OPEN FRACTURES: THE MANAGEMENT OF FIREARM MISSILE FRACTURES OF THE EXTREMITIES

BY

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Open fractures: The Management of firearm missile fractures of the extremities, in partial fulfillment of the requirements for the degree of Master of Science in Orthopaedics and Traumatology.

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DEDICATION

To my mother Kwezi-Ana whose goodness I cannot repay.

To my daughters

Kwezi-Dora

And

Kwezi-Dorothea

For enduring parental absences for much too long.

ABSTRACT

TITLE: OPEN FRACTURES: THE MANAGEMENT OF FIREARM MISSILE FRACTURES OF THE EXTREMITIES

Type of study:

A prospective study of civilian firearm missile fractures during a three years period from July 1996 to June 1999 was conducted at Muhimbili Orthopaedic Institute, Dar es Salaam , Tanzania, to identify the specific problems of firearm injuries and their treatment in our civilian society.

Subjects:

Patients with firearm missile injuries to the extremities admitted and managed at Muhimbili Orthopaedic Institute, in Dar es Salaam, Tanzania between July 1996 and June 1999.

Objectives:

1. To identify specific problems of firearm injuries and their treatment in our civilian society.
2. To compare the clinical and functional results for plaster cast, skeletal traction, external fixation and screw fixation treatments

for the various types of open firearm missile fractures to the extremities.

3. To compare the complications and the complication rates of the named firearm open fracture injuring agents and of the mentioned types of treatment.

Patients

All the patients admitted to the Muhimbili Orthopaedic Institute with open firearm missile fractures to the extremities requiring surgical debridement and stabilization were entered into the study. Patients with firearm injuries to other parts of the body other than the extremities were excluded from the study.

Forty eight long bone open fractures caused by firearm missiles to the extremities in 40 patients were treated during this period. A male predominance was evident with a male to female ratio of 19:1. The age range was between 18 and 70 years with a mean of 29.5 years. The injuries were inflicted by rifle bullets in 18 patients (45%), shotgun shots in 8 patients (20%), pistol bullets in 8 patients (20%), landmine shrapnel fragments in 3 patients (7.5%) and a terrorist bomb explosion in 3 patients (7.5%). The most frequently injured bones were the femur in 20 patients (50%) and the tibia in 13 patients (32.5%). Thirty four of the fractures (70.8%) were Type III while 13 (27.1%) were type II by Gustilo classification. Associated

injuries were present in 13 patients with scalp lacerations in 3 patients, penetrating chest injury with haemothorax in 2 patients, abdominal injury with gut perforation in 2 patients and superficial burns to the body in 2 patients.There was one irreparable axillary artery injury resulting in an above elbow amputation. Thirty three patients (82.5%) arrived to hospital within 24 hours of injury and underwent primary surgery by wound debridement and stabilization. Seven patients arrived to hospital more than 24 hours after injury and underwent secondary surgery.

Treatment

Treatment with plaster cast, skeletal traction using a Braun's splint, external fixation with a Tanzfix or a tubular AO external fixator, mini-external fixator and cancellous screw fixation was used, depending on what was judged to be the most suitable option from the available facilities at the time of treatment.

Stabilization was achieved by skeletal traction in 15 patients (37.5%), plaster of Paris in 17 patients (42.5%), screw fixation in one patient (2.5%), external fixation in 7 patients (17.5%). Amputation was done in three patients (7.5%): two primary and one secondary. The immediate post-operative course was uneventful in 37 patients while 3 polytrauma patients from a bomb explosion died within 24 hours of admission, one patient died due to septicaemia, one due to haemorrhagic shock and one died of associated abdominal injuries.

Assessment of outcome

Clinical outcome assessment included fracture union, average duration to fracture healing or union, average hospital stay, functional results, average time to return to work and the complication rate of each method of treatment and of each injuring agent. Follow up averaged 9 months (range 6-12 months).

Results

At the end of the study 29 patients (72.5%) had healed and six patients (15%) died. Patients treated by plaster cast took longer time to heal (25 weeks), had poorer functional results and took on average longer time to return to work (15 months) as compared to the other treatment groups. The gross complication rate was also high at (60.4%) in the 4 types of treatment, the highest being in the treatment with casting (37.5%) and the lowest in the treatment with external fixation (7.5%). Fractures secondary to shrapnel and rifle injuries had worse prognosis as compared with fractures secondary to pistol shot injuries.

Treatment with skeletal traction had better clinical results than the plaster cast treatment. The average healing time was the same at 25 weeks but the functional results were better and 75% of the patients returned to work in an average time of 15 months. The complication rate in this group was 60.4%. There were six deaths in all

constituting 15% of the patients. Three deaths were due to severe polytrauma, one was due to associated abdominal injuries, one death was due to haemorrhagic shock and one was due to septicaemia.

The two patients who died from severe polytrauma were among the 6 patients treated by external fixation. All the 4 surviving patients healed within an average time of 16 weeks with good functional results. All of them returned to work within an average time of 10 months. The most common comp,ication was infection in 16 patients constituting 40% of the cases.

Conclusion

It is concluded that firearm missile injuries, as it has been shown in many other societies, are on the increase even in our traditionally peaceful country. The treatment problems are immense given the limited resources and options of treatment and stabilization in our hospitals.

It is also concluded that the external fixator should continue to be the treatment of choice for severe grade III open firearm missile fractures of the extremities secondary to high-velocity mechanism. Non-operative treatment with plaster cast and skeletal traction can be used for selected stable, non-displaced fractures secondary to low-velocity mechanism.

Appropriate preventive measures of firearm injuries should include restriction of the availability of firearms to the public and a broad-based approach to the current unemployment problem. The ongoing peace initiatives currently taking place in and around our geographical region should be given all the necessary support to end the violence among the warring factions and ethnic groups in our region.

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1.0. INTRODUCTION

As it has been demonstrated so many times, the world has so far failed to create life without violence and war. Hence we are all exposed to the use of inhumane weapons. Surgeons should therefore be knowledgeable and capable of correctly managing these types of injuries.

In this work a brief overview is given to provide the historical perspective of the efforts conducted over the years to help those who had the misfortune to be injured by these weapons. The treatment problems related to our surroundings are discussed.

There are many things that need to be addressed to but were not addressed to in this article. Things like the loss of lives, the direct in patient medical costs of firearm wound treatment, the indirect costs such as the despair, pain and loss of the anguished family, the loss of income, effects on the work force or the cost of the changes in quality of life incurred by society secondary to the fear or avoidance of firearm violence.

Injuries are among the ten most common causes of morbidity and mortality in Tanzania.[1] Trauma is a surgical illness that is continuously increasing worldwide and firearms are one of the major causes of morbidity and mortality.[2] Although in our situation infectious diseases like malaria are said to be the major causes of death, it is certain that deaths due to trauma are on the increase.

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Firearm missile wounds present a serious medical problem today[3]. In some countries firearm violence is a serious threat to health[4]. It is estimated that in the USA about 30,000 people are fatally wounded by firearms every year.[5]. It is also estimated that an American child dies of gunshot wounds every 1½ hours and every 2 days 30 children - the equivalent of a school classroom- lose their lives due to guns[4] According to a report by the International Committee of the Red Cross[6] from 1985 to March 1995 Inteinational Committee of the Red Cross (ICRC) hospitals and surgical teams treated over 140,000 wounded people worldwide. