) described fibrous scar tissue being excised from the bone ends and hydrogen peroxide being rubbed in to help prepare a tissue bed for subsequent bone grafting. Hydrogen peroxide releases water and oxygen when placed on organic tissue and is commonly used as a means of wound decontamination utilising the bubbling effect of oxygen which loosens foreign material (Goodman and Gilman 1975, Beattie et al. 2010) and has a satisfactory spectrum of antimicrobial activity including spores and viruses (Katzung et al. 2009). Hydrogen peroxide and povidine iodide solution has been used successfully in the initial decontamination of GSWs to the face (Motamedi 2011) and is reminiscent of First World War practices. Extreme caution however must applied as oxygen bubbles can be pushed into the blood circulation (oxygen embolism) leading to cardio-respiratory complications including cardiac arrest (Bassan et al. 1982, Haller et al. 2002, Henley et al. 2004, Beattie et al. 2010) or along tissue spaces resulting in massive bubbles being formed in anatomical spaces that prove catastrophic to the patient such as inside the skull (Chhabra et al. 2000, Zimmerman and Lipow 2004). The irrigation of closed spaces with hydrogen peroxide should be avoided and may necessitate a higher degree of caution in maxillofacial surgery due to the potential of pushing bubbles into spaces within the bony facial skeleton (such as the orbit) and intracranially and as such is generally no longer advocated.

**21st Century Management**

A similar injury of a coalition soldier in Afghanistan would be stabilised following Damage Control Surgery (DCS) and Damage Control Resuscitation (DCR) guidelines – namely haemorrhage control, decontamination of the wound, haemodynamic resuscitation and rearward evacuation to a more advanced hospital facility (Beekley 2008, Blackbourne 2008, Breeze and Bryant 2010, Duchesne et al. 2011). The definitive repair, in this situation taken to mean reconstruction with bone grafting with a view to secondary procedures in the future, would be performed at a base hospital facility away from the military theatre of operations, such as the US Air Force Base in Landstuhl, Germany or the United Kingdom, with transportation of the wounded soldier back to such facilities within 36-48 hours depending on tactical situation and weather conditions.

There is some literature suggesting that primary reconstruction with bone grafting at time of initial surgery is advantageous or at least not detrimental to the patient in terms of infection rate and surgical outcome (Gruss et al. 1991, Motamedi 2003, Motamedi 2007). However, in a combat environment where the tactical situation is highly variable and resources may be limited, lengthy operative procedures are often impractical and inappropriate in terms of holding up theatre space for one patient and inadequate use of staff and materials - considerations discussed in the previous section. If a staged approach is considered, a degree of fibrous scar tissue may form while waiting for the tissue to heal prior to definitive surgery, however the tissues will have had time to recover from the initial injury and surgery with the main advantages being less tissue swelling (therefore giving a better idea of tissue availability and anatomical boundaries) and the chance for any infection to be resolved with systemic antibiotic therapy. This is certainly in keeping with what Pickerill noted in 1917 that bone grafting should not be performed until the wound was healthy. Tissue viability and prevention of infection still remain fundamental to a successful outcome.

## Reconstructing continuity defects

Re-establishing mandibular continuity is not only important for facial contour and aesthetics but also allows functional oral rehabilitation to take place, which traditionally was in the form of a removable denture once bony union has taken place. A greater scope of prosthetic rehabilitation of the oral cavity is more readily available with the development of dental implants and implant borne prostheses, the concepts of which may also be applied outside of the mouth in the field of maxillofacial prosthetics and will be discussed in a later section. To date the options for reconstruction of major maxillofacial defects include free transfer bone grafts (taken from the patient or other sources such as a bone bank), microvascular flaps and distraction osteogenesis (Wilk 2004, Torroni 2009). All three options have their advantages and disadvantages and the choice of which technique to use is determined in part by surgeon experience, availability of resources and most importantly what is the desired final outcome that is to be achieved. For example, microvascular flaps have the advantage of blood vessels that can be re-attached giving optimal vascular supply to the graft and is particularly useful for reconstructing both hard and soft tissue defects. The disadvantages however include donor site morbidity, lengthy surgery and limited ability to reproduce complex three dimensional shapes often found in the facial skeleton (Torroni 2009). As Pickerill did not have distraction devices and microvascular flaps at his disposal, further discussion will be limited to free transfer bone grafts (bone taken from a donor site without soft tissue or vascular supply) in order to maintain contextual continuity.

Early attempts at bone grafting in orthopaedic surgery were showing positive results and pioneers in this field such as William Macewan showed the feasibility of such procedures by bone grafting a defect of the humerus due to osteomyelitis (Macewan

1881, Pringle 1924, Elsalanty and Genecov 2009). During the First World War, bone grafting procedures were being performed by Pickerill and his contemporaries for defects in the mandible with the tibia and ribs being common sites for harvesting. Waldron and Risdon (1919) reported on the use of the iliac crest as a superior source of bone due to a greater amount of cancellous bone and a larger surface area covered by osteoblasts. Waldron and Risdon acknowledge that their choice of iliac crest was guided by scientific studies in the biology of bone grafting – perhaps an early example of what is considered today as evidence-based medical practice. Certainly animal studies by Axhausen (1908) described histological changes in the cells and bony architecture including osteoclastic remodelling. Furthermore, Axhausen concluded that the cells in the bone graft must be vital for a period of time and that the recipient site must provide a nutrient supply ("a rich lymph stream") to the bone graft in order for the bone graft to survive.Apart from the tibia, rib and iliac crest, other donor sites for bone include the fibula and when smaller amounts of bone are required, the calvarium and scapula may also be considered (Connole et al. 1977, Wilk 2004, Marx and Stevens 2010). Large block bone grafts may have the potential for osteoinduction and osteoconduction but this only occurs after significant resorption and remodelling takes place (Wilk 2004). Although forming an initial and crucial bridge, the block bone graft poorly integrates with the adjacent bony ends of the defect. Excessive resorption of the graft tends to take place with continuity defects of the mandible larger than six to nine centimetres or when there is poor blood supply in the surrounding tissues (Wells 1996, Pogrel et al. 1997). This was noted as early as the Second World War and the New Zealand plastic surgeon Rainsford Mowlem addressed this issue of poor osteointegration by using cancellous bone chips rather than a solid block of bone, replacing what he described as an "almost non-cellular transplant" with a cellular mass of bone chips which produced good result

in a matter of weeks (Mowlem 1944). The one major advantage of using a block bone graft is the ability to bridge a large defect with a rigid piece of bone and offer a degree of stability across the gap. Tissue engineering has become a very important research topic utilising various materials and techniques including bone morphogenic proteins (BMPs) and other tissue factors such as bone marrow stromal cells (BMSCs) (Groeneveld and Burger 2000, Wilk 2004, Cancedda et al. 2007, Torroni 2009). Experimental work has been done utilising animal models where BMPs carried in a non-bone scaffold have been placed in bony defects resulting in successful bone formation (Bruder et al. 1998, Laurencin et al. 2006, Schieker et al. 2006, Cancedda et al. 2007, Riechert et al. 2009). Similarly human recombinant BMPs and BMSCs with and without autogenous bone grafts, have been used in clinical trials both in orthopaedic and maxillofacial surgery and show early promise of faster bony healing (Herford and Boyne 2008, Schmidmaier et al. 2009, Schuckert et al. 2009, Yasuda et al. 2012).
However, these tissue engineered reconstructive options are far removed from the realities of war surgery but provide exciting possibilities for surgical reconstruction outside of the combat environment.

The following principles may be summarised:

1. No bony union occurs when the gap between bone ends is too wide
2. Bone grafts need to be held as stable as possible for optimal healing
3. Prevention of bone graft infection is crucial to bony healing and union
4. Autogenous bone provides both osteoinduction and osteoconduction but a large block graft poorly integrates with the adjacent bone and tends to resorb

5. Later timing of bony reconstruction of the jaws is anecdotally favoured from a Damage Control Surgery and a wound healing standpoint (see systematic review on this topic)

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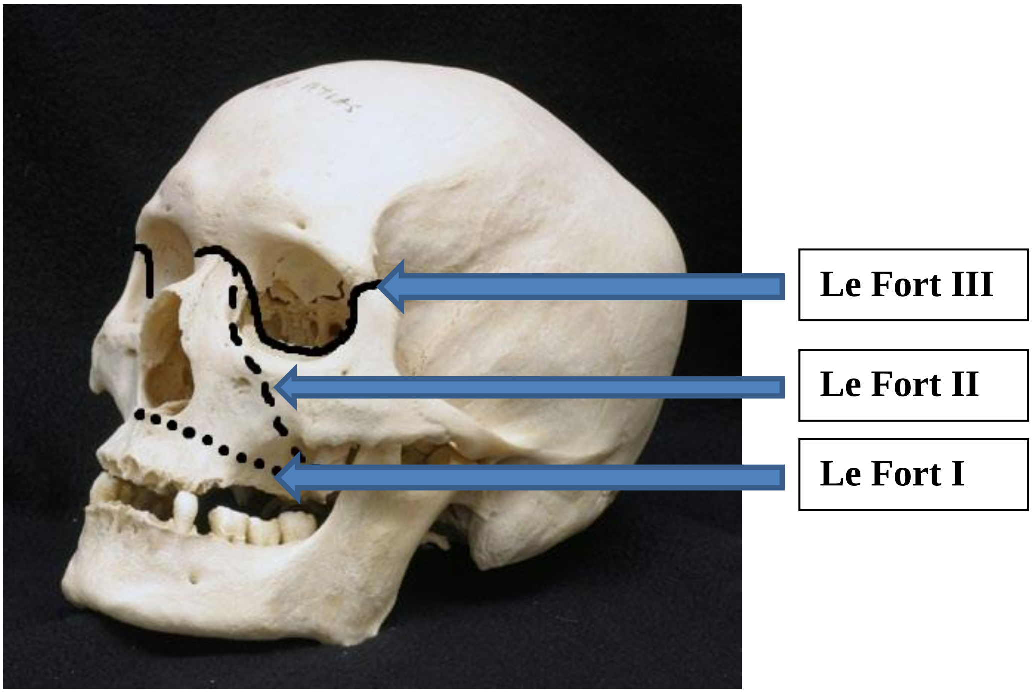
## 3.6 Case Illustration: Mid-face and orbital injuries

### General considerations

The mid-face comprises of the maxilla, the right and left zygoma and the naso-orbito-ethmoid complex – the region between the eyes including the nasal bridge and the ethmoid air cells which lie behind the nasal bones and in between the orbits. Injuries to the orbit itself are generally considered separate from mid-face injuries but may be concurrent with these injuries especially when the zygoma is significantly displaced as the zygoma and the maxilla form the lateral and inferior parts of the orbit (Cook and Rowe 1990). In 1901, the French Surgeon Rene Le Fort published a three part study which categorised patterns of mid-face fracture using cadavers which were subjected to various means of blunt trauma to the face (Le Fort 1901a, b, Tessier 1972a, b). The facial fractures found in the cadavers were documented and revealed three distinct anatomical patterns of fracture as a result of blunt force trauma - maxillary fractures at the level of the nasal floor (Le Fort I); maxillary fractures that extended across the nasal bones forming a triangular fracture pattern (Le Fort II) and fractures that involved the separation of the facial skeleton from the base of the skull (Le Fort III) (Figure 3.6a). These eponymous fracture patterns are still used to describe mid-face injuries today both clinically and radiographically. Isolated maxillary fractures however are uncommon and tend to be in conjunction with other facial injuries such as zygoma fractures or pan-facial injuries (Cunningham and Haug 2004). In comparison, fractures of the zygoma are relatively common injuries and is either the most common (Scherer et al.1989) or the second most common facial fracture site in terms of anatomical location, the other most common anatomical site being the mandible (Haug et al. 1990).

**Figure 3.6a** Skull showing Le Fort fracture patterns levels I to III




(Adapted public domain image)

Unlike the single piece mandible, the mid-face is comprised of a number of bones with complex articulations and relationships with vital structures such as nerves and blood vessels. Significant bleeding may occur from mid-facial injuries which may lead to airway issues and continuous haemorrhage which is not easily controlled with direct pressure or ligation. The limitations facing surgeons during the First World War in managing mid-facial injuries involved the relatively primitive equipment available to manage these patients. Le Fort's cadaver studies would have been available to surgeons for reference but the diagnosis of these fractures would have remained a challenge due to the primitive radiographic imaging at the time (compared to modern computerised tomography with three-dimensional viewing software). Even if midface fractures were adequately visualised, the means to reduce and fix these fractures were very limited due to the reluctance of surgeons to perform open reduction with intraosseous wire fixation for fear of infection. Maxillary fractures would have been managed using similar concepts of cast dental appliances and intermaxillary fixation similar to the treatment of mandibular fractures, perhaps with the addition of extraoral extensions that could be attached to bandages or plaster splints.

Untreated displaced zygoma fractures give rise to a flattened appearance to the affected side of the face with resultant asymmetry due to loss of the malar (zygomatic) eminence. Additionally, if the zygomatic arch is involved, the mandibular opening may also be obstructed due to the coronoid process impinging on the inwardly displaced fractured arch. A dimple may also be seen in the cheek itself when the arch is significantly pushed inwards. Fractures of the orbital floor may result in the eye moving posteriorly (enophthalmos). This is due to an increase of the orbital volume allowing the eye itself to retrude into the expanded orbit and giving the appearance of a "sunken eye" once soft tissue swelling has subsided. Apart from being aesthetically noticeable, enophthalmos may also result in double vision, known as binocular diplopia which is analogous to having a set of binoculars with one lens extended and the other not, the result being that the two eyes are not in synchronous position with each other. Diplopia in one eye only (monocular diplopia) usually indicates intraocular injury and is not able to be treated by fixing the fractured orbit alone.

To summarise the issues faced by Pickerill and his colleagues, imaging of midface injuries was primitive and the actual anatomical reduction of the bony segments was made difficult due to the midface being comprised of several different bones with complex articulations and relationships with each other (as compared to a single bone such as the mandible or femur). Even if anatomical reduction was achieved, fixing the bones in place was not attempted due to the issues surrounding direct wiring techniques.

What was available to surgeons at the time was indirect fixation methods using splints and appliances as the following case study will show.

**Case Study Four**

This case illustration is interesting from a number of aspects, the least being an excellent example of the problems outlined above regarding the challenge of reducing and fixing mid-facial fractures involving multiple bones and articulations. The innovative use of an external traction device combined with an intraoral appliance is of particular significance as the concept of gradually moving separate bony segments into position overtime using a screw-traction appliance has been reincarnated for craniomaxillofacial use today in the guise of distraction osteogenesis devices for the surgical management of congenital craniofacial deformities.

Pickerill described the management of this soldier, aged in his mid to late twenties using orthodontic principles – a truly dental orientated management plan that plastic surgeons would not have had as part of their extensive repertoire of treatment (Pickerill 1918b).

The soldier received a GSW which had perforated through both cheeks with resultant fractures of the maxillary sinuses, nasal bones and both zygomas. The patient was septic and not a candidate for extensive facial reconstruction. His appearance was summarised by *"the whole of the upper face had fallen backwards, the nose was sunken and depressed, the maxilla was too far back by three quarters of an inch, as judged by the hiatus between upper and lower teeth, zygomas had united but were in malposition and bulging outwards; there was also a long scar and an unsightly swelling on the right cheek"* (Pickerill 1918). Figures 3.6b and c give a good indication of the acquired facial deformities, the striking features being the degree of retrusion of the maxilla as seen in the dental casts and the overall flat face appearance of the patient. Even in the reproduced photo (Figure 3.6c), the differences between the eyes can be appreciated with a deeper skin fold superiorly in the upper eyelid of the right eye. In other images the right eye can clearly be seen as sunken in (enophthalmos).

The case notes indicate that the patient was shot in February 1917 but was not admitted to the Queen's Hospital until November 1917, some nine months after the initial injury. By this stage some bony union either complete or fibro-osseous in nature would have taken place making reducing the fractures into normal anatomical position difficult if not almost impossible without surgically opening the fracture sites and disarticulating the bony union between the fractured bones either by removing the fibro-osseous tissue or in some situations performing a bony osteotomy through solid hard tissue.

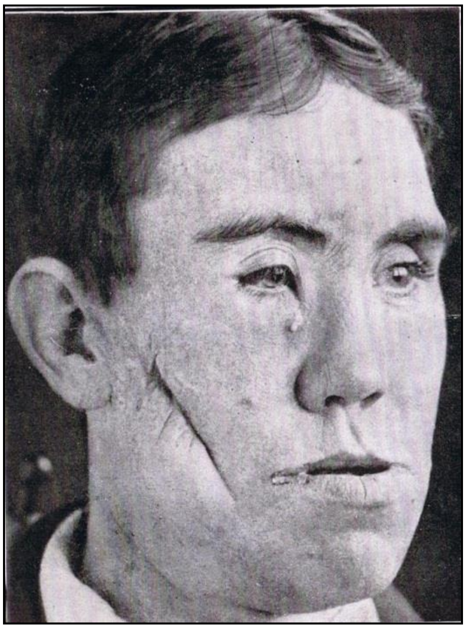
**Figure 3.6b**

Dental casts showing retruded maxilla in malposition relative to the mandible

(By kind permission of the Editor, New Zealand Dental Journal)

**Figure 3.6c**

Photograph showing flattened midface and sunken in appearance of right eye



(By kind permission of the Editor, New Zealand Dental Journal)

The traction device was innovative in design and manufacture and Pickerill pays tribute to the skill and expertise of his dental surgeon colleague Major Rishworth of the NZ Dental Corps. The device consisted of cast splints which were cemented onto the upper and lower dentition. The maxillary splint had a pair of short vertical arms that extend on either side of the nose, while the mandibular splint had two longer arms extending up to a metal plate which rested onto the forehead and secured there by bandages (Figures 3.6d and e). The maxilla was gradually pulled forward by tightening a set of screws which were spring loaded to give slight tension during the distraction of the maxilla. The screws could be replaced over time as the length of the threads became too short and this was accomplished by simply removing the threaded screw by means of a housing into which the head of the screw was slotted (Figure 3.6f). The technical expertise and art cannot be fully appreciated until the appliance is examined close up, a luxury that is possible due to the device (either the actual one or a replica) being archived in the School of Dentistry at the University of Otago.

**Figure 3.6d**

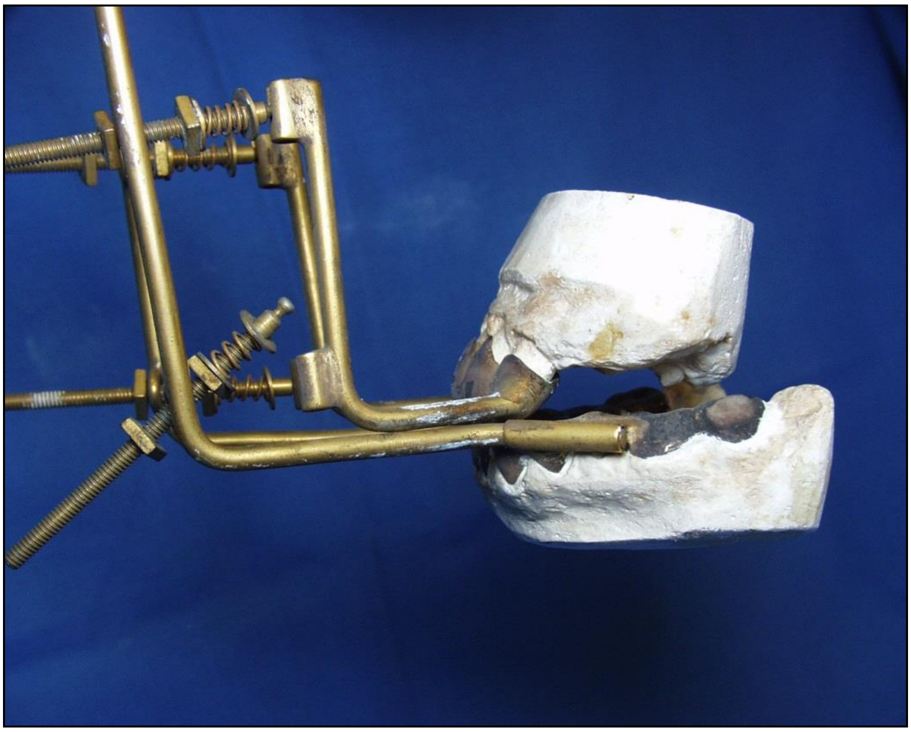
Dental traction device as described by Pickerill for case illustration four. It is unknown if this device was used in the patient or a replica for teaching purposes

**Figure 3.6e**

Dental traction device in situ. The device appears different from Figure 3.6d and may represent an earlier version of the appliance

(Both images courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Figure 3.6f** Photograph showing the spring mechanism and slotted housing for screw component. The craftsmanship involved in making such a device is particularly noteworthy.

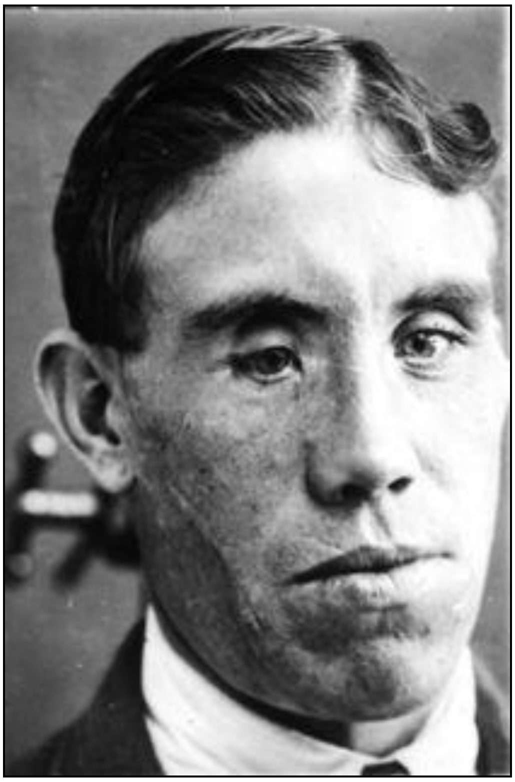


(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

Pickerill performed a number of secondary procedures to improve nasal profile and reduce the projection of the right zygoma over the next seven months but it is unclear when the appliances were totally removed, however by September 1918 the patient was reported as resuming a normal diet and more socially acclimatised. Figure 3.6g shows what possibly could be the final post-operative photograph of the patient and one can appreciate the improvement of the maxillary position and facial scar. However the mid-face appears flat post-treatment and the enophthalmos of the right eye remains obvious as the fractures above the maxilla, namely the zygoma fractures and probable right orbital floor fracture could not be addressed by the traction appliance. No notes are available to evaluate any post-operative diplopia which may be a potential problem given the patient appears to have limited movement of his right eye.

**Figure 3.6g**

Late post-operative photograph (undated) of patient showing improved midface position and scar. The left eye appears to be gazing at the camera whereas the right eye looks in another direction.



(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

This case study is an excellent example of good record keeping with written operation notes, pre- and post-operative photographs and replica models of the patient (Figure 3.6h) and the appliance. Pickerill's surgical plan utilised options available at the time and involved a relatively conservative approach to manage a difficult surgical situation. By gradually distracting the maxilla forward into the correct skeletal and dental relationship and keeping it in place with the use of the dental splint appliances, Gillies' principle of "replacing what is normal in normal position and retain it there" applies not only to soft tissue defects but equally to fractured facial bones according to Gillies' commentary (Gillies and Millard 1957).

**Figure 3.6h**

Captured in stone. The traction device mounted onto a plaster facial cast of the patient

(Courtesy of School of Dentistry Archives, University of Otago, Dunedin)

**Enophthalmos and orbital floor fractures**

The sunken-in appearance and limited movement of the right eye in Figure 3.6g is most likely due to disruption of the orbit associated with trauma to the right side of the face involving the zygoma. Diagnostic imaging is important to assess the severity of the orbital fractures which in most cases may be managed conservatively without an operative procedure (Rosado and Bincente 2012). The diagnostic value of plain films has been questioned due to its two-dimensional limitations and often the superimposition of other structures which limit the diagnostic value of the film. The diagnostic imaging modality of choice is computerised tomography (CT) which allows the surgeon to view the orbit in multiple planes and can be reformatted into a three-dimensional image if required (Ochs 2004, Caranci et al. 2012). Surgical correction is undertaken when orbital fractures are either unstable or displaced with a view to reconstituting normal orbital volume either by reducing the fracture and fixing the bones by means of miniplates and screws, or if a defect is present, reconstructing the orbit with either bone, non-resorbable or resorbable materials which include titanium mesh, dura, teflon, silicone, polygalacatic acid and polydioxanone (Bratton and Durairaj 2011, Gabrielli et al. 2011, Avashia et al. 2012, Gierloff et al. 2012). Unless there is a pre-existing wound, surgical access into the orbit itself is made through skin creases or inside the lower eyelid to maximise cosmetic outcome post-operatively (Ellis and Zide 1995, Ochs 2004, Kothari et al. 2012). The two main complications from orbital floor fractures resulting in a defect in the bone (orbital floor blow out fractures) are enophthalmos and diplopia but the correlation between these complications and the severity of the fracture is not well understood (He et al. 2012), although one retrospective study of 127 patients concluded that enophthalmos of less than 2mm and orbital defects of less than $3cm^2$ may be treated non-surgically (Kunz et al. 2012). Furthermore, there is considerable variation in terms of timing for surgery depending on surgeon experience and differences in approaches by sub-specialty (Alinasab et al. 2012). Early surgical intervention is recommended (within 24 hours) if there is muscle entrapment, neurological involvement or early enophthalmos with the fracture (Alinasab et al. 2012, Hwang et al. 2012). The main issue with late enophthalmos is one of cosmetic appearance, although diplopia may also arise due to binocular vision becoming unsynchronised which appears to be more of an issue in older individuals perhaps due to decreased adaptive abilities (Hwang et al. 2012). Predicting late enophthalmos is difficult and there is no consensus among surgeons in terms of diagnostic indicators and timing of surgery, however one study of 119 patients reported that multiple wall fractures of the orbit, particularly those involving the medial wall and floor of the orbit, have a higher incidence of enophthalmos (He et al. 2012) and another study of 23 patients reported orbital fractures behind the equator of the eyeball with herniation of soft tissues correlated well with late enophthalmos according to review of CT-scan images (Zhang et al. 2012).

Pickerill therefore would not have had the diagnostic tools to predict the degree or even likelihood of enophthalmos from occurring and once established did not have the means to reconstruct the orbital volume. By re-establishing the projection of zygoma, the lateral aspect of the orbit would have been brought back into anatomical alignment but the problem of increased orbital volume due to loss of bone could not have been addressed. Pickerill's patient in Figure 3.6g shows an acceptable cosmetic result compared to Figure 3.6c and one can only speculate the results that could have been achieved with this patient had he presented with his injuries today not only from a cosmetic standpoint but also a functional standpoint with his eye movements.

The following principles may be summarised:

1. Accurate diagnosis results from the cumulative information gained from a detailed history, thorough physical examination and appropriate imaging
2. External appliances like the one illustrated, may aid in reducing zygomatic and lateral orbital wall fractures but not orbital floor defects
3. Computerised tomography is considered the imaging modality of choice and yields greater diagnostic information regarding orbital fractures in terms of extent and severity compared to plain films
4. Late enophthalmos is difficult to predict and is managed by surgically correcting the orbital volume

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## 3.7 Case Illustration: Maxillofacial Prostheses

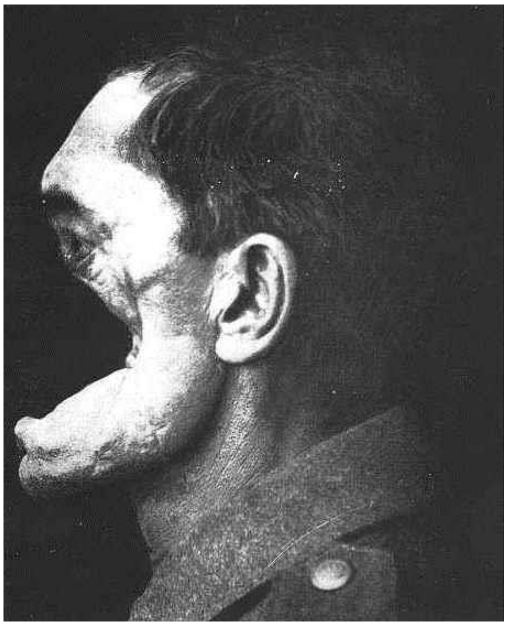
### General considerations

Staged surgery is not uncommon in trauma especially when the injuries are severe and healing time is required between surgical procedures. Tissue loss requiring grafting procedures, both hard and soft tissues including skin grafts, is often surgically managed by a series of operations with each procedure laying the foundation for the next procedure. This was certainly not an uncommon occurrence for Pickerill and his contemporaries and there are anecdotes of patients undergoing twenty or more operations for facial reconstruction. All successful medical relationships between patient and doctor are built on trust. No better example illustrates this simple but vital ingredient than the burnt airmen treated by Sir Archibald McIndoe during the Second World War – members of the exclusive Guinea Pig Club. Criteria for membership included being admitted to East Grinstead for surgery and having been operated on by McIndoe himself (Mosley 1962, Mayhew 2004). There comes a time, however when the patient themselves may decide that they have had enough. This may be an unwillingness to face more surgery or being comfortable with what has already been done and tolerant of whatever residual facial deformity is present. There are other times when the patient is physically or psychologically too frail or unwell to have more surgery, future plans being suspended sometimes indefinitely. Then there are situations where the injury is beyond the technical abilities or resources available at the time, as illustrated in Figure 3.7a. Rather than embarking on a series of surgical procedures that may or may not hold any significant advantage for the patient other options need to be considered, the most conservative being not to provide any more surgery but to hide the deformity by prosthetic means.

**Figure 3.7a**

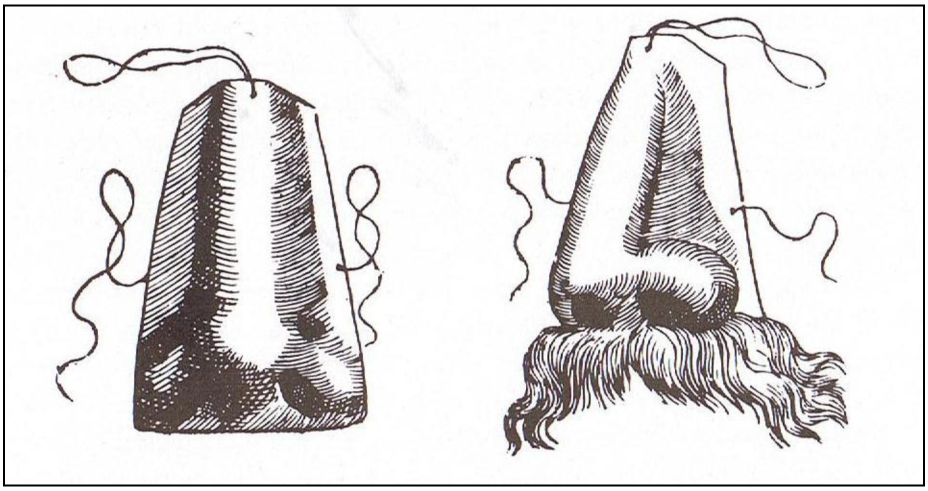
Astonishing profile photograph of a casualty from the First World War showing the loss of the entire midface including nose and maxilla. Reconstruction by surgical means alone would have been impossible during that time period.

(By kind permission of Dr Andrew Bamji, Curator, Gillies Archives,Queen Mary's Hospital, Sidcup, UK)



Facial prostheses are not new innovations although the current available range of materials offer patients a greater degree of comfort, for example softer materials against skin or mucosa and potentially provides the prosthodontist and technician more choice in the materials used in order to provide an aesthetic end result. Dental prostheses have been found dating back to the 4$^{th}$ and 5$^{th}$ centuries BC (Ring 1985) and further refinements and developments of such prostheses have been described thereafter, a particularly detailed account being part of Ambrose Paré's *Ten Books of Surgery* in which Paré discusses methods of tooth extraction and rehabilitation with intraoral prosthetic devices. Paré did not limit his discourse on prosthetic appliances to the oral cavity as there are illustrations of prosthetic limbs and noses, one nasal prosthesis providing the wearer with a realistic moustache (Figure 3.7b).

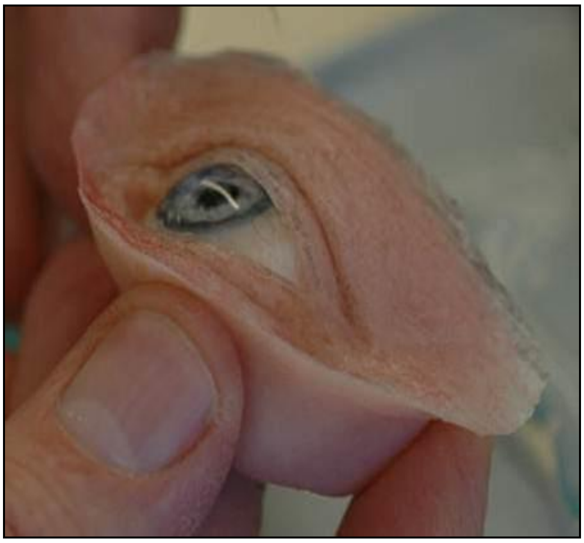
**Figure 3.7b** Illustrations of nasal prostheses from Ambrose Paré's Ten Books of Surgery



(adapted from Lyons AS, Petrucelli RJ (1987). Medicine – An Illustrated History. New York, Harry N. Abrams Inc., p387)

The limitations are immediately apparent namely the method of attaching the prostheses onto the face whereas intraoral prostheses have the advantage of other teeth and the musculature of the oral cavity, lips and cheeks to help hold devices in situ. Apart from tying the facial prosthesis in position, other means include incorporating the prosthetic device into the framework of glasses or fitting the device into a defect with an obturator. Furthermore, the prosthetic materials available at the time would have been very limited and compromises would have been made to fulfil patient comfort, aesthetic appearance and anatomical fit – aspects of prosthetic rehabilitation that remain extant today. During the First World War, painted or enamelled tin masks were used and given to patients either as interim appliances to be more "socially acceptable" between surgeries or as the final prosthesis. Some prostheses were very crude in design and appearance but some were works of art in their own right, testimony to the skill and talent of the people who made them, some of whom were dental mechanics (dental technicians) and others like Francis Wood and Anna Ladd were from a fine arts background, both Wood and Ladd being sculptors and artists who were able to translate their talents into medical benefit (Feo 2007). Just like surgery was individualised to the patient, prosthetic masks were also custom made and with the help of premorbid photographs, some resemblance of facial features could be recreated in the mask. The technique for manufacturing the masks was relatively simple in that a plaster cast was made of the face and its defects, on which a the missing anatomy was sculpted in a rubber like compound called gutta percha (more commonly known now as a root canal filling material for endodontic treatment in dentistry). The finished gutta percha sculpture was the electroplated in a copper bath and painted to match the surrounding skin tones (Feo 2007). The blending of artistic instinct and the manual dexterity of sculpting and hand painting of the prostheses, so skilfully manifested in people like Wood and Ladd, made these prostheses that much more acceptable to look at, but not necessarily to wear. Some of the masks were attached to spectacle frames, some had attachments to upper dentures through a facial defect and some, like those of Paré's era, would have simply been tied on. Modern maxillofacial prostheses are typically silicone based and are secured to the face by a number of means. These include the use of adhesives, obturators made of soft silicone materials which literally plug into the defect or attached to titanium implants placed into the maxillofacial skeleton. The difference between materials is evident in the more natural appearance of modern maxillofacial prostheses and importantly, the physical comfort of wearing them from a patient point of view. Figures 3.7c and d show examples of orbital prostheses from two different eras. The difference in realistic appearance between the two prostheses is apparent.

**Figure 3.7c and d** Comparison between orbital prostheses dating from the First World War (left) and a modern construction (right) which is far more realistic in appearance.

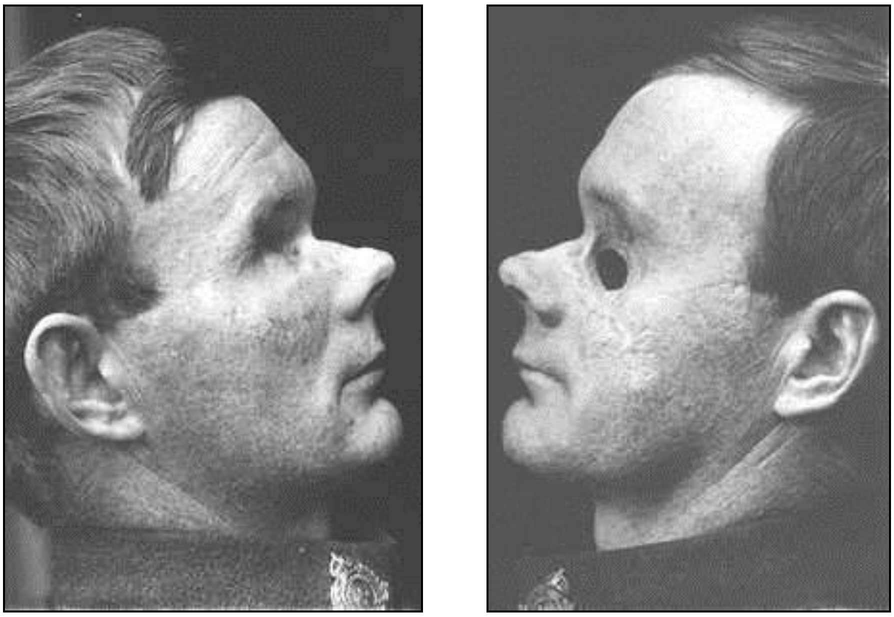


(Fig 3.7c by kind permission of Dr Andrew Bamji, Curator, Gillies Archives, Queen Mary's Hospital, Sidcup, UK)
(Fig 3.7d by kind permission of Dr J Neil Waddell, Senior Lecturer, University of Otago, Dunedin, NZ)

**Case Study Five**

The final case study is one of Corporal GS who from the clinical photographs sustained a high velocity injury which resulted in the loss of both eyes and at least the nasal bones forming the nasal bridge area. The anterior cartilage of the nose and nasal tip have been preserved as was the frontal bone (Figures 3.7e and f). There is a defect on the left lateral nose in the area of the medial infraorbital margin near the naso-maxillary junction (Figure 3.7f). Unfortunately the case notes could not be located either in the Hocken Library, School of Dentistry Archives or the Gillies Archive at Sidcup and no further comment can be made in regards to extent of injury and operative procedures performed for Cpl GS, although it appears that a skin graft procedure has been performed to close over the empty orbits. It is unknown whether further surgery was planned to close the residual left facial defect seen in figure 3.7f or whether this was left open for a prosthetic device to be anchored into it.

**Figures 3.7e and f** Clinical photographs showing injuries described in case study 5



(Both images by kind permission of Dr Andrew Bamji, Curator, Gillies Archives,Queen Mary's Hospital, Sidcup, UK)

Figure 3.7g shows the soldier from a frontal position wearing a prosthesis that was incorporated into a pair of wire frame spectacles. Even in this black and white photograph it is evident that the shading of the skin tone is slightly darker in the prosthesis and the margins remain distinct (although black and white photography does bring out more contrast and perhaps the margins were less noticeable in real life). Figure 3.7h shows a current example of a similar prosthetic appliance which replaces the region of the left orbit and nose.

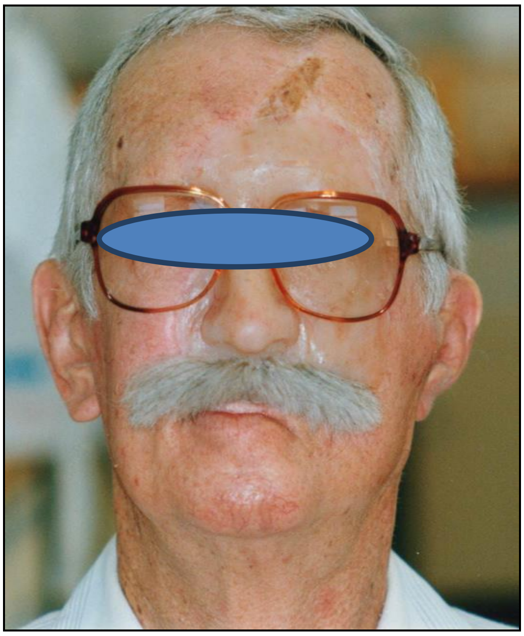
**Figure 3.7g**

Frontal Photograph showing facial prosthesis in situ

(By kind permission of Dr Andrew Bamji, Curator, Gillies Archives, Queen Mary's Hospital, Sidcup, UK)

**Figure 3.7h**

Photograph of similar facial prosthesis using spectacle frames.



(By kind permission of Mr J Neil Waddell, Senior Lecturer, University of Otago, Dunedin, New Zealand)

**Psychosocial aspects**

The provision of a facial prosthesis to hide what has been lost seems a very clever method of achieving a socially acceptable result for patients with facial defects, either from trauma or following tumour removal. But no matter how skilful the technician or artist, the stark fact remains that the appliance merely hides something that is unsightly or is missing and as Sandy Callister writes in her study of photographs of wounded New Zealand soldiers from the First World War, as the camera shutter closes at that moment of time "*one which records faithfully, one of our primal terrors. To lose one's face is, in part, to lose one's identity*" (Callister 2007). The prosthesis may also serve as a constant reminder of the injury or defect, not only for the patients but also for those who look at them, particularly difficult in some instances for families and loved ones, who at first glance may see what is familiar, only to realise the truly superficial nature of the aesthetic appearance. The sheer futility of war may be summarised by saying that in concealing the disfigurement, the prostheses themselves serve as reminders of the destructive cost of conflict (Feo 2007).

Figures 3.7i and 3.7j show two wounded French soldiers from the First World War. In Figure 3.7i the two soldiers are shown playing cards. The soldier on the left is clearly wearing a sculpted mask that appears to hook around the ears similar to spectacles whereas his compatriot is wearing a prosthesis that incorporates a full pair of spectacle frames. Figure 3.7 j shows the soldier on the left in figure 3.7i, nonchalantly smoking a cigarette, with and without his prosthesis. With his mask removed there is instinctive shock by the disfigurement that was hidden. There is no way of knowing whether the mask is a stylised sculpture of a lower face (one suspects that this is the case) or whether it is a realistic representation of the patient's actual features prior to his disfigurement. These haunting reminders captured on film bring home the terrible costs of war injuries that affect not only the patients themselves, but also their families and communities.

**Figure 3.7i** French soldiers wearing facial prostheses

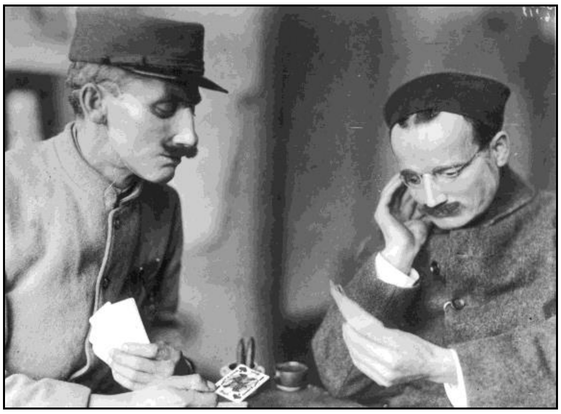


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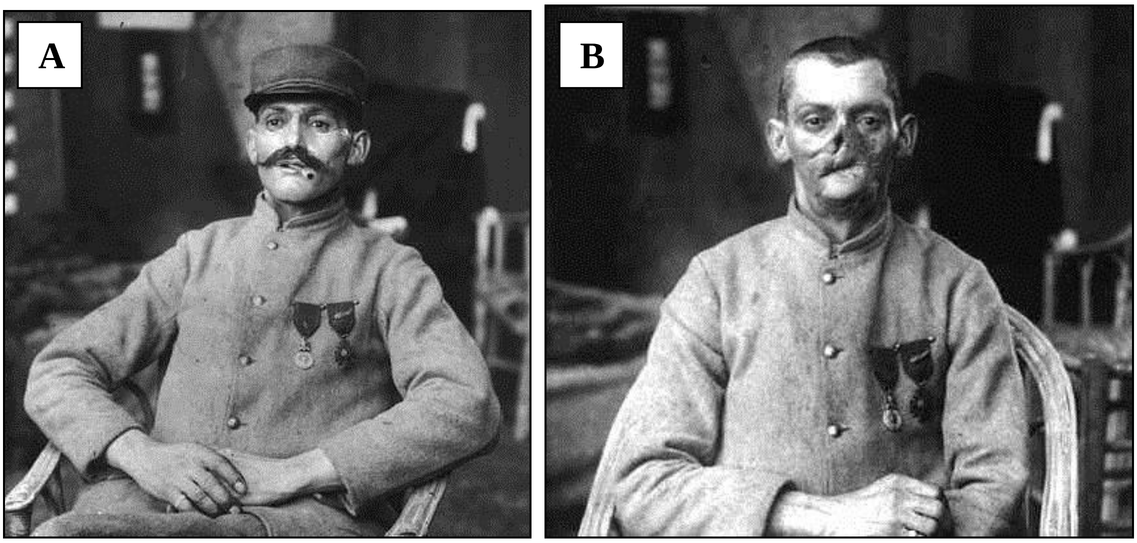
**Figure 3.7j** Photographs showing the soldier on the left in Figure 3.7i wearing his facial prosthesis (A) and with it removed (B)

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The two most common psychological disorders associated with significant facial trauma are depression and anxiety with a significant proportion of patients reporting indicators of post-traumatic stress disorder four to six weeks post injury (Hull et al. 2003, Islam et al. 2010, Islam et al. 2012a, b). A previous history of psychological illness, permanent facial scarring and fear of the unknown appear to be significant factors in psychological poor outcome following facial trauma (Hull et al. 2003, Islam et al. 2012). One study of 102 patients reported that a higher prevalence of anxiety and depression were found among those who blamed others for their facial injuries and tended to be young men who have been involved with intentional trauma (Islam et al 2012a). Although this study was civilian-based, the characteristics of young men exposed to intentional trauma fits well with combat soldiers and this may be an area of future research. The need for surgeons to be aware of these psychological aspects has been highlighted with a multidisciplinary approach recommended to meet different psychosocial aspects at different times during facial reconstruction (Bradbury 2011, Pitak-Arnop et al. 2011).

The holistic approach to surgery practiced by McIndoe in particular but also a feature of Gillies' management of patients during the First World War, may have been due to the recognition of the importance of the face in psychosocial wellbeing and rehabilitation. McIndoe wrote that his patients were once strong, healthy young men and were totally unprepared for the physical and psychological effects of their injuries (Mosley 1962). Most of McIndoe's patients were ambulatory – the horrific burns to faces and hands did not limit the ability to walk about as there were no major orthopaedic injuries or internal damage. As such, these young men were described as having a zero threshold for boredom and integrating them into society was vital to their rehabilitation (Mayhew 2004). McIndoe could not have been as successful if he was not supported by the townsfolk who visited the hospital and even opened their homes to "McIndoe's boys" as alternate accommodation for convalescence outside of the hospital. East Grinstead may have become the "town that never stared" but the capacity for people to be unkind remains bewildering. In a moving personal account of facial disfigurement following a dog-bite at the age of five, Krysia Saul recounts people's cruel reactions to her facial disfigurement which included comments of her not being allowed in public or being put down at birth (Saul and Thistlethwaite 2011). Living with her disfigurement as she grew up, Saul has accepted her appearance stating "*Although disfigured, I am not ill and I do not regard myself as a patient* …" and rather pointedly highlights how insensitive the comment "what an interesting scar" really is when offered by healthcare professionals (Saul and Thistlethwaite 2011). McIndoe would have been most displeased with this attitude.

The capacity to accept permanent disfigurement, no matter how minor, appears to be a key factor towards psychosocial wellbeing and rehabilitation which for some is an inward looking journey and for others an outward experience involving friends and family or others who have shared similar experiences. Interestingly, a review of the literature found that the severity of disfigurement was a poor predictor of psychological distress (Thompson and Kent 2001). Another study proposed that when forced to deal with people's reactions, patients with visible burn scars learn to adapt to their reality compared to those patients whose scars remain hidden (Cahners 1992). The human psyche is already a difficult area to analyse without the additional variables of illness and injury.

The following principles may be summarised:

1. Facial reconstructive surgery may involve a series of procedures that may take place over a long period of time
2. Maxillofacial prostheses should be considered in management options especially in situations where surgery alone may not produce the desired outcome
3. Anxiety and depression are common psychological sequelae for facial trauma patients and must be recognised by health care professionals
4. Psychological wellbeing and rehabilitation following facial trauma should be managed by a multidisciplinary team approach

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## 3.8 Lessons Learned: - Principles for the modern military surgeon

The surgical principles outlined in *The Principles and Art of Plastic Surgery* (Gillies and Millard 1957) was a distillation of clinical experiences that evolved over forty years. The Second World War also provided clinical material in abundance but by then plastic surgery had become a specialty in its own right and Gillies had others to help promote plastic surgery, most notably Archibald McIndoe and his work with burns victims. Today's readers may find some of Gillies' principles quaint and a little dated. Most of his principles however continue to be taught to surgical trainees simply because they still make sense and provide sound clinical foundations in managing face and jaw injuries.

General principles such as detailed observation and examination of the patient; establishing a diagnosis; having a surgical plan with back-up options and making records of treatment appear straight forward in concept but often difficult to master. One would hope that a consultant-level surgeon would have a firm grasp of these principles as part of their routine practice. The more technical of Gillies' principles need to be adapted for current military medicine to include the advances in technology and medical understanding but at the same time adhering to the basics. Summarising the principles highlighted from Pickerill's case studies and discussion of management, an adaptation of Gillies' original set of surgical principles is as follows (Table 3.8):

**Table 3.8 Adaptation of Gillies' original surgical principles**

| Gillies' Original Set of Principles | Modern adaptation or commentary |
|---|---|
| 1. *Observation is the basis of surgical diagnosis*<br>2. *Diagnose before you treat* | • A detailed history, thorough physical examination and special tests including blood tests and imaging result in accurate diagnosis |
| 3. *Make a plan and a pattern for this plan*<br>4. *Make a record* | • Make a logical management plan and document treatment and progress using operative notes, photographs and diagnostic imaging. |
| 5. *The lifeboat* | • Always have a plan B, C and D. Especially in a tactical environment; flexibility and adaptability are necessary tools for a military surgeon. |
| 6. *A good style will get you through* | • Technical dexterity aside, basic principles such as wound toilet and appropriate surgical debridement and gentle tissue handling are fundamental. Adjunctive systemic antibiotics and patient resuscitation prior to surgery also contribute to a successful outcome. |
| 7. *Replace what is normal in normal position and retain it there*<br>8. *Treat the primary defect first*<br>9. *Losses must be replaced in kind* | • Be meticulous in tissue handling.<br>• Surgically repair tissue according to normal anatomy and function.<br>• Management of bony fractures include anatomical reduction, rigid internal fixation, immobilisation and early rehabilitation.<br>• Ensure good vascular supply and prevent wound infection to maximise wound healing and minimise scarring.<br>• Definitive reconstructive procedures requiring bone grafts or soft tissue flaps should be considered at a later stage and performed outside of the combat environment |

| | |
|---|---|
| 10. *Do something positive* | • Be decisive in surgery. In a tactical environment, operating time in theatre cannot be taken for granted. |
| 11. *Never throw anything away* | • Alloplastic or synthetic materials may have diminished the need to save every bit of tissue but due consideration must be made in not being overly aggressive with debridement and excision. |
| 12. *Never let routine methods become your master* | • As in Gillies' time, every patient is an individual and should be treated accordingly |
| 13. *Consult other specialists* | • A multidisciplinary team approach is crucial to cover all aspects of physical, psychosocial and spiritual wellbeing for the individual and members of their support group |
| 14. *Speed in surgery consists of not doing the same thing twice* | • Speed in surgery is not due to rushing through the procedure but rather methodical efficiency and planning |
| 15. *The after care is as important as the planning* | • This applies to wound care, vigilant follow up and review and rehabilitation both physically and psychosocially |
| 16. *Never do today what can honourably be put off till tomorrow* | • Damage Control Surgery and Resuscitation applies here<br>• Allow time for tissue swelling and decontamination to occur before further surgery.<br>• Allow time for any infections to resolve with systemic antibiotics<br>• Consider timely medical evacuation for definitive surgery if appropriate |

**Reference**

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# CHAPTER FOUR

# EVIDENCE-BASED SYSTEMATIC REVIEWS

## 4.1 Evidence-Based Systematic Reviews

This chapter consists of three evidence-based systematic reviews that cover selected topics pertinent to current military operations. In chapter two, the history and development of war surgery of the face and jaws was discussed and from the watershed years of the First and Second World Wars, particularly the First World War, a set of surgical principles evolved and since then have been applied, modified and tested again in the years that followed in various fields of conflict.

Chapter three used case illustrations from Pickerill's First World War surgery during his time at Sidcup and matched them with contemporary patients from the current conflict in Afghanistan. Each case illustration draws attention to specific principles outlined by Gillies and showed that these principles are still as pertinent and fresh today as it was almost a century ago.

Despite these techniques and principles having been adopted and applied by generations of face and jaw surgeons since the First World War, this success nonetheless remains anecdotal and subjective in nature despite having the not-so-insignificant validation of time and clinical practice. The current trend in medicine and dentistry today is to practise according to evidence-based guidelines formulated from objective scientific research and reviews. The so-called "gold standard" of evidence-based health research is the double blind, randomised control trial (RCT), which is appropriate for some areas of health research but inappropriate in others. Proponents of this type of research maintain that RCTs are the only valid method of conducting health research but at least one set of authors have taken it upon themselves to point out that this is not always the case. A paper published in the *British Medical Journal* by Smith and Pell (2003) described the phenomenon that parachutes, when used correctly, saves lives when jumping out of airplanes. However, as no RCTs had been performed, the authors claimed that no evidence exists to prove that parachutes do indeed save lives when jumping out of airplanes. The paper of course pokes fun at individuals who the authors have labelled "radical protagonists of evidence-based medicine" and invited them to conduct a RCT to trial the parachute with half of them having functional parachutes and the other half not thereby doing  the rest of us a favour. Written in a deadpan scientific fashion, the bone-dry wit of the authors serves to highlight the problem that exists for observational type studies to be accepted in validating certain interventions or practises in medicine. Another pertinent example is testing the effectiveness of combat body armour – it would be nonsense to provide only half the study population with body armour in order to validate its effectiveness in a combat environment. Therefore non-RCT systematic reviews and meta-analyses have an important place in evidence-based medical research especially in situations where randomised controlled trials put test groups at risk. . Although this chapter cannot systematically review each of Gillies' principles in turn it attempts to cover a broader topic or concept and provides a framework in which Gillies' principles can still be applied.

The first systematic review discusses the role of combat body armour (CBA) and injuries to the head, face and neck (HFN), highlighting the need for military surgeons to have more training in this complex area due to the proportional increase in HFN injuries seen in Iraq and Afghanistan, second only to extremity injuries. This increased incidence in HFN injuries reflects the effectiveness of modern CBA and the nature of modern conflict in Iraq and Afghanistan where the primary cause of injury is due to explosive blast fragments and not gunshot wounds.

This sets the scene for the next systematic review, where having increased the awareness for military surgeons to know more about HFN injuries what is the initial management of jaw injuries as they present to the field hospital? The second systematic review discusses whether or not wire intermaxillary fixation remains the best method for the initial stabilisation of jaw fractures. Although the practice of wiring jaws together for fracture management has been described since just after the First World War, the technique of wire intermaxillary fixation is not without its drawbacks and a critical appraisal is needed for potential alternatives if appropriate. The third systematic review is aimed at consultant specialist level and discusses the role of damage control surgery (DCS) in HFN injuries. The concept of DCS is straightforward: identify bleeding; arrest bleeding, wound toilet, resuscitation and evacuation of the patient to a higher-level facility for definitive surgery. Pertinent, especially for abdominal or extremity injuries where delayed surgery allows swelling and possible infection to subside, is this necessary for the HFN region given its excellent blood supply and healing potential? The last section of this chapter gives an overview that focuses on strategic level planning. Having discussed the need for a greater awareness of HFN injuries in a battlefield environment, the most appropriate form of initial stabilisation of jaw injuries and then the need for DCS rather than primary reconstruction, what should the ideal composition be for a military surgical team? Should military planners include maxillofacial surgeons as a primary member of the surgical team displacing another surgical specialty given the changing pattern of injuries in combat?

Therefore, this chapter gives a stepwise progression from generalist to specialist to strategic level thinking in terms of war surgery involving the face and jaws and to complete the circle, provides a modern day context in which the historical developments in war surgery and Gillies' surgical principles can be appreciated.

## Reference

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## 4.2 Combat Body Armour and injuries to the Head, Face and Neck region

### Introduction and Literature Review

Maxillofacial injuries are common both in civilian and military trauma settings. The importance of having specialized surgeons dealing with the head, face and neck (HFN) was fully illustrated during the First World War by pioneering plastic and maxillofacial surgeons such as Gillies, Kelsey-Fry, Pickerill, Ivy and Kanzanjian who laid the foundations for surgical principles still used today. Dobson et al. (1989) found that 16% of all wounds sustained in war from 1914-1986 involved the maxillofacial region. In their review of war time injuries, they noted that head and neck injuries were more common in terrorist attacks than in conventional warfare. Recent literature from contemporary theaters of conflict in Iraq and Afghanistan has noted an increase in maxillofacial injuries ranging from 26 to 36% (Owens et al. 2008; Belmont et al. 2010; Lew et al. 2010; Petersen et al. 2011). This increase may be due to better soldier survivability with modern combat body armor (CBA) and the nature of asymmetric warfare - when a weaker force employs a way of fighting that neutralises the numerical or technological superiority of another force (Goulding 2000). In Iraq and Afghanistan this includes the use of improvised explosive devices and fighting in built up urban areas rather than confronting coalition forces in a conventional armed engagement. The majority of the literature reporting maxillofacial war injuries is descriptive and often retrospective analyses of patient data during a defined period of time in a specific area of conflict. Most of these studies describe or comment on an increase in maxillofacial combat injuries but provide no evidence supporting this change in injury pattern. As CBA is in routine use it is important to answer the question of whether the wearing of CBA influences the incidence of maxillofacial injuries among combat soldiers in theaters of modern conflict. The aim of this review is to systematically summarize the literature reporting on maxillofacial injuries sustained by combat personnel wearing CBA and to highlight recommendations for increased protection to the facial region.

## Methods

### *Search strategy*

A literature search was performed using web-based on-line databases (PubMed, ISI Web of Science, Medscape and Google Scholar), the Cochrane Library and hand-searches of major journals, reference texts and published abstracts. For web-based on-line searches the following key words were used to identify relevant publications: combat body armor OR armour, maxillofacial war injuries and head, face, neck (HFN) war injuries. The searches were confined to English language literature. The abstract of each article was reviewed and the relevant articles retrieved or copied in full for further evaluation including a further literature search utilizing the reference list from the publications themselves.

The key question to be answered was: *do military personnel who wear CBA have a greater incidence of HFN injuries than others not wearing CBA*?

### *Article evaluation*

Articles identified by on-line and hand searches were evaluated using a set of inclusion and exclusion criteria. Articles fulfilling all inclusion criteria were accepted for review. The criteria for including studies were:

1. Literature reporting on military or combat related HFN (including maxillofacial) injuries
2. Literature reporting the use of modern CBA in relation to maxillofacial injuries

3. Literature limited to military conflicts in Iraq, Afghanistan and Israel from 2001 to 2011

*Study Design*

In terms of study design, the articles sought were prospective or retrospective cohort studies, case controlled studies and review articles. The identification of randomized controlled trials (RCTs) would be ideal but unrealistic given the unethical nature of randomizing combatants to groups not given CBA for protection. Some studies outside of the areas of conflict and the time period studied were considered for reference. Editorials, case reports and opinion pieces were not accepted for review.

*Critical appraisal of the articles*

Studies that did not fulfil the simple inclusion criteria were excluded however further reasons for not accepting publications for final analysis included studies limited to technical or procedural aspects of surgery where the data was ambiguous and where there was no clear distinction between civilian and military maxillofacial trauma. Furthermore, publications limited to neurosurgery, ocular trauma or otologic injuries that did not form part of the overall HFN data were also excluded. Some publications used the same patient population or combined data from previous studies and difficulties arose as to which publications to accept for review. In those situations, the studies that clearly reported a defined time period that did not overlap with other studies and only those with the most recent outcomes were included for review.

*Statistical analysis*

Statistical analysis could not be performed because of the heterogeneity of the data reported including different reporting methods, data entry criteria and the lack of raw data that was required to maintain operational security.

## Results

*Study inclusion and exclusion*

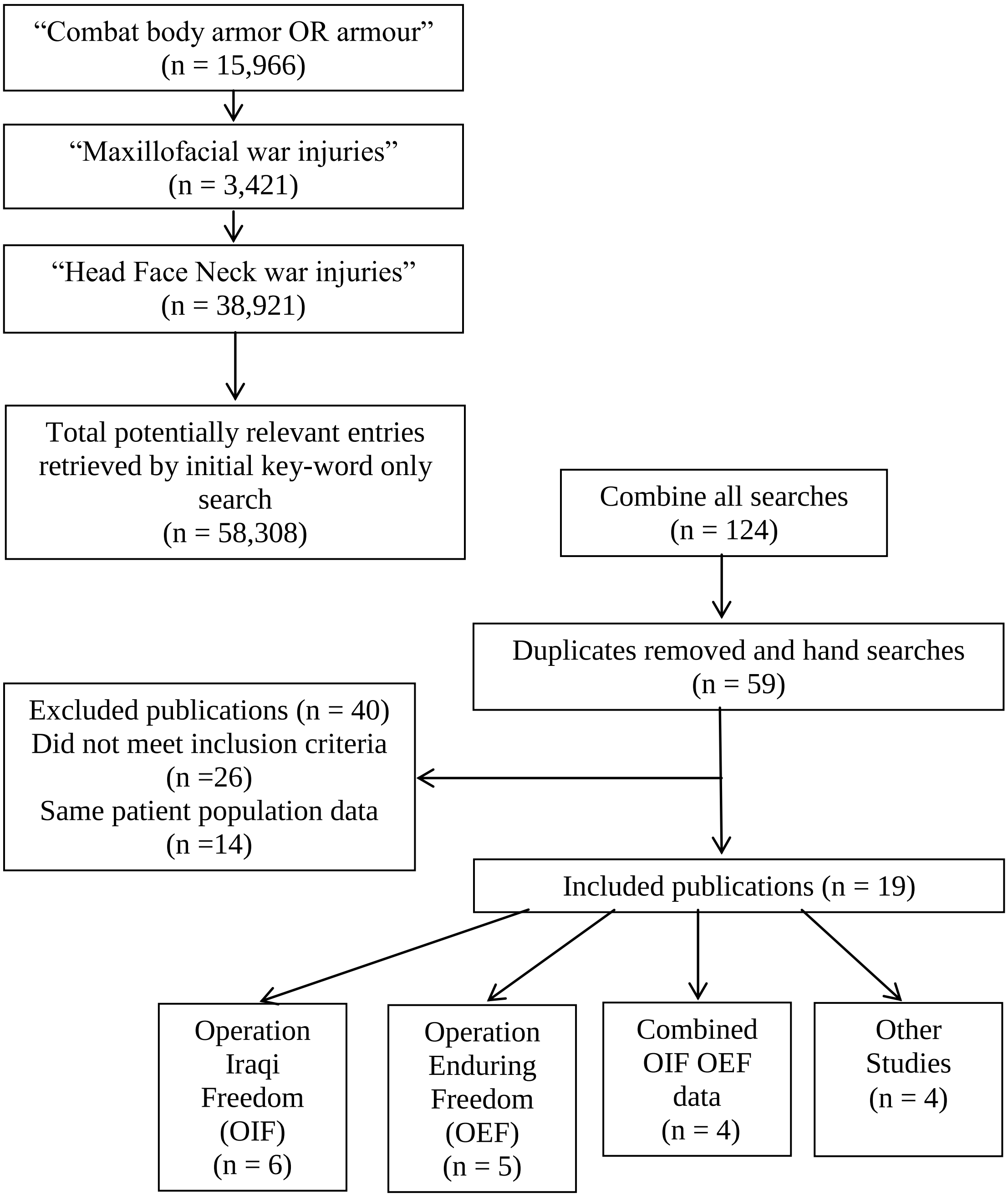
Figure 4.2 summarises the search strategy used to make the final selection of publications for review. The use of “armor” versus “armour” was taken into account due to the differences in spelling used in US literature compared to literature from the United Kingdom and British Commonwealth.

Using PubMed, “combat body armor OR armour” yielded 1,272 results; “maxillofacial war injuries” yielded 157 results and “Head Face Neck war injuries” yielded 23 results. A combined search using all the terms yielded 34 results.

Using ISI Web of Science, “combat body armor OR armour” yielded 10,462 results; “maxillofacial war injuries” yielded 157 results; “Head Face Neck war injuries” yielded 26 results and the combined search yielded 60 results.

Using Medscape, “combat body armor OR armour” yielded 32 results; “maxillofacial war injuries” yielded 127 results and “Head Face Neck war injuries” yielded 672 results. The combined search yielded two results.

**Figure 4.2. Search strategy flowchart summary**



Using Google Scholar, “combat body armor OR armour” yielded 4,200 results; “maxillofacial war injuries” yielded 2,980 results and “Head Face Neck war injuries” yielded 38,200 results. A combined search using all these terms yielded 28 results.

After the removal of duplicate search results and using a manual search, a total of 59 articles were included for initial review. Subsequent evaluation of these articles however removed a further 40 articles that did not meet the inclusion criteria or reported duplicate patient population data. This gave a final total of 19 articles that met all inclusion criteria for this review (Place et al. 2003, Beekley and Watts 2004, Patel et al. 2004, Koshashvili et al. 2005, Lakstein and Blumenfield 2005, Xydakis et al. 2005, Brennan 2006, Peleg et al. 2006, Wade et al. 2007, Levin et al. 2008, Breeze et al. 2010a, Gibbons and Mackenzie 2010, Powers 2010, Belmont et al. 2010, Lew et al. 2010, Breeze et al. 2011a, Breeze et al. 2011b, Breeze et al. 2001c, Salinas et al. 2011).

*Study characteristics*

Of the 19 articles, 14 were retrospective cohort studies; four were prospective cohort studies and one was a review article. There were no RCTs or case controlled series identified for review. Categorising the articles by theater of conflict, six involved data solely from OPERATION IRAQI FREEDOM (OIF); five solely from OPERATION ENDURING FREEDOM (OEF); four combined OIF and OEF data and four articles were from Israel. Four of the articles reported solely on US casualty figures and three on British casualty figures alone. Eight articles included US military forces, coalition forces, local national military forces (including Enemy Prisoners of War) and civilians. The four Israeli articles reported on either Israeli Defence Force (IDF) casualties or a mixture of IDF and civilian casualties. Table 4.2 summarises some the major characteristics of the papers included for review.

**Table 4.2 Summary of characteristics of articles selected for systematic review**

| Reference | Study Design and Population characteristics | Theatre of conflict and study period | Aim of study | Main Results |
|---|---|---|---|---|
| Beekley et al. (2004) | Retrospective, US military, Coalition military, ANF [a] | Afghanistan Aug 2002 to Mar 2003 | Review of casualty statistics, distribution of wounds and experiences of the US Army 102nd FST | Trauma related surgery 78%. HFN injuries 17%. Damage control surgery and resuscitation commonly used |
| Belmont et al. (2010) | Prospective, US military | Iraq Jan 2007 to Dec 2008 | Review of combat casualty care statistics, distribution of wounds and mechanisms of injury | 22% KIA and 3% died of wounds HFN injuries 36.2% IED related trauma 78%. Lethal GSW decreased due to CBA. |
| Breeze et al. (2010a) | Retrospective, UK military | Iraq and Afghanistan Jun 2001 to Dec 2007 | Review of maxillofacial injuries sustained by UK military personnel | HFN injuries 18% [b] IED most common mechanism of injury. Lacerations most common type of injury to the face |
| Breeze et al. (2011a) | Retrospective, Coalition military, ANF, local civilians | Afghanistan Feb 2007 to Oct 2008 | Review of maxillofacial surgical activity at Kandahar Filed Hospital over a 21 month period | HFN injuries 16%. Debridement and closure of wounds most common operation. Need for inclusion of sub-specialty surgeons familiar with HFN injuries |
| Breeze et al. (2011b) | Retrospective, UK military | Afghanistan Jan 2008 to Dec 2009 | Review of maxillofacial injury statistics and management among UK military casualties | HFN injuries 21%. Abbreviated Injury Score excellent predictor of mortality but poor predictor of morbidity from HFN injuries. A separate score specific to the HFN and eyes is recommended. |
| Breeze et al. (2011c) | Retrospective, UK military | Iraq and Afghanistan Mar 2003 to Dec 2008 | 5-year review of combat-related craniofacial and cervical injuries among UK military personnel | Overall HFN injuries 29% with individual incidences for facial injuries 19% [c] head injuries 15% [d]. 73% of injuries required evacuation back to UK. Increased isolated neck injury higher in UK military vs. US military personnel |

| | | | | |
|---|---|---|---|---|
| Brennan (2006) | Retrospective, US military, Coalition military, EPWs[d], Coalition and local civilians | Iraq Sep 2004 to Jan 2005 | Review of casualty statistics, distribution of wounds and experiences of specialist head and neck team | No HFN injury % incidence given. Most common procedures were facial laceration repair, tracheostomy and neck exploration. |
| Gibbons et al. (2010) | Review, Coalition military, ANF | Afghanistan Jul 2006 to Apr 2007, Sep 2008 to Apr 2009 | Review of lessons learned in managing combat related maxillofacial trauma among UK military | Proportional increase in HFN injuries with CBA. Copious wound toilet and techniques based on sound surgical principles most appropriate in a combat field hospital. |
| Kosashvili et al. (2005) | Retrospective, Israeli military | Israel Mar to Apr 2002 | Forensic evaluation of wound distribution among soldiers killed in action wearing CBA | HFN region most vulnerable area to injury when CBA worn with incidence of HFN injuries of 18%. |
| Levin et al. (2008) | Retrospective, Israeli military and civilians | Israel Jul to Aug 2006 | Review of maxillofacial injury statistics, severity of trauma and duration of hospital stay among Israeli military and civilians | Particularly low incidence of maxillofacial injuries found in this limited conflict. HFN injuries 6.4%. |
| Lakstein et al. (2005) | Retrospective, Israeli military | Israel Sep 2000 to Feb 2001 | Review of casualty statistics, patterns of injury and evacuation chain for Israeli military | Explosives and fragments most common mechanism of injury. HFN injuries very high at 54%. Better facial protection recommended. |
| Lew et al. (2010) | Retrospective, US military | Iraq and Afghanistan Oct 2001 to Dec 2007 | Review of casualty statistics, wound distribution and patterns of craniomaxillofacial injuries among US military | HFN injuries 26% over a 6-year period. Penetrating soft tissue injuries and fractures caused by explosive devices most common mechanism. Increased soldier survivability due to CBA being worn. |

| | | | | |
|---|---|---|---|---|
| Patel et al. (2004) | Prospective, (a) US military (b) EPWs (c) local civ. | Iraq March to Apr 2003 | Review of casualty statistics, distribution of wounds and experiences of the US Army 555th FST | Extremity injuries most common among US soldiers with incidences of HFN injury as below (a) 22% (b) 4% (c) 26% |
| Peleg et al. (2006) | Retrospective, Israeli military and civilians | Israel Oct 2000 to Dec 2003 | Review of effectiveness of combat body armor against small arms fire | CBA protects against high velocity GSW with decreased incidence and severity of injury to the torso and abdomen. HFN injuries 9%. |
| Place et al. (2003) | Prospective, US military and special forces, coalition special forces, ANF | Afghanistan Oct 2001 to Apr 2002 | Review of casualty statistics, injury patterns, personal protection measures and surgical experiences of the US Army 250th FST | Extremity injuries most common despite CBA not worn by special forces personnel. Overall incidence of HFN injuries 15%. Unexpected longer medevac delay to surgery due to tactical environment. |
| Powers (2010) | Retrospective, US Military, coalition, Iraqi Forces, Iraqi civilians, others | Iraq Sep 2004 to May 2008 | Review of maxillofacial surgical procedures and statistics over a 4-month period at an Air Force Hospital at Balad Air Base, Iraq. | Iraqi Nationals and Military accounted for 69% of the patients treated with US/Coalition force personnel 29%. Almost 90% of injuries were due to explosives. CBA increases survivability leading to increased HFN injuries seen. |
| Salinas et al. (2011) | Retrospective, US military | Iraq Oct 2004 to Sep 2007 | Correlation between massive facial trauma with increased risk of eye, brain and injury severity scores in the context of IEDs. | Massive facial trauma as a result from IED blast carries a higher injury severity score and increased risk of eye and brain injury due to blast mechanism and fragments. Despite wearing CBA the HFN region had the highest density rate for penetrating fragment injuries. |

| | | | | |
|---|---|---|---|---|
| Wade et al. (2007) | Retrospective, US military | Iraq<br>Mar to Sep 2004 | Review of HFN injury statistics, mechanisms of injury and characteristics utilising data from the US Navy-Marine Corps Combat Trauma Registry | Incidence of HFN injuries 39%. IEDs most frequent cause of injury in combat and motor vehicle accidents most common cause in non-combat related HFN trauma. Due to high HFN penetrating injury rate, call for better protection of the face needed. |
| Xydakis et al. (2005) | Prospective, US military | Iraq and Afghanistan<br>Jan 2003 to Mar 2004 | Review of combat related HFN injuries among US and Coalition soldiers evacuated to Landstuhl Regional Medical Center, Germany | Incidence of HFN injuries 21%. The use of CBA resulted in a new pattern of injury with unprotected areas of the body (including HFN region) vulnerable to injury. |

a ANF Afghani National Forces (including army, police and militia)
b 2007 HFN incidence excluding brain, skull and eye injuries
c 2006-2008 data only
d EPW Enemy Prisoners of War

*CBA and lethal penetrating injuries to the torso*

Twelve papers (Patel et al. 2004, Kosashvili et al. 2005, Xydakis et al. 2005, Brennan 2006, Peleg et al. 2006, Wade et al. 2007, Belmont et al. 2010, Breeze et al. 2010a, Gibbons and Mackenzie 2010, Lew et al. 2010, Powers 2010, Breeze et al. 2011a) of nineteen made specific mention of the role of modern CBA in the reduction of lethal penetrating injuries to the torso. One paper also attributed the use of armoured vehicles in addition to modern ceramic-plate CBA resulting in decreased penetrating torso injuries but increased extremity injuries (Patel et al. 2004). Another paper reported more than double the number of torso injuries in combatants not wearing CBA compared to those who wore CBA (24% versus 10%) (Brennan 2006).

*Incidence of HFN injuries*

Fifteen papers (Beekley and Watts 2004, Patel et al. 2004, Kosashvili et al. 2005, Lakstein and Blumenfeld 2005, Xydakis et al. 2005, Peleg et al. 2006, Wade et al. 2007, Levin et al. 2008, Belmont et al. 2010, Breeze et al. 2010, Lew et al. 2010, Breeze et al. 2011a, 2011b and 2011c) gave an overall incidence of injuries to the HFN region as part of total body injuries. The incidence ranged from 6.4 to 54% with most papers using data from OIF and OEF giving an incidence of 18 to 26%. Four papers (Brennan 2006, Gibbons and Mackenzie 2010, Powers 2010, Salinas et al. 2011) did not report an overall incidence and focussed on the range and severity of HFN of injuries that presented.

*Mechanisms of injury*

Nine papers (Place et al. 2003, Beekley and Watts 2004, Lakstein and Blumenfeld 2005, Wade et al. 2007, Levin et al. 2008, Belmont et al. 2010, Breeze et al. 2010a, Lew et al. 2010, Salinas et al. 2011) discussed the primary or main mechanism of injuries to the HFN region with seven of these nine papers reporting that fragments from IEDs, RPGs or other explosive ordnance were the main cause of HFN injuries and two papers reporting GSW as the main mechanism of injury. Explosive fragment injuries appear to be the primary wounding mechanism for the HFN in Iraq and Afghanistan.

*Further development in protective equipment*

Five papers (Lakstein and Blumenfeld 2005; Wade et al. 2007; Gibbons and Mackenzie 2010; Breeze et al. 2011a; 2011c) included discussion on the deficiencies in current CBA systems and the need for further development and research. Whereas CBA has been reported as very effective against penetrating injuries to the torso, the exposed extremities and HFN region remain vulnerable to ballistic wounding. Lethal penetrating head injuries have also been reported where bullets have entered in the space between the helmet and CBA vest, penetrating the face, neck or cervical region (Lakstein and Blumenfeld 2010). The use of ballistic protective eyewear is available but compliance in wearing this eyewear may be an issue (Wade et al. 2007).

**Discussion**

The biggest challenge in selecting the articles for final review was to identify those which used the same patient population but were published by different authors in different journals. Even when the patient population and the reporting time period have been clearly defined, some articles include ocular and otologic injuries with HFN injuries whereas others have not included these injuries. This variability in reporting injuries create inconsistent results between different publications. Computerized programmes that map injuries (Gofrit et al. 1996; Champion et al. 2010; Breeze et al. 2011d) could be of great value in standardizing reporting methods and accurately assessing the distribution of injuries but like all database systems, the accuracy is in the data collection and entry.

*Ceramic-plate armor*

Several articles report a decrease in the incidence of fatal penetrating injuries to the chest and abdomen with the use of modern CBA that utilises ceramic-plate inserts (Harcke et al. 2002; Gondusky and Reiter 2005; Greer et al. 2006; Peleg et al. 2006; Zouris et al. 2006; Beekley et al. 2007; Rustemeyer et al. 2007; Breeze and Bryant 2009; Breeze et al. 2011d; Brennan et al. 2011; Larsen et al. 2011). Ceramic plates are very hard materials made by sintering (fusing under high heat) non-metallic minerals, the most common being aluminium oxide or alumina (Tobin and Iremonger 2006). Other ceramics can be made from silicon carbide, aluminium nitride or boron carbide, all of which are harder and lighter than alumina-based ceramics but are considered too expensive for large scale manufacture. Because ceramics are generally harder than most bullets, the projectile will fragment rather than penetrate the ceramic plate. However, ceramics by themselves are also brittle and will shatter producing fragments which potentially could cause secondary missile injuries. To compensate for this, ceramic-plate inserts are backed by a fibre-composite material and encapsulated in a cover which not only protects the ceramic from everyday use but also helps contain the ceramic when it is broken from the impact of a bullet. The effectiveness of ceramic-plate CBA was well described by Mabry et al. (Mabry et al. 2000) who reported on US casualties during the three day battle of Mogadishu in 1993 and found that no projectiles (bullets or fragments) penetrated the anterior chest or upper abdomen, areas protected by ceramic-plate armour. The authors also found that penetrating wounds to the face, groin and pelvis were major causes of mortality with 36% of deaths resulting from penetrating head trauma and all caused by bullets entering through areas not protected by the Kevlar helmet. Although ceramic-plates are effective at stopping projectiles entering into the torso, unprotected areas such as the limbs, groin and face are vulnerable to penetrating injuries.

*Increased incidence of HFN injuries*

The HFN region accounts for 12% of the total body surface area but the incidence of HFN injuries sustained in Iraq, Afghanistan and Israel are disproportionately high (26 to 36%). According to Dobson et al. (1989), who studied the incidence of combat related

HFN injuries from 1914-1986, there was no evidence of increasing incidence in HFN injuries during the periods studied, the overall incidence being 16%. However, Rustemeyer et al. (2007) reviewed HFN injuries in combat from 1982 to 2005 and found an incidence of up to 40% suggesting that an increase in fragment injuries may account for the difference perhaps reflecting a change towards fighting in urban areas or use of explosive devices and munitions. Current literature places the incidence of HFN injuries between 18% and 30% of total injuries sustained by combat personnel, making these injuries the second most common behind extremity injuries (Holcomb 2005, Wade et al. 2007, Breeze and Bryant 2009, Breeze et al. 2010a, Hale et al. 2010, Lew et al. 2010, Gibbons and Breeze 2011). From the articles selected for systematic review, the increase in incidence of HFN injuries may be attributed to three main reasons namely the survivability of combat personnel; the common use of explosive devices resulting in increased fragment injuries and lack of adequate protection for the face and neck. The issue of survivability is not only associated with a decrease in fatal penetrating wounds to the chest and abdomen but also enhanced medical facilities, resuscitation procedures and availability of surgical subspecialists having a positive outcome in survival rates (Lopez et al. 2007, Owens et al. 2008, Lew et al. 2010). Therefore combat personnel who may have died from concomitant chest or abdominal wounds in previous conflicts are surviving to have their HFN injuries operated on. This places greater demands on surgeons and medical facilities who must deal with injuries much more complex in nature compared to most civilian maxillofacial injuries.

Unlike experiences from both the Vietnam War and Somalia, injuries from bullets are less common compared to fragment injuries sustained from explosive devices such as mines, rocket propelled grenades (RPGs) and improvised explosive devices (IEDs) (Champion et al. 2003, Goksel 2005, Marshall 2005, Reed et al. 2008, Ramasamy et al.

2009). Furthermore, the distribution and severity of wounds due to fragment injuries differs in terms of greater distribution, multiple entry points and multiple organ involvement when compared to gunshot wounds (GSW) (Peleg et al. 2004, Sheffy et al. 2006). With increased use of IEDs it is not surprising that the areas of the body not protected by CBA, namely the limbs, face and neck are especially vulnerable to injury, highlighting a need for increased protection for these areas. Post-mortem data from the Lebanon War in 1982 showed that over 20% of all lethal penetrating injuries (fragment and GSW) involved the face and in particular the midface region (Gofrit et al. 1996). Two articles have suggested that fatal penetrating head injuries are a result of aimed fire specifically targeting the facial region (Mabry et al. 2000; Arora et al. 2009). The authors attribute the close proximity in which GSWs were sustained and that the exposed areas of the face and neck were vulnerable to aimed fire. However, the majority of literature where combatants are also fighting in urban areas does not support this.

*CBA design*

There appears to be no evidence that suggest that there are any specific design issues of modern CBA and helmets that directly cause HFN injuries, either by channelling or ricochet of fragments or bullets. However, a major contributing factor cited by the reviewed articles is the lack of adequate protection specifically to areas not covered by CBA or the helmet – the face and limbs. Even when CBA was worn properly, fatalities have been reported due to penetrating bullet wounds entering through the space between the helmet and collar of the vest (Lakstein and Blumenfield 2005).

Whereas ballistic eyewear protection is available (but not always worn) and is effective against small fragment penetration (Biehl et al. 1999, Mader et al. 2006, Thach et al. 2008, Shuker 2008, Arora et al. 2009), no such lightweight protection is available for the face. Some authors have suggested the incorporation of a transparent, lightweight full face visor or shield that may be attached to the helmet (Gofrit et al. 1996, Breeze et al. 2010b, Breeze et al. 2011d) which may increase protection from small fragment injuries but would not protect against high velocity projectiles due to limitations with current materials. Any improvement in design or increased protection cannot be to the detriment of the combat soldier in terms of sacrificing mobility and the ability to process sensory information during enemy contact (Fang et al. 2010). Full face visors may impede vision when fogged or soiled, may reflect light and also affect weapon aiming. The claustrophobic nature may also be an issue for some individuals. Similarly, added protection around the neck using flexible collars attached to the CBA vest is beneficial and yet even when issued, soldiers are reluctant to use neck protectors citing design and mobility concerns (Breeze 2010c). One study states that the balance between protection and mobility lies not in the materials, but in better human engineering and performance (Kosashvili et al. 2005).

*Future planning*

The collation of data by the Joint Theater Trauma Registry has been invaluable in reviewing trends and incidences of combat related injuries. With this information however, strategies must be developed to address issues that have been identified and not merely highlight their existence. It is acknowledged that the current state of biomaterial science and engineering cannot provide CBA systems that offer full body protection and yet remain mobile and lightweight. Care of the wounded combat soldier lies in the skills of health practitioners and it is the adequate training and resourcing of medical units that will provide the best care for injured soldiers in the current combat environment. Due to the high incidence of HFN injuries, military planners must consider the inclusion of surgical subspecialists expert in dealing with these injuries for future deployments or at least provide suitable training modules for military surgeons to deal with basic HFN trauma particularly in the areas of penetrating head, ocular, maxillofacial and neck trauma (Xydakis et al. 2005; Brennan 2006; Breeze and Bryant 2009; Thach et al. 2008; Cho et al. 2009).

**Conclusion**

As a result from the systematic review of the literature there appears to be no evidence to suggest that by virtue of wearing CBA that the likelihood of sustaining a HFN injury increases, but a higher incidence of fragment injuries to the HFN region may be due to the more common use of IEDs and other explosive devices. Furthermore, the review papers report a proportional increase in HFN injuries due to increased survivability as a result of a relative decrease in fatal penetrating torso injuries due to CBA protection. In other words, the increased incidence in HFN in recent combat trauma is proportional and appears to involve the increased survivability of penetrating wounds to the torso, an increase in fragment injuries sustained from explosive devices such as IEDS and RPGs and the lack of facial protection. This pattern of HFN injuries has ramifications in future military surgical training and the inclusion of surgical sub-specialists expert in dealing with HFN wounds on the modern battlefield. It would appear that similar to the early days of the First World War when there were no dedicated face and jaw surgeons among the British and Empire armed forces, the increase in face and jaw injuries seen in Iraq and Afghanistan may have been somewhat of a surprise to surgical planners, rectified in part by the inclusion of specialist face and jaw surgeons (such as oral and maxillofacial and ear, nose and throat surgeons) in major hospital units such as Camp Bastion, Kandahar and Baghdad. Unlike the pioneering days of face and jaw surgery during the First World War, current surgeons have the luxury of 90 years worth of development to draw upon as well as a much larger pool of collegial support and expertise to discuss patients and problems with, but it would appear that with the changing face of warfare comes a reactive change in surgical needs. We should learn from the past, practice in the present but train for the future.

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## 4.3 Wire intermaxillary fixation and battlefield injuries to the mandible

### Introduction

The management of mandibular fractures can be broadly summarised by anatomical reduction, fixation, immobilisation and rehabilitation. Prior to reliable internal fixation methods such as direct wiring techniques of bony segments and metal plates and screws, the anatomical reduction and fixation of mandibular fractures relied on intraoral appliances which utilised the existing dentition or edentulous alveolar ridges to re-establish the continuity of the mandibular arch and stabilise the fracture by indirect means (Mukerji et al. 2006).

The use of wire in the management of facial trauma was described as early as the 5$^{th}$ century BC, the technique attributed to Hippocrates involved a gold wire ligature applied around the teeth adjacent to the fracture followed by binding the chin with strips of leather (Siegert and Weerda 1990). Face and jaw injuries would feature only sporadically in medical treatises over the next several centuries with notable contributions from Ambroise Pare and Pierre Fauchard but it was not until the latter half of the nineteenth century that a watershed period for fracture management of the mandible took place. Recognising the limitations of simple wiring techniques, a series of intraoral appliances or splints were invented, which include such appliances bearing the eponymous names of Kingsley, Hayward and Gunning (Mukerji et al. 2006). These appliances or splints provided greater stability to the fracture segments after anatomical reduction utilising the dentition as indirect fixation. Slightly later during the nineteenth century were reports of using heavy metal wires adapted into an arch form against which the teeth are directly wired individually and the re-introduction of intermaxillary fixation using an arch bar appliance and interdental wiring (as opposed to using external attachments extending from an intraoral splint) was described by Thomas Gilmer in 1887, the concepts of which remain in use today (Rowe 1971). During the carnage of the First World War when face and jaw surgery became a specialty in its own right; the use of intraoral appliances remained the treatment of choice for jaw injuries throughout the war as a tried and true method. However by the end of the war in 1918, direct osseous wiring techniques, initially condemned by German surgeons prior to 1914 based on observations from the Balkans war of 1912-1913, were being performed with a degree of success by the likes of Pickerill and Kanzanjian (Mukerji et al. 2006). In 1922 the American plastic surgeon Robert Ivy devised a modified system of intermaxillary fixation using wire ligatures formed into loops without an archbar or splint appliance – popularly known as Ivy Loops or eyelet wires (Rowe 1971). Several other modifications of splints and wiring techniques were developed over the next few decades but the decline of using wire intermaxillary fixation for the definitive management of mandibular fractures coincides with the advent of reliable internal fixation systems using metal plates and screws. By having a more rigid method of fixing fractures, lengthy periods of immobilisation of the jaws could be avoided. Currently, the routine use of intermaxillary wire fixation is to establish the correct occlusion when applying internal fixation once the fracture sites have been opened and visualised (open reduction, internal fixation or ORIF). There are situations when ORIF is inappropriate such as grossly comminuted fractures were opening the surgical site and stripping off the periosteum in order to apply plates and screws may devitalise the bone leading to sequestrum formation and infection. In these situations, the time honoured techniques of wire intermaxillary fixation or utilising an existing denture or manufacturing a splint are suitable alternatives. However, in the modern setting what options are available for the initial stabilisation of mandibular fractures especially in a pre-hospital setting? One option is no active intervention on the part of the primary care clinician with the patient being transferred to a setting where the appropriate treatment can take place. Another option is to limit the mobility of the fracture by the application of a bandage to help stabilise the mandible. Both these options however do not adequately immobilise the fracture segments giving rise to pain and possibly bleeding and limited speech and swallowing due to the discomfort produced by unstable bone ends. Wire intermaxillary fixation is another common option to stabilise mandibular fractures in the prehospital setting and feature as part of military medicine manuals such as the NATO Emergency War Surgery handbook (Lounsbury et al. 2004). The technique described uses a prefabricated arch bar for both maxillary and mandibular arches and different gauges of wires to secure the arch bar to the dentition and to provide the intermaxillary fixation itself by looping around the hooks of the arch bar. Elastics can also be used to provide the intermaxillary closure but the archbar is still wired in situ. One advantage of wire intermaxillary fixation is that it can be used as the definitive management as well as a method of stabilisation of mandibular fractures. Problems arise however particularly in a combat situation when the tactical environment is unstable or not secure where there is lack of equipment and suitably trained personnel or when airway issues are present. The technique of wiring a patient into intermaxillary fixation is not straightforward and requires significant training and experience in order to become proficient without endangering the patient, clinician or any assistants that may be helping at the time. The aim of this review is to systematically summarise the literature on the use of wire intermaxillary fixation in the management of mandibular trauma with a particular focus on its use for stabilising fractures prior to definitive surgical management.

## Methods

*Search strategy*

A literature search was performed using web-based on-line databases (PubMed, ISI Web of Science, Medscape and Google Scholar), the Cochrane Library and hand-searches of major journals, reference texts and published abstracts. For web-based on-line searches the following key words were used to identify relevant publications: intermaxillary wire fixation OR maxillomandibular wire fixation. The searches were confined to English language literature. The abstract of each article was reviewed and the relevant articles retrieved or copied in full for further evaluation including a further literature search utilizing the reference list from the publications themselves.

The key question to be answered was: *is intermaxillary wire fixation the best method for initial management of mandibular fractures in a field (non-operating room) situation*?

*Article evaluation*

Articles identified by on-line and hand searches were evaluated using a set of inclusion and exclusion criteria. Articles fulfilling all inclusion criteria were accepted for review. The criteria for including studies were as follows:

1. Literature reporting on intermaxillary or maxillomandibular wire fixation for mandibular trauma
2. Literature reporting the use of alternate methods of intermaxillary fixation but still involving wiring techniques
3. Literature reporting the use of archbars and wiring techniques
4. Literature reporting on mandibular fracture stabilisation in dentate patients

The criteria for excluding studies were as follows:

1. Literature reporting on the use of intermaxillary fixation for non-trauma patients
2. Literature reporting wire fixation techniques for orthodontic or orthognathic surgery purposes
3. Literature comparing either intermaxillary wire fixation or open reduction internal fixation techniques as the sole means of definitive management of mandibular fractures
4. Post-operative management of complications using intermaxillary wire fixation
5. The use of intermaxillary wire fixation for isolated injuries of the mandibular condyle
6. The use of intermaxillary wire fixation in paediatric patients
7. Intermaxillary fixation techniques using bonded resin appliances, cast appliances or Gunning-type splints or acrylic splints
8. Literature reporting experimental studies not directly relating to patient management

*Study Design*

In terms of study design, the articles sought were randomized controlled trials (RCTs); prospective or retrospective cohort studies; case controlled studies, review articles and case series. Editorials, letters to the editor, single case reports, technical notes and opinion pieces were not accepted for review.

*Critical appraisal of the articles*

Studies that did not fulfil the simple inclusion criteria were excluded as the main emphasis of the research question is the initial management of mandibular fractures in a field environment where limited resources such as dental laboratories, dentally trained personnel and adverse conditions all necessitate the use of the simplest but most robust method of initial trauma management in terms of mandibular fractures excluding condylar region injuries.

**Results**

*Study inclusion and exclusion*

Figure 4.3 summarizes the search strategy used to make the final selection of publications for review. The use of “intermaxillary” and “maxillomandibular” was taken into account due to the differences in global literature; the former being Latin based and perhaps more classical and the latter being a more modern and “anglicised” version of the same.

Using the key words “intermaxillary wire fixation OR maxillomandibular wire fixation” a search of PubMed yielded 178 results; ISI Web of Science yielded 287 results; Medscape, yielded 227 results and Google Scholar yielded 2,530 results.

After the removal of duplicate search results and using a manual search, a total of 89 articles were included for initial review. Subsequent evaluation of these articles however removed a further 49 articles that did not meet the inclusion criteria or study designs acceptable for review. This gave a final total of 40 articles that met all inclusion criteria for this review (Hudson 1962, Bailey and Gaskill 1967, Melmed 1972, Goss et al. 1979, Chambers and Scully 1987, Shetty and Niederdellmann 1987, Lello and Lello 1988, Busch and Prunes 1991; Avery and Johnson 1992, Luyk and Ferguson 1992, Oikarinen et al. 1993, Busch 1994, Karlis and Glickman 1997, Ho et al. 2000, Schneider et al. 2000, Vartanian and Alvi 2000, Coburn et al. 2002, Ayoub and Rowson 2003, Fabbroni et al. 2004, Roccia et al. 2005, Iizuka et al. 2006, Imazawa et al. 2006, Stacey et al. 2006, Coletti et al. 2007, McGinn and Fedok 2008, Pigadas et al. 2008, Poeschl et al. 2008, Cousin 2009, Roccia et al. 2009, Breeze et al. 2010, Cornelius and Ehrenfeld 2010, Lopez-Arcas et al. 2010, Powers 2010, Ansari et al. 2011, Bali et al. 2011, Englestad and Kelly 2011, Nandini et al. 2011, Rai et al. 2011, Adeyemi et al. 2012, Ghazali et al. 2012, Widar et al. 2012).

*Study characteristics*

Of the 40 articles, there were three RCTs; fifteen prospective cohort studies; fourteen retrospective cohort studies; seven review articles and one case series consisting of three case reports. Categorising the articles by study population, the majority of the studies included for review were civilian population based with only three articles with a military or mixed military and civilian focus. Eight articles discussed mandibular or maxillofacial trauma in terms of general management including the use of wire intermaxillary fixation; sixteen articles discussed the use of intermaxillary screw fixation techniques, complications or comparisons with wire intermaxillary fixation and the remaining articles described intermaxillary wiring techniques in general; intra-oral complications arising from wire intermaxillary fixation, needle-stick injury and other alternative methods of intermaxillary fixation such as hook appliances and other forms of wiring.

Table 4.3 summarises some the major characteristics of the papers included for review.

**Figure 4.3 Search strategy flowchart summary**

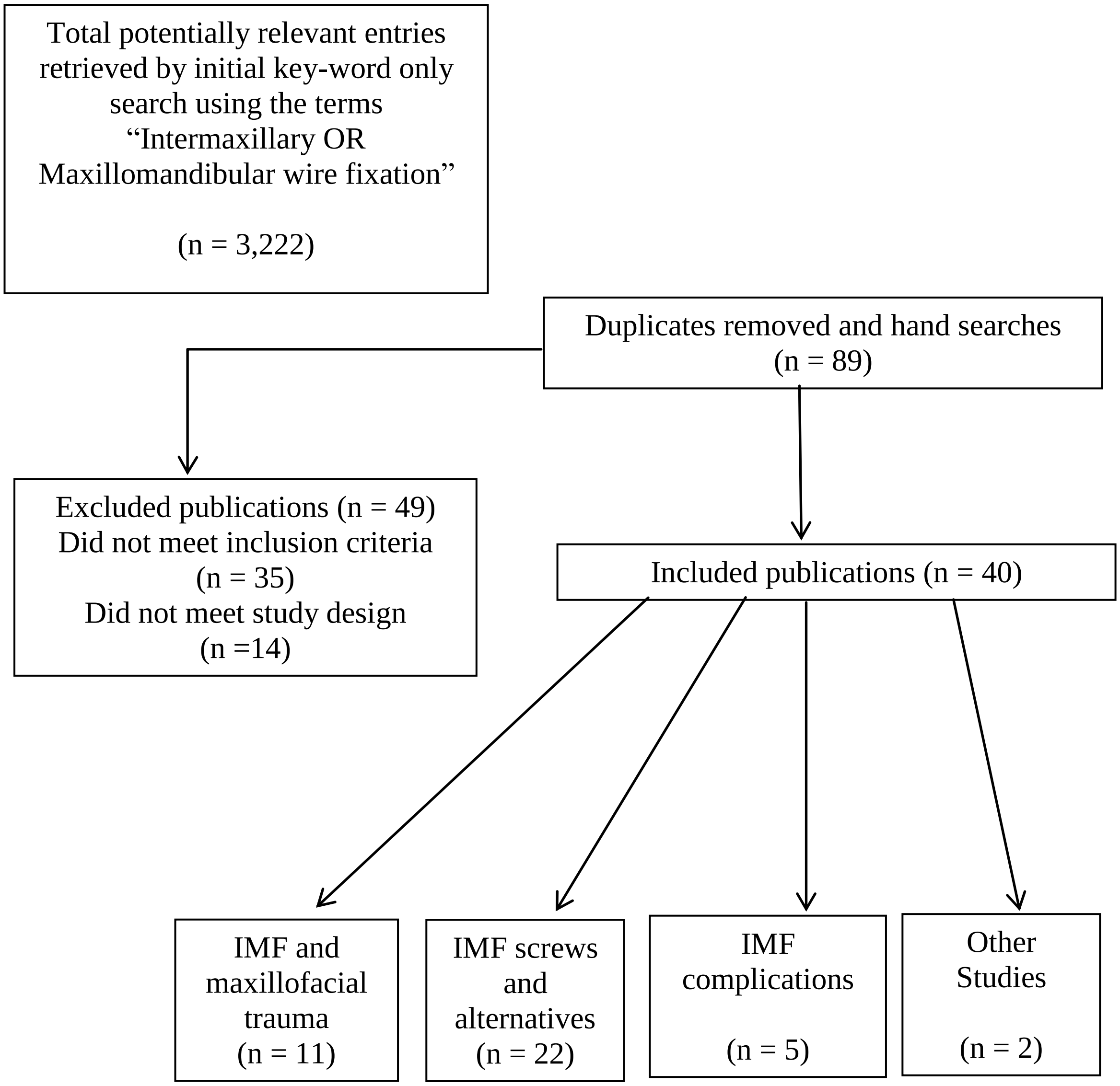

**Table 4.3 Summary of characteristics of articles selected for systematic review**

| Reference | Study Design and Population characteristics | Patient Sample Size | Aim of Study | Main Results |
|---|---|---|---|---|
| Adeyemi et al. (2012) | Randomised Controlled Trial, civilian | 43 | Comparison of healing outcomes between 2 week period of IMF with 4-6 week period for mandibular fractures in the tooth bearing area. | Satisfactory healing was observed in both groups but earlier in the 4-6 week group than the 2-week group. Better oral hygiene and less weight loss was found with the 2-week IMF group. |
| Ansari et al. (2011) | Retrospective, civilian | 53 | To compare complication rates using IMF screws in managing anterior vs. posterior mandible fractures. | There was a higher complication rate with posterior mandible fractures including infection, malocclusion and malunion of fractures. IMF screws were easier and safer to use but may be more suitable for use in the treatment of selected patients with anterior mandible fractures. |
| Avery and Johnson (1992) | Prospective, civilian | 60 | Comparison of surgical glove perforation rate when using miniplate fixation techniques vs. wiring techniques alone. | Statistical significant reductions in the incidence of penetrating sharps injuries and a decrease in glove perforations were found when miniplate fixation was used. |
| Ayoub and Rowson (2003) | Randomised Controlled Trial, civlian | 50 | Clinical study comparing the use of Dimac wires (stainless steel wires with a threaded nylon nut at one end ) vs. archbars for IMF immobilisation. | Application of Dimac wires was faster than arch bars (mean time 20 minutes vs. 35 minutes) and produced less periodontal complications than arch bars. A decreased risk of sharps injuries was speculated using this technique. |

| | | | | |
|---|---|---|---|---|
| Bailey and Gaskill (1967) | Retrospective, civilian | 153 | Review of mandibular trauma statistics, patterns of injury and management over a 2-year period in a major civilian hospital. | Young adult males were over-represented. 64% of mandible fractures involved the body and angle. Archbars and elastics with or without inter-osseous wiring was the most common form of treatment. |
| Bali et al. (2011) | Prospective, civilian | 12 | Incidence of needlestick injury among trainee surgeons over a 12-month period. | 40 needlestick injuries were recorded over a 12-month period from 172 IMF procedures (23% incidence). 78% of injuries were superficial but 22% were considered deep with ramifications of blood-borne infectious disease transmission. |
| Breeze et al. (2010) | Retrospective, military and civilian | 259 | Review of surgical workload over a 5-month period at the Multinational Field Hospital, Afghanistan with emphasis on maxillofacial injuries and operative procedures. | Over a 5-month period 288 operations were performed with 63% of the procedures involving the extremities and 24% involving maxillofacial surgery. Almost all of the operations were performed for acute trauma. |
| Busch (1994) | Retrospective, civilian | 67 | Review of IMF screws over a 2-year period with recommendations for placement. | Overview of technique and general considerations of IMF screw placement including patient preparation intraoperatively. IMF screws are easy to use, reduce operating time and decrease the risk of sharps injury from wires. IMF screws should not be used in comminuted fractures, extensive alveolar bone fractures and missile injuries to the jaws. |

| | | | | |
|---|---|---|---|---|
| Chambers and Scully (1987) | Retrospective, military | 124 | Analysis of mandibular trauma treated by No.2 Indian Maxillofacial Unit during WW2. | In this series, most of the mandibular injuries were non-combat related (47%). GSW was the most common mechanism of injury followed by shell or grenade explosions. Eyelet wire IMF was used in half the patients and silver cap splints were used in 35% of the patients. Infection rate was higher with ballistic injuries vs. blunt force trauma. |
| Coburn et al. (2002) | Retrospective, civilian | 122 | Review of complications with temporary IMF screws in the open management of mandibular fractures. | A complication rate of 4% was reported (5 /122 patients). Complications included fracture of screw on placement, iatrogenic tooth root damage and bony sequestration around a screw. Ease of use and safety outweigh the risk of complications. |
| Coletti et al. (2007) | Retrospective, civilian | 49 | Review of the use of IMF screws in the management of maxillofacial trauma. | IMF screws were used in ORIF procedures, conservative management and prevention of fracture after dentoalveolar surgery. A single complication was noted in 39% of patients and more than one complication in 4% of patients. The single most common complication was screw loosening (29%). Other complications included screw fracture, dental injuries, loosened wires and malocclusion. IMF screw placement is a safe and time-sparing technique but not without potential limitations. |

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| Cornelius and Ehrenfeld (2010) | Review | N/A | Literature review of techniques, indications, contraindications and problems involved with the use of IMF screws. | IMF screws are inserted into bone and provide anchorage for wires, elastics and other methods of closing the jaws together. Advantages include ease of technique, time-sparing and decreased risk of glove perforation and sharps injuries. Disadvantages include iatrogenic tooth root damage and screw loosening. Contraindications for IMF screws include comminuted fractures, alveolar bone fractures, poor bone quality and the presence of unerupted and developing teeth . |
| Cousin (2009) | Prospective, civilian | 150 | Review of patients with mandibular fractures treated without wire IMF using either hand-held occlusion or Rapid-IMF™ non-wire system. | 98 patients had their fractures fixed while in hand-held occlusion and 52 had Rapid-IMF™ placed. Complication rates were low and included postoperative infection, malocclusion and soft tissue trauma as a result of Rapid-IMF™ anchorage points. The use of non-wire alternatives for IMF was supported. |
| Engelstad and Kelly (2011) | Retrospective, civilian | 50 | Review of the use of embrasure wires as an alternate method of IMF using archbars. | Embrasure wires took less time to place and are a reliable form of intraoperative IMF for mandibular fracture repair. Sharps injury and disease transmission may be reduced by decreasing the number of wires used to gain IMF. |

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| Fabbroni et al. (2004) | Prospective, civilian | 54 | Review of the incidence of tooth root damage using predrilled IMF screws. | Radiographic assessment of patients was performed and tooth root contact classified into minor (<50% impingement of screw hole over the root) or major (>50%). Major contact incidence was 11% and minor contact 16%. Clinically significant damage from tooth root contact appeared to be very low. |
| Ghazali et al. (2012) | Retrospective, civilian | 77 | Pilot study using Leonard buttons in the management of bilateral mandibular fractures. | The use of Leonard buttons in conjunction with ORIF procedures was described. Good occlusion, shorter operating time and better gingival health support the use of Leonard buttons as a suitable alternative to archbars. |
| Goss et al. (1979) | Prospective, civilian | 32 | Health care professionals timed for efficiency of releasing IMF wires for patients in the post-operative phase of recovery. | Average time for releasing IMF wires for oral surgeons 35 seconds compared to 2 minutes 9 seconds for other hospital staff including recovery nurses and anaesthetists. The practicality of having wire cutters at bedside given these times was questioned. Awake extubation, anti-emetics and delayed IMF until the patient was more awake mitigate issues. |
| Ho et al. (2000) | Case series, civilian | 3 | Description of IMF screw placement in a case series of patients with mandibular fractures. | IMF screw technique is a fast and easy alternative method of achieving IMF. |

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| Hudson (1962) | Retrospective, civilian | 114 | Review of statistics, mechanism of injury, management and complications in patients with mandibular trauma treated from 1956- 1960 at an urban hospital. | Almost 75% of patients were male. 62% of patients were aged between 10 and 30 years. Motor vehicle accidents were the most common mechanism of injury with the body and condyle of the mandible the most frequent anatomical sites fractured (38% and 29%). Arch bars and elastics were the most common form of treatment (70%). |
| Iizuka et al. (2006) | Prospective, civilian | 100+ | Review of the use of a new design of prefabricated titanium archbars for IMF. | Titanium archbars are easier and faster to apply than conventional stainless steel archbars and gives excellent stability and better conformity around the teeth. |
| Imazawa et al. (2006) | Retrospective, civilian | 15 | Review of the use of IMF screws in managing mandibular fractures. | Predrilled placement of IMF screws was used in all patients. No iatrogenic dental injuries were found in this study but mental paraesthesia was observed in 40% of patients. Ease and speed of placement and IMF release make IMF screw technique a suitable alternative to arch bar IMF. |
| Karlis and Glickman (1997) | Prospective, civilian | 5 | Pilot study using IMF screws as an alternative to arch bar IMF. | Titanium IMF screws are easy to apply and significantly reduce operating time. Loosening of the screws was noted in one patient at week 5. IMF screws are not indicated in comminuted alveolar fractures of the maxilla and mandible. |

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| Lello and Lello (1988) | Prospective, civilian | 30 | Review of the effects of IMF and interdental wires on periodontal tissues. | Increased gingival inflammation and irritations was found throughout the duration of the wires being in place despite oral hygiene regimens being followed. Resolution of gingival inflammation occurred after 2 weeks following removal of wires. |
| Lopez-Arcas et al. (2010) | Review | N/A | Workbook on IMF techniques from the European Association for Cranio-Maxillo-Facial Surgery | Comprehensive history, overview and technical instructions on various IMF techniques. |
| Luyk and Ferguson (1992) | Review | N/A | Review of injury patterns, characteristics and management options for mandibular trauma from an educational standpoint for general dentists who may be involved with post-operative care. | Overview of patterns of injury, clinical examination, investigations and initial management. |
| McGinn and Fedok (2008) | Review | N/A | Review of principles and specific IMF techniques including arch bars, Ivy loops and bone screws. | Overview of techniques and potential general complications of IMF |
| Melmed (1972) | Review | N/A | Review of mandibular trauma epidemiology, presentation, general management and case illustrations. | General overview with case illustrations as examples of management principles. |
| Nandini et al. (2011) | Prospective, civilian | 20 | Comparative clinical study using IMF screws vs. arch bar IMF in treating mandibular fractures. | Significant reduction in operating time was noted with a mean time of 8.5 minutes for IMF screw placement compared to 100 minutes for archbar placement. Better oral hygiene was noted in patients with IMF screws and a significant reduction was noted in glove perforations when using IMF screws. |

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| Oikarinen et al. (1993) | Review, civilian | 317 | Review of the management of mandibular trauma during the decade of the 1980s in Finland. | 452 mandibular fractures in 317 patients (mean 1.4 fractures per patient). Condylar fractures most common (39%) followed by body (22%) and angle (20%). Use of titanium plates and screws more common used as the decade progressed. |
| Pigadas et al. (2008) | Prospective, civilian | 120 | Comparison between conventional wire IMF and non-wire Rapid - IMF™ system for glove perforation and infection control. | Rapid-IMF™ quicker to apply and showed significant reduction in glove perforation due to the absence of wires. Some loosening of the plastic anchors noted but surgical outcome not affected. |
| Poeschl et al. (2008) | Prospective, civilian | 44 | Review of conservative management of mandibular fractures using bone screws and IMF hooks. | The use of cortical bone screws and specially designed IMF hook (Ottenhaken) was described. Main complications included loss of elastics and local tissue irritation around the screw head. No dental root injuries were noted. Use if cortical screw and IMF hooks is a suitable alternative to arch bar IMF in selected patients. |
| Powers (2010) | Prospective, military and civilian | 190 | Review of maxillofacial surgical procedures and statistics over a 4-month period at an Air Force Hospital at Balad Air Base, Iraq. | Iraqi Nationals and Military accounted for 69% of the patients treated compared with US/Coalition force personnel 29%. Almost 90% of injuries were due to explosives. CBA increases survivability leading to increased HFN injuries seen |

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| Rai et al. (2011) | Randomised Controlled Trial, civilian | 90 | Randomised clinical study to determine if IMF screws are a better option than arch bars for achieving IMF. | 60 patients were assigned to the IMF screw group and 30 assigned to the arch bar IMF group. Mena placement times for IMF screws were 19 minutes and arch bars 95 minutes. Poorer oral hygiene was noted in the archbar group. Tooth root damage was 6% with IMF screws. IMF screws are faster to use and easier to maintain from an oral hygiene standpoint. Archbars were recommended for long term as screws loosened after 5-6 weeks. |
| Roccia et al. (2005) | Retrospective, civilian | 62 | Audit of mandibular fractures using IMF screws over a 10-year period. | Radiographic and clinical testing of patients was performed. Main complications included iatrogenic tooth root trauma (1.5%), mucosal overgrowth of screw heads (4.9%) and loss of screws (1.9%). No screw fractures were identified. One patient had postoperative malocclusion and bony malunion was found in one patient with complicated mandibular fractures and diabetes. |
| Roccia et al. (2009) | Prospective, civilian | 186 | The use of IMF screws as an alternative to arch bar IMF in mandibular fracture management. | Main complication was screw loss in 4.4% of patients. No dental trauma, screw fracture or malunion of the mandible fractures were reported. IMF screws are a useful alternative to arch bar IMF. |

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| Schneider et al. (2000) | Prospective, civilian | 19 | Review of the use of IMF screws in managing mandibular fractures. | Stable occlusion and adequate healing was noted for all patients. One patient had mental nerve disturbance following screw removal. Patient satisfaction was high. IMF screws are a safe and reliable method of IMF but care needs to be taken in placement to avoid tooth and nerve injury. |
| Shetty and Neiderdellmann (1987) | Prospective, civilian | 53 | Clinical evaluation of the use of IMF mini-hooks for the management of mandibular fractures. | The use of commercially available titanium cortical screws and minihooks fabricated from 0.8mm stainless steel was described. Patient selection was important and guidelines were provided. |
| Stacey et al. (2006) | Review, civilian | N/A | Review of epidemiology, management options and complications of mandibular trauma. | Overview of techniques and trends in the management of mandibular trauma. |
| Vartanian and Alvi (2000) | Retrospective, civilian | 23 | Review of the use of IMF screws as an alternative to arch bars in the intraoperative management of mandibular fractures. | Normal dental occlusion was achieved in over 90% of patients bone screw IMF during mandibular fracture repair. IMF screws decreased operating time, lowered risk of sharps injuries due to wires and were easy to use. |
| Widar et al. (2012) | Retrospective, civilian | 123 | Review of iatrogenic tooth root damage comparing predrilled vs. drill free placement of IMF screws | 64 patients had IMF screws placed with predrilled holes and 59 patients had drill free placement of IMF screws. Tooth root damage was found only among the predrilled group (45%) with 16% of these patients having permanent damage. Predrilling holes for IMF screw placement increases the risk for iatrogenic tooth root damage. |

*Intermaxillary fixation and fractures of the mandible*

Eleven papers (Hudson 1962, Bailey and Gaskill 1967, Melmed 1972, Chambers and Scully 1987, Luyk and Ferguson 1992, Oikarinen et al. 1993, Iizuka et al. 2006, Stacey et al. 2006, Breeze et al. 2010, Powers 2010, Adeyemi et al. 2012) of the forty made specific mention of the role of wire intermaxillary fixation in the overall management of mandibular and maxillofacial trauma. Most of these papers were descriptive reviews that discussed an overview of management rather than specific comparative techniques. Typically, wire intermaxillary fixation was used to initially stabilise the fracture and re-establish the dental occlusion using a prefabricated archbar (typically the stainless steel Erich arch bar, although one paper described the use of a titanium archbar) and circumferential interdental wires of various gauges. Intermaxillary fixation was achieved by using wire loops that were placed around the hooks of the archbar and tightened so that maximal intercuspation between the teeth were achieved and a stable occlusion established. The mandibular fractures were either definitively management by the use of wire intermaxillary fixation alone or by ORIF techniques either using osseous wires or plates and screws. One paper (Adeyemi et al. 2012) compared the duration of intermaxillary fixation after mandibular repair. Earlier healing was found with patients who had four to six weeks of intermaxillary fixation rather than two weeks but oral hygiene was better in the two week group.

*Intermaxillary screw fixation and other alternatives*

Twenty two papers (Shetty and Neiderdellmann 1987, Busch 1994, Karlis and Glickman 1997, Ho et al. 2000, Schneider et al. 2000, Vartanian and Alvi 2000, Coburn et al. 2002, Ayoub and Rowson 2003, Fabbroni et al. 2004, Roccia et al. 2005, Imazawa et al. 2006, Coletti et al. 2007, Poeschl et al. 2008, Roccia et al. 2008, Cousin 2009, Cornelius and Ehrenfeld 2010, Ansari et al. 2011, Engelstad and Kelly 2011, Nandini et al. 2011, Rai et al. 2011, Ghazali et al. 2012, Widar et al. 2012) of the forty for review discussed alternatives to archbars and wire. Of the twenty two papers, sixteen papers discussed the use of IMF screws as an alternative to archbars and wires including two papers specifically looking at complications associated with the use of intermaxillary fixation screws. Five papers described the use of hooks, buttons, beaded wires and embrasure wires without the use of archbars as alternatives. The one remaining paper described a prospective study of 146 patients with mandibular fractures and five patients with maxillary fractures treated with ORIF without the use of wire intermaxillary fixation. Ninety eight mandible fractures were fixed while the teeth where held in occlusion by hand while 52 were treated using a non-wire intermaxillary fixation system. All twenty two papers reported satisfactory outcomes and proposed that alternatives to wire intermaxillary fixation should be considered for mandibular fracture repair.

*Complications associated with wire intermaxillary fixation*

Five papers (Goss et al. 1979, Lello and Lello 1988, Avery and Johnson 1992, Pigadas et al. 2008, Bali et al. 2011) discussed complications associated with the use of wires in intermaxillary fixation. Three of the five papers discussed problems with infection control including glove perforation and penetrating injuries from wires associated with wire intermaxillary fixation techniques. Sharps injury was common among junior surgeons with an incidence of 23% (Bali et al. 2011). Lello and Lello (1988) reported increased oral soft tissue/periodontal inflammation for the duration of wire intermaxillary fixation. Once the wires were removed however, resolution of the inflammation was seen after two weeks. Goss et al. (1979) discussed the problems associated with releasing intermaxillary fixation wires for vomiting and airway issues when performed by non-oral surgeons. Oral surgeons on average took 35 seconds to release intermaxillary fixation wires compared to over two minutes for the non-oral surgeon group.

**Discussion**

Wire intermaxillary fixation using archbars remains one of the most effective ways of initially stabilising mandibular fractures and can be used as a definitive means of fracture management when used as a closed reduction technique, similar to intraoral splint appliances. Wire intermaxillary fixation aids in re-establishing normal occlusal relationships and the reduction of the fracture segments for ORIF techniques.

However, there are several limitations which affect the patient, the operator and other clinicians. For the patient, wire intermaxillary fixation is uncomfortable as the archbar (if used) is secured to the dentition by passing a stainless wire around the necks of the teeth and tightening them. Not only does this adversely affect oral hygiene but also the ends of each wire is twisted then turned back into the gingival soft tissues causing further irritation and discomfort. The main issues arising from wire intermaxillary fixation (for closed reduction of fractures typically 4-6 weeks) include limited nutritional intake for the patient, periodontal complications, tooth mobility and limited mandibular movement (Shephard et al. 1982, Lello and Lello 1988). Once the wires were removed however the periodontal effects were reversed within two weeks but tooth mobility issues and mandibular range of motion required a longer period of time before returning to baseline. In the trauma setting having the jaws wired together can have significant ramifications on airway management and clearing of secretions such as vomit, blood or mucus. The maxilla and mandible are closed into position by looping wire around the hooks of the upper and lower archbars and tightened so that the teeth are literally cinched together with wire. Usually there are two wire loops along the buccal segments of the posterior and premolar teeth but an anterior loop may be used as well. Should the airway need to be accessed or the patient requires the intermaxillary fixation to be released (such as anxiety attack for example), these loops are cut and the wires removed. It sounds simple to do so but one study showed that nursing staff and anaesthetists took on average over two minutes to remove six intermaxillary fixation wires compared to 35 seconds for an oral surgeon using wire cutters that were provided to the patient and families as routine (Goss et al. 1979). In this instance, further education and training on the release of wire intermaxillary fixation is clearly required.

The application of wire intermaxillary fixation can be time consuming and potentially hazardous for the operator(s) in terms of glove perforation and penetrating injuries, increasing the risk of infectious disease transmission.

There have been several case reports and technical notes regarding the use of screws as a means anchoring wire intermaxillary fixation without the use of archbars (but not included for review as they did not meet the desired study designs). That over half of the papers reviewed were dedicated to alternate means of intermaxillary fixation with archbars with the vast majority of those papers discussing the use of IMF screws, would suggest that considerable concerns exist with archbar fixation.  IMF screw technique has the advantages of being faster to perform (95 minutes to place archbars compared to 19 minutes for IMF screws (Rai et al. 2011)  having less periodontal trauma and less chance of penetrating injury with needlestick.

The two main complications associated with IMF screws appear to be loosening of the screws and potential damage to tooth roots (Schneider et al. 2000, Coburn et al. 2002, Fabbroni et al. 2004, Roccia et al. 2005, Coletti et al. 2007, Widar et al. 2012). Other less common complications include the loosening of wires, overgrowth of mucosa covering the screw head, local injury to nerves and in one patient, ingestion of the hardware (Coletti et al. 2007).
In situations where there are loose teeth, dentoalveolar fractures or difficulty in reducing the fracture even with the teeth in occlusion (due to torsion or twisting in a horizontal plane), IMF screws may not be appropriate and archbars remain the best option (Karlis and Glickman 1997, Cornelius and Ehrenfeld 2011, Rai et al. 2011). Due to the loosening of both screws and wires over weeks, longer periods of closed reduction and situations requiring active traction with elastics are also more suited for archbar placement (Rai et al. 2011).

Patients may be placed into temporary dental occlusion by manually holding the jaws together (hand-held occlusion) while ORIF takes place (Fordyce at al. 1999, Dimitroulis 2002, Bell and Wilson 2008, Cousin 2009). In certain situations this method appears to be a suitable and very quick alternative to intermaxillary fixation but patient selection is probably the most important factor in choosing this method.

There appears to be no clear consensus that archbar and wire intermaxillary fixation is the best method for stabilising mandibular fractures especially when over half the papers reviewed offered alternatives to this traditional method due to concerns of lengthy placement time, patient discomfort and potential exposure to infectious disease. However, the use of these alternatives, such as IMF screws, is not without their significant disadvantages as well and patient selection appears to be the key factor in success. Focussing on the initial, pre-hospital management standpoint, the use of archbars gives a robust means of stabilising all types of mandibular fractures (including dentoalveolar), allows for reliable closed reduction of fractures without significant loosening of hardware (either screws or wires) and in situations where the anatomical reduction of the fractures is difficult due to torsion or twisting of segments, can be more reliable than IMF screws in aiding ORIF. This must be balanced by the required skill set of the operator, potential airway management issues and release of wires and exposure to infectious disease due to glove perforation and penetrating injury. Even with non-wire systems, issues arise with placement times and the potential for breakage of plastic components. The teaching of wire-IMF techniques should probably be limited to health professionals familiar with the jaws such as dental professionals and surgeons involved with maxillofacial surgery including Ear, Nose and Throat and Plastic Surgeons with the possibility of including emergency medicine specialists. This is not an elitist or patch-protection measure but rather limiting the risk of sharps injury to a set of clinicians who are used to dealing with wires, teeth and jaws.

**Conclusion**

To answer the initial research question *is intermaxillary wire fixation the best method for initial management of mandibular fractures in a field (non-operating room) situation* it would appear that the traditional system of archbars and wires probably remains the best option currently available for initial management of mandibular fractures. There are however, significant issues that may discourage its use despite its inclusion in military trauma manuals. Other methods of achieving intermaxillary fixation need to be explored that do not involve technique sensitive training, breakable components, potential injury to teeth and nerves and is safe for the operator in terms of needlestick injury and is able to be used in adverse environments with minimal equipment and expertise.

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## 4.4 Managing maxillofacial trauma in the context of Damage Control Surgery

### Introduction

Damage Control is a very apt description of the management strategies involved in the care of patients with massive trauma both in civilian and military settings. Borrowed from the US Navy, “damage control” refers to the rapid assessment and temporary repair of any hull damage in order for the ship to return its operational mission or to port for more definitive repairs (Loveland and Boffard 2004, Blackbourne 2008). In direct military language, damage control describes the “capacity of a ship to absorb damage and maintain mission integrity” (US Navy 1996). Translating this into surgical terms, damage control may be interpreted as rapid assessment of the patient, life-saving resuscitation and abbreviated surgery and early medical evacuation to a higher echelon of hospital care. It was recognised that severely injured trauma patients were more likely to die from metabolic failure (non-surgically related issues) involving hypothermia, acidosis and coagulopathy – the “lethal triad” resulting in the patient having a decreased ability to cope with traumatic injuries at a physiologic level (Patt et al. 1988, Hirshberg and Mattox 1993, Loveland and Boffard 2004, Keel et al. 2005, Blackbourne 2008, Blackbourne et al. 2009). Because of this the current concepts in managing massive trauma revolve around limiting haemorrhage and contamination as part of resuscitating the patient stabilisation. Damage Control Resuscitation (DCR) aims to regain an acceptable physiologic state prior to medical evacuation and further surgery. Damage Control Surgery (DCS) therefore should not be regarded as an isolated entity but rather should be seen as the surgical component of the overall resuscitation of the severely injured patient (Hodgetts et al. 2007, Fries and

Midwinter 2010, Kam et al. 2010). One integrated approach proposes commencing DCR as early as possible once a patient has been identified as needing aggressive resuscitation measures with DCS performed *concurrently* with tailored DCR using real-time technologies to monitor the patient's physiologic status. In other words DCR and DCS are complementary parts in the dynamics of managing the patient with severe traumatic injuries (Fries and Midwinter 2010).

The principle of damage control surgery traditionally has been applied to penetrating abdominal injuries where haemorrhage control is often difficult and the risk of faecal contamination is high from bowel perforation. Accounts of life-saving only surgery with the specific goal of controlling bleeding (in particular packing and vessel ligation in liver injuries) was performed as early as the American Civil War and revisited during the First and Second World Wars but fell out of favour after the Second World War due to poor patient outcomes due to re-bleeding after pack removal and late sepsis (Pringle 1908, Halsted 1913, Bowley et al. 2000, Keel et al. 2005, Waibel and Rotondo 2012). As surgical care evolved after the Second World War, a shift towards a single, big operation for "definitive" surgery also took place and this attitude prevailed through the decades that followed. It was noted that gunshot wounds to the abdomen from small calibre weapons could be adequately managed under this model but as more lethal and higher-velocity weapons became more common place, the severity of injuries increased and the concept of abbreviated surgery and physiologic resuscitation was revisited, this time with more success leading to a wider adoption of this concept (Holcomb and Champion 2005, Parker 2006). Rotondo et al. (1993) reported a seven-fold improvement in mortality comparing one group undergoing definitive surgery for major abdominal trauma (11% survival) and another group using DCS principles (77% survival) over a three and a half year period.

More recently the DCS concept has expanded to areas outside of the abdomen with severe limb, neurosurgical and maxillofacial injuries being managed within the context of DCR and DCS (Loveland and Boffard 2004, Teff 2010, Parker 2011). Isolated maxillofacial injuries are rarely life threatening unless the airway is compromised making airway security the first priority (Goksel 2005, Rezende-Neto et al. 2008). Unlike massive abdominal or extremity injuries, it is exceedingly uncommon to exsanguinate from maxillofacial trauma although significant bleeding can take place especially with penetrating neck trauma (Ardekian et al. 1993, Breeze and Bryant 2009). The potential loss of vision also necessitates a higher priority for surgical intervention and is consistent with life, limb and eyesight saving procedures taking priority for the operating theatre. Although the principles of DCS have been advocated for severe maxillofacial trauma and in practice surgeons have used the DCS concept to good effect for maxillofacial injured patients; there appears to be no evidence in the literature to support this in terms of comparative outcome measures. The aim of this review is therefore is to systematically summarise the literature discussing the appropriateness of using the principles of Damage Control Surgery in the management of combat related maxillofacial trauma.

## Methods

*Search strategy*

A literature search was performed using web-based on-line databases (PubMed, ISI Web of Science, Medscape and Google Scholar), the Cochrane Library and hand-searches of major journals, reference texts and published abstracts. For web-based on-line searches the following key words were used to identify relevant publications: "Damage Control Surgery" AND maxillofacial trauma. The searches were confined to English language literature. The abstract of each article was reviewed and the relevant articles retrieved or copied in full for further evaluation including a further literature search utilizing the reference list from the publications themselves.

The key question to be answered was: *is DCS applicable to combat related maxillofacial injuries*?

*Article evaluation*

Articles identified by on-line and hand searches were evaluated using a set of inclusion and exclusion criteria. Articles fulfilling all inclusion criteria were accepted for review. The criteria for including studies were as follows:

1. Literature reporting on damage control surgery with combat-related maxillofacial trauma as part of a general discussion
2. Literature reporting on damage control surgery with a specific focus on combat-related maxillofacial trauma
3. Literature on the above limited to military personnel or mixed military and civilian populations in a theatre of conflict

The criteria for excluding studies were as follows:

1. Literature reporting on damage control surgery not involving maxillofacial trauma
2. Literature reporting on non-surgical management under the umbrella term of "damage control" procedures
3. Literature specifically looking at replacement fluids, antibiotics or component therapies
4. Literature not related to military personnel or outside of a theatre of conflict
5. Literature reporting experimental studies not directly relating to patient management

*Study Design*

In terms of study design, the articles sought were randomized controlled trials (RCTs); prospective or retrospective cohort studies; case controlled studies, review articles and case series. Editorials, letters to the editor, single case reports, technical notes and opinion pieces were not accepted for review.

*Critical appraisal of the articles*

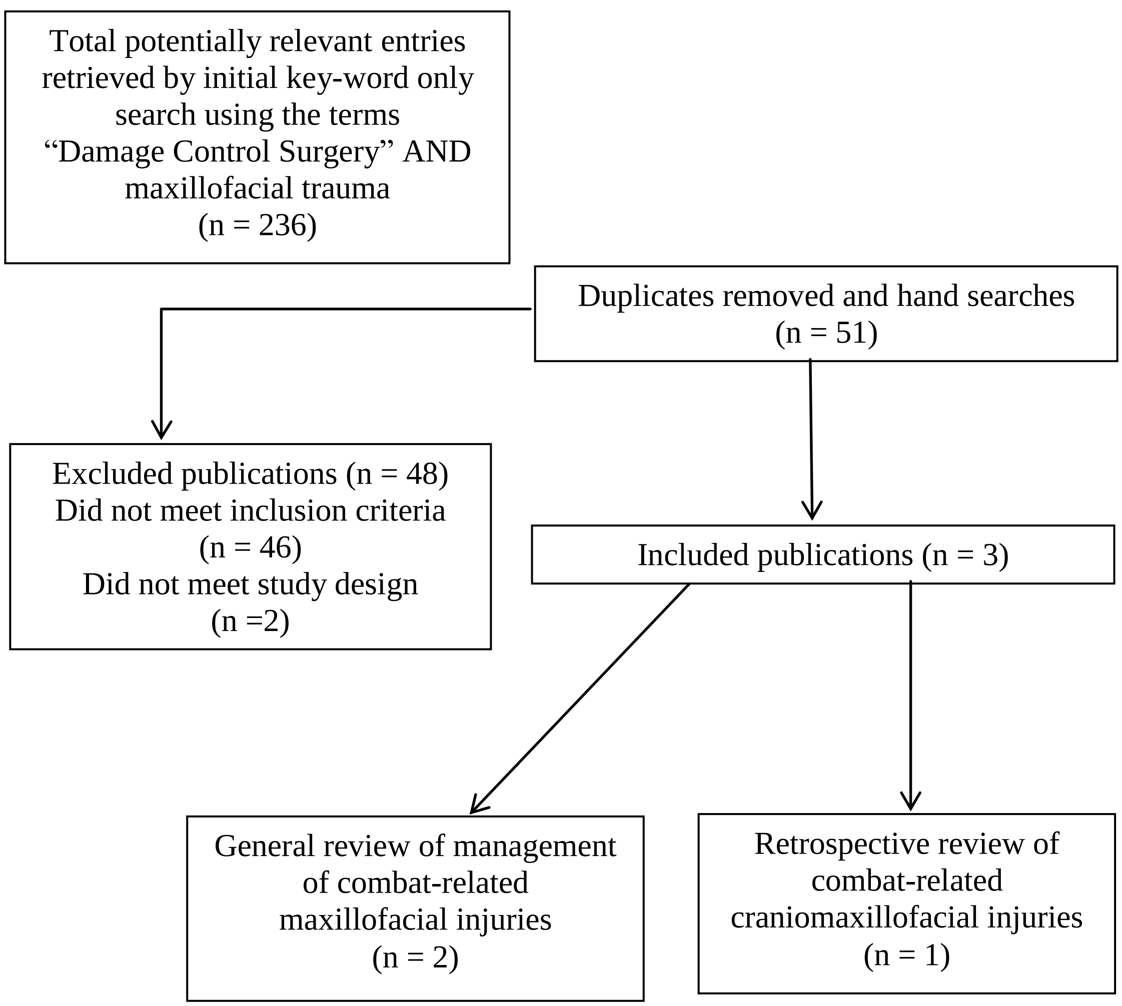
Studies that did not fulfil the inclusion criteria were excluded as the main emphasis of the research question is the applicability of DCS principles with combat-related maxillofacial trauma. Studies that reported general principles of DCS however were used in general discussion but did not form part of the systematic review as such.

## Results

*Study inclusion and exclusion*

Figure 4.4 summarizes the search strategy used to make the final selection of publications for review. The use of “Damage Control Surgery” as a complete phrase was taken into account as the individual words “damage”, “control” and “surgery” yielded far more search results than necessary and did not reflect the specific entity or concept of “Damage Control Surgery”.

**Figure 4.4 Search strategy flowchart summary**



Using the key words “Damage Control Surgery” AND maxillofacial trauma, a search of PubMed yielded 69 results; ISI Web of Science yielded four results; Medscape yielded 41 results and Google Scholar yielded 122 results. After the removal of duplicate search results and using a manual search, a total of 51 articles were included for initial review. Subsequent evaluation of these articles however removed a further 48 articles that did not meet the inclusion criteria or study designs acceptable for review. There were 21 articles that specifically focussed on DCS principles and war surgery but did not include any maxillofacial component and therefore did not meet the inclusions criteria. One article described technical components of what was essentially DCS in relation to combat-related maxillofacial injuries but did not specifically mention surgical management within the context of DCS principles and guidelines and therefore was excluded from the systematic review. A final total of three articles were found that met all inclusion criteria for this review involving the management of combat-related maxillofacial trauma within the context of DCS.

*Study characteristics*

All three articles were general review-type articles. Two articles focussed on lessons learnt and management principles for combat-related maxillofacial trauma based on the experiences of the UK cadre of oral and maxillofacial surgeons at the Multinational Role 3 Hospital at Kandahar, Afghanistan (Gibbons and Mackenzie 2010, Gibbons and Breeze 2011). The remaining article reviewed the indications and role of DCS and trauma resuscitation in general, stating that DCS principles were applicable to maxillofacial injuries but did not further elaborate on this focussing instead on abdominal and limb salvaging procedures (Fries and Midwinter 2010). Although this article met the inclusion criteria of including maxillofacial injuries as part of a wider picture in the context of DCS principles, because no further discussion was offered on maxillofacial injuries as such, the paper unfortunately offered little value to this review. Table 4.4 summarises some of the major characteristics of the papers included for review.

**Discussion**

Two major limitations of this systematic review are apparent - namely only three articles that have met the simple inclusion criteria for systematic review and the non-evidence based nature of the review articles. The two articles that specifically address maxillofacial injuries in the context of DCS summarised the collective experiences of British armed forces oral and maxillofacial surgeons deployed to Afghanistan and provide pertinent and practical considerations in the management of combat-related head, face and neck (HFN) injuries which also include maxillofacial trauma. Although the recommendation that patients with HFN injuries should be managed following DCS principles, it is unclear whether these recommendations have been influenced by the need for DCS for other injuries in conjunction with HFN trauma given these patients often had more than one body system involved – in other words DCS principles would have been applied anyway due to the range and severity of injuries sustained as a whole.

Hodgetts et al. (2006) suggested a paradigm shift from traditional civilian-based primary trauma management of ABC (airway, breathing, circulation) to C-ABC where catastrophic haemorrhage must be controlled first before airway, breathing and circulation is addressed.

**Table 4.4 Summary of characteristics of articles selected for systematic review**

| **Reference** | **Study Design and Population characteristics** | **Theatre of conflict and study period** | **Aim of Study** | **Main Results** |
|---|---|---|---|---|
| Fries and Midwinter (2010) | Review | Not specifically mentioned but includes data from Afghanistan and Iraq | Overview and discussion of an integrated DCR-DCS approach. | The pathophysiology of severe trauma was discussed and concepts DCR and DCS elaborated separately then combined into a proposed integrated DCR-DCS approach. DCS therefore should not be regarded as a stand- alone entity. |
| Gibbons and Mackenzie (2010) | Review | Afghanistan<br>Jul 2006- Apr 2007<br>Sep 2008 – Apr 2009 | Overview and discussion on the lessons learned from the combined experiences of the British Oral and Maxillofacial Surgery cadre deployed to Kandahar. | The epidemiology and injury patterns of patients with HFN injuries was discussed with recommendations based on the clinical experiences of the surgeons summarised into sections including DCS. Future planning, training and the need for better protection for the HFN were also discussed. |
| Gibbons and Breeze (2011) | Review | Not specifically mentioned but includes information and case illustrations from Afghanistan and Iraq | Overview and discussion of the initial management of combat-related maxillofacial injuries | The epidemiology and initial management of maxillofacial ballistic injuries was discussed including airway, soft tissue and facial fracture management. DCS principles are applicable to all severely injured maxillofacial surgery patients. |

This is based on life-threatening bleeding from extremity injuries or penetrating abdominal injuries involving major vessels or solid organ damage such as the liver. The primary cause of death in HFN injuries however involves airway compromise with life-threatening bleeding being an uncommon cause of death (Breeze and Byant 2009).

*Damage Control Surgery and combat-related maxillofacial trauma*

The two papers that discuss DCS principles in relation to severe maxillofacial trauma are based on the experiences of British military oral and maxillofacial surgeons who were deployed to Kandahar, Southern Afghanistan from 2006 to 2009. These surgeons were responsible for maxillofacial injuries for the entire Southern half of Afghanistan and were frequently involved with managing penetrating neck injuries, ocular injuries and neurosurgical trauma as well. The Role 3 Multinational Medical Unit (R3MMU) is a NATO level III hospital facility which provides the highest echelon of surgical care closest to the combat zone. While the primary responsibility at the R3MMU was to provide medical support to coalition personnel and Afghan National Security Force personnel, local civilian ballistic trauma was also treated at this facility.

The range of work done by the maxillofacial cadre at the R3MMU included not only craniomaxillofacial trauma but also penetrating neck wounds hence the current descriptor of head, face and neck (HFN) injuries to encompass the full range of trauma seen by these specialists. The maxillofacial surgeons at the R3MMU were also de facto ophthalmologic surgeons and when specialist neurosurgery support was unavailable, became the neurosurgeon as well when required. Furthermore, when not involved with HFN trauma, maxillofacial surgeons became force expanders by assisting general and orthopaedic surgeon colleagues with patients who had sustained multisystem injuries. – in other words, the maxillofacial surgeons at Kandahar did more than HFN surgery and were intimately involved with DCS in practice and not just in theory. Having this practical familiarity meant that DCS principles could be applied not only to isolated severe maxillofacial injuries but also when these injuries were part of multisystem trauma.

Gibbons and Mackenzie (2010) described lessons learned from the collective experience of British military maxillofacial surgeons deployed to Kandahar from July 2006 to April 2007 and September 2008 to April 2009. After a brief background introduction, the paper describes patient statistics, patterns of injury and initial management concepts and practices involved with severe maxillofacial injuries. The paper then briefly highlighted the proportional increase in HFN injuries due to modern combat body armour (see Chapter 4.2) and recommended training in the management of HFN injuries to be included for all military surgeons during predeployment training.

Gibbons and Breeze (2011) described in more detail the initial management of combat related ballistic facial injuries including emergency management following the C_ABC protocol proposed by Hodgetts et al. (2007) which addresses the need to control catastrophic bleeding rather than airway issues as the first priority. The assessment, short-term management and later management of ballistic facial injuries were discussed with soft tissue and hard tissue injuries dealt with as separate entities.

Both papers state that DCS can be applied to severe maxillofacial trauma but do not discuss outcome measures or guidelines on how DCS concepts should be applied or modified specific to the maxillofacial region. The statement that DCS principles work with maxillofacial trauma may be supported in part by local influences and also in part by the excellent medical evacuation chain available to coalition military personnel. The surgeons at the R3MMU as a group would have practiced under similar clinical guidelines or would have influenced each other in terms of surgical practice. This is not to detract from the autonomy of the surgeons or their respective specialties but it is easier to fit in with a collective way of practice given the volume of patients and the small number of surgeons. Following this reasoning through, if DCS principles are routinely practiced by a surgical team it would be divisive for a team member not to follow along with routine practice as long as it is applied appropriately. DCS principles are directly applicable to maxillofacial injuries as they are often concurrent with multisystem trauma which require DCR/DCS and due to long surgical procedures in the reconstruction of severe maxillofacial injuries, the patients would benefit from having these procedures done at a higher echelon facility outside of the combat zone using strategic medical evacuation back to the UK or Germany. Even with relatively minor maxillofacial injuries such as a fractured mandible, although the surgery itself can be performed at a field hospital facility, consideration for stabilising and delaying definitive repair can still be made as the soldier would benefit from rest and rehabilitation in a place where oral hygiene, nutrition (a liquid or pureed, non-chew diet would be difficult to maintain in a combat environment) and follow up reviews can be catered for more easily.

*Further Research*

Many surgical practices are adopted as they appear to produce good outcomes clinically at the time or at very least do not seem to be detrimental to patient care, but to truly evaluate the effectiveness of a procedure or concept, scientific evaluation and evidence of positive outcome measures are required to validate that system. DCS principles applied to severe maxillofacial trauma appears to fit in with current military surgical practice in field hospital environments such as the R3MMU both at an immediate clinical management level and also from a strategic level of stabilisation and delayed definitive surgery after the soldier is evacuated out of the combat environment. However, further research is needed in order to validate the effectiveness of DCS principles applied to severe maxillofacial injuries with meaningful outcome measures. Randomised control trials are clearly inappropriate for this research question but one possible avenue is to evaluate patient management and outcomes between coalition personnel who have the option of having definitive treatment elsewhere and local patients – either Afghan Security Force personnel or civilians whose surgical care is totally managed in Afghanistan. It would also be useful to separate patients with isolated maxillofacial injuries from those with maxillofacial injuries as part of multisystem trauma when managed under DCR/DCS principles.

*Conclusions*

DCS principles appear to be directly applicable to maxillofacial trauma either in isolation or as part of multisystem trauma as these patients fit into the concept of haemorrhage control, airway security, stabilisation and evacuation for definitive repair of injuries. Even with relatively moderate maxillofacial injuries, due to oral hygiene needs, nutritional support and rehabilitation needs, the stabilisation and evacuation of these patients is in keeping with overall DCS concepts. Due to the scarce scientific literature available on this area however further studies are required to validate DCS in the context of maxillofacial injuries.

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### 4.5 Planning for military surgery for future combat operations

With the proportional increase in head, face and neck (HFN) injuries seen in combat soldiers wearing combat body armour, the need for surgeons with expertise in dealing with these injuries is readily apparent but often such specialists are not automatically included in surgical teams deployed on military operations to support combat soldiers. The terminology used to describe the level of medical and surgical support can often be confusing but is based on what resources (both in personnel and materials) are available and how close to potential enemy contact the facility is located. The US military describes echelons of care in "Levels" whereas current NATO terminology uses "Roles" but essentially these terms can be interchangeable (Lounsbury et al. 2004). For simplicity and uniformity, this discussion will use US military terminology to describe the level of surgical support for combat operations.

The most basic echelon of care is Level I which is at unit level where the combat medic/paramedic is the key person who delivers immediate medical attention to a combat casualty. Casualty evacuation to the next level of care - Level II, ideally should be less than one hour and typically includes a Forward Surgical Team (FST) comprising of five to twenty personnel depending on the service and where the FST is physically located. The US Army FST typically comprises of twenty personnel including four surgeons, two nurse anaesthetists, one critical care nurse and others (Nessen et al. 2008). The function of the FST is to provide life-saving resuscitative surgery only and is resourced for 10 operating room procedures per day over a 72-hour period, in other words, 30 surgeries over three days. Evacuation to a Level III facility occurs as soon as practicable depending on the tactical environment and availability of transport.

As a deviation from doctrine and an example of the environment dictating practical needs, the diverse and remote geographical locations where combat personnel are deployed in Iraq and Afghanistan have led to situations where the FST has been split into two smaller 2-surgeon teams which have been deployed to different locations with good patient outcomes (Nessen et al. 2009). The Level III facility provides the most advanced level of surgical care in an area of combat operations and includes capabilities of triage, resuscitation, transfusion, various levels of surgical care, intensive care and patient holding (ward) facilities (Nessen et al. 2008). The number and mix of medical personnel is increased with general, orthopaedic, thoracic, neuro and oral/maxillofacial surgeons as a part of the surgical team composition. The surgeons are supported by anaesthesia, radiology, intensive care and emergency medicine specialists and greater post-operative and patient holding ward capabilities. The NATO Role 3 Multinational Medical Unit (R3MMU) based at Kandahar is a Level III facility. Note that although oral and maxillofacial surgeons are included in the Level III surgical team composition, this does not preclude other specialists from being deployed in their place – such as otorhinolaryngology- head and neck surgeons (Xydakis et al. 2005, Brennan 2006) or any other specialty that routinely manages HFN trauma as part of normal practice. Levels IV and V are regional medical centres based outside of the combat zone and include facilities such as the Landstuhl Regional Medical Center in Germany, the Royal Centre for Defence Medicine in the United Kingdom and Walter Reed Army Medical Center in Washington DC. The difference between the two levels appears to be the inclusion of dedicated teaching and research facilities in addition to the provision of major trauma care. Table 1 summarises the different echelons of surgical care.

**Table 4.5. Levels of military surgical care facilities**

| Level | Military description | Civilian equivalent |
|---|---|---|
| I | Battalion Aid Station or Regimental Aid Post | Ambulance or Paramedic team |
| II | Forward Surgical Team | Rural district hospital with limited surgical and emergency medicine facilities |
| III | Combat Surgical Hospital, Field Hospital or Role 3 facility* | Regional trauma centre |
| IV<br>V | Regional Medical Centre or General Hospital | Major trauma centre with teaching and research |

*The Mobile Army Surgical Hospital (MASH) units would be a Level III facility although the doctrine has moved away from lengthy definitive care procedures being performed at this level

Rew et al. (2004) reported on the surgical workload provided by the UK 202nd Field Hospital between March and April during the 2003 Gulf War and described the range of surgeries performed with the conclusions that the patterns of injuries were consistent with other high intensity conflicts and that an integrated, multidisciplinary approach to total surgical care was optimal with specialists not only dealing with their own areas of expertise but being able to provide assistance with other specialities. The implications on decreasing surgical time on table and surgeon fatigue are evident but what happens when a service or specialty is not readily available such as ophthalmology at the R3MMU in Kandahar? Information collected by the Joint Theater Trauma Registry (JTTR) give valuable information about the severity, pattern and types of injuries sustained by combat soldiers in

Iraq and Afghanistan and could be used to help modify and plan for future military surgery training prior to deployment. If a particular specialist is not available for an imminent deployment, training in basic procedures in that specialty should be provided for those surgeons to be deployed. With the proportional increase in HFN injuries seen among combat soldiers in Afghanistan and the proactive approach of British military oral and maxillofacial surgeons with their wealth of practical experience from Kandahar, teaching modules have been developed specifically on HFN trauma management and are now part of a 5-day military surgery course (Breeze and Bryant 2009, Gibbons and Mackenzie 2010). This "cross-fertilisation" and transfer of information and experience should be fundamental to all military surgery training and hopefully will better equip modern military surgeons with skills and knowledge to manage combat-related casualties taking into account evolving patterns of injury and trauma care. Furthermore, opportunities for international cooperation need to be fostered between countries but are typically relegated to surgical conferences or highly competitive entry training courses or programmes. A greater understanding of this need is being slowly realised by military surgical planners and the development of training groups such as the Military Surgical Training Committee under the auspices of the NATO Centre of Excellence in Military Medicine reflects this awareness of holistic and cross-disciplinary training of military surgeons for the future and increased cooperation and resource sharing between countries.

Anson (1960) wrote of maxillofacial injuries as part of the Official History of New Zealand Dental Services during the Second World War - *"The number of maxillofacial casualties among New Zealand troops was proportionately small and cannot be accurately assessed* *for the future, but it is reasonable to assume that there will always be a need for an organisation to treat this type of casualty"* and continued on the topic of further training of dentists in maxillofacial trauma – *"It can open the door to that fascinating subject* (meaning maxillofacial surgery) *or, at least, put a little oil on the hinges , with reasonable chance that some will be interested enough in it is attractions to study further"*. Anson wrote this during a time when the war experiences of clinicians in the field and who could speak with authority on the subject were being forgotten and the lessons learned at grave risk of being lost. As with any long period of peace and prosperity, the hardships of war and conflict soon fade as successive generations fortunately are not exposed to such deprivations. Despite numerous of minor conflicts since the Second World War, it was only recently with Iraq and Afghanistan that war surgery became such a prominent topic in surgical and trauma literature with areas such as whole blood transfusion and damage control surgery being discussed once again as if they were new discoveries when in fact these topics were pertinent during the First World War. Anson (1960) concludes his chapter on maxillofacial injuries with a single sentence that encapsulates military surgical training for the future, irrespective of speciality or theatre of conflict – *"The time to train for war is in peace"*.

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# CHAPTER FIVE

## SUMMARY AND CONCLUSION

This thesis is not an exhaustive review of all the aspects of face and jaw surgery and is certainly not intended to be a history of the development of any one particular surgical specialty but rather a more general view of combat-related injuries to the head, face and jaw region. War surgery of face and jaws have been described since antiquity but it was not until the mid-nineteenth century that the sustained publication of surgical literature occurred, coinciding with the new found acceptance of surgery as a science as well as an art. The First World War saw many technological advancements, some advantageous but equally some devastating to mankind, especially in finding more effective and efficient ways of killing enemy soldiers. From this carnage of global conflict, pioneering surgeons such as Gillies, Kelsey-Fry, Pickerill, Kazanjian, Ivy and others developed a branch of surgery to rebuild shattered faces and provided the seeds of growth for various head, face and neck specialties both in medicine and dentistry. The subsequent conflicts that followed the First World War saw the continuation of lessons learned from that war and the incorporation of new techniques or discoveries. The most significant innovations were the introduction of antibiotics and more rapid medical evacuation of wounded soldiers. As death from wound sepsis decreased and combat injured soldiers were seen in a more timely fashion, attitudes began to change after the Second World War from delayed surgery and evacuation to definitive repair in forward based hospital facilities such as the Mobile Army Surgical Hospital (MASH) units during Korea and Vietnam. Fifty years later, First World War concepts such as damage control surgery and the use of whole blood transfusions (developed by the Canadians during the First World War) are being actively promoted. The development of reliable internal fixation (largely made possible by the advent of antibiotics) has shifted surgical repair of the face and jaws towards open reduction procedures with the direct repair of bone with wires or plates and screws. The necessity to use intraoral appliances rapidly fell into decline although the use of intermaxillary wire fixation still remains a part of maxillofacial trauma management. What modern face and jaw surgeons take for granted today – systematic training, sterile operating environments, equipment, antibiotics and patient rehabilitation, were either non-existent or not available to the same extent a century ago and yet, the surgical outcomes of some patients operated on by the likes of Gillies and Pickerill are nothing short of amazing given the severity of injuries, relatively primitive conditions and sometimes experimentation that took place.

The case studies show various outcomes of some of Pickerill's patients and one must bear in mind, given the technology and understanding at the time, it is easy for a modern surgeon to be critical of the surgical outcome. Analogous to the proverb of not judging or criticising another until you have walked a thousand miles in their shoes, similarly, surgeons should not criticise other surgeons' work unless they have the full picture or were present at time of surgery where mitigating circumstances may have influenced certain decisions during surgery. The discussions at the end of each case study in chapter three illustrate current advances and offer a comparison of how aspects of the surgical management may have changed over time with the advent of new technologies and better understanding of biological processes.

The systematic reviews highlight aspects of contemporary war surgery relevant to the head, face and neck region in the context of current combat operations. The importance of including specialists with expertise in managing head, face and neck injuries should be self-evident for military planners and the risk of not including such specialist in military surgical teams would be detrimental to soldiers with combat-related facial injuries and also to the state of knowledge and expertise of current military maxillofacial surgeons now and in the future. This is reminiscent of the decline in preparedness between the two world wars, or during any lengthy period of relative peace and prosperity. The repair of shattered faces goes beyond the trauma bays and operating theatres and has direct relevance and influence on civilian trauma management and on the psychosocial rehabilitation of soldiers and civilians alike.

The combined lessons learned on military operations should be incorporated into teaching modules and with the wealth of information collected by the Joint Theater Trauma Registry. Hopefully further scientific literature will be forthcoming in the near future that would be of benefit for military surgeons and soldiers involved with combat-related trauma. Unfortunately there is no indication that threats from improvised explosive devices will decrease in the near future and as the main mechanism of injury for the head, face and neck region further development in better protection for the exposed areas of the body is greatly needed with particular emphasis on better materials and design including full face protection but without adversely affecting combat functionality.

**Conclusion**

This thesis has provided an historical perspective that gives depth and background texture to the technical advances and procedures that are being performed by face and jaw surgeons today, both in military and civilian settings. As a result of having a good grasp of the historical developments in war surgery, some of the lessons learnt from contemporary conflicts in Iraq and Afghanistan, may have a certain degree of familiarity– for example damage control surgery, early medical evacuation and whole blood transfusion. These concepts were identified during the First World War and therefore are not new principles arising from current military surgery, but are seemingly regarded as new developments nonetheless.

A further example of a seemingly new concept having been done before is that of bony reconstruction of the jaws and the choice of harvest site of the bone graft being guided by scientific studies. The current trend of evidence-based medicine appears to have been practiced by some surgeons ninety years ago and one may be slightly surprised by this precendent.

Modern surgical practice appears to be focussed on technology and molecular biological research, which are necessary for progress but in some ways de-humanise the specialty. It is the appreciation and knowledge of surgical history that enriches the practice of surgery especially in a military context where there is so much published literature from previous conflicts to which modern surgeons can refer back to, History, therefore is the foundation which gives meaning to lessons learnt and the necessary framework for future developments.

*"Kneel warrior, kneel: to-morrow's sun*
*May see thy course of glory run;*
*And batter'd helm and shiver'd glave*
*May lie neglected near thy grave.*
*Kneel; for thy prayer in battle field*
*May sanctify thy sword and shield,*
*And help to guard, unstain'd and free,*
*Our altars, home and liberty".*

(Adapted from: Cotton E (1877). A Voice from Waterloo, 7$^{th}$ ed. Mont St.Jean, p41)

# APPENDICES

## APPENDIX ONE: Major developments in face and jaw war surgery per conflict

### First World War

- Establishment and recognition of face and jaw units as part of military surgery
- Creation of maxillofacial teams of surgeons, dentists and dental technicians
- Rigid fixation utilising intraoral cast cap splints
- Wound toilet and debridement of ballistic injuries to the face and jaws
- Soft tissue procedures such as skin grafting, local flaps and pedicle flaps
- Early successes in bone grafting for reconstruction of the jaws

### Second World War

- Antimicrobial therapy
- Improvements in rigid fixation including craniofacial suspension techniques
- Use of intermaxillary wire fixation
- Direct intraosseous wiring techniques using biocompatible stainless steel wire
- External pin fixation
- Corticocancellous chip bone graft techniques

### Korean War

- Routine primary closure of facial soft tissue wounds
- Open reduction of facial fractures
- Establishment of "oral surgeons"
- Success of Mobile Army Surgical Hospital (MASH) units
- Improved medical evacuation with advent of helicopter transport

**Vietnam War**

- Use of stainless steel plates and screws for facial fracture repair
- Dedicated medical evacuation helicopter platforms (MEDEVAC)
- Rapid evacuation and transfer of casualties to higher echelons of surgical care

**Falklands War**

- Use of silver dressings and creams for burn injuries

**Iraq and Afghanistan post-2001**

- Damage control surgery principles used for severe maxillofacial injuries
- Increased incidence of head, face and neck injuries necessitating inclusion of surgeons with expertise in managing these injuries
- External pin fixation systems revisited
- Documentation of injuries and data collection e.g. Joint Theater Trauma Registry

## APPENDIX TWO: List of journal publications based on thesis research material

**Tong DC,** Beirne OR (2013). Combat Body Armor and the increased incidence of head, face and neck injuries: A systematic review. *Military Medicine* 178: 421-426.

**Tong DC,** Brooking TH, Love RM (2011). The management of maxillofacial trauma during the Korean War – a coming of age. *Journal of Military and Veterans Health* 19:10-14

**Tong DC**, Trottier VJF (2011). Interdisciplinary approach to the management of an 18-month old burn victim in Afghanistan. *Military Medicine* 176: 115-118

**Tong DC,** Bamji AN, Brooking TWH, Love RM (2008). Plastic Kiwis – New Zealanders and the development of a specialty. *Journal of Military and Veterans' Health* 17: 11-18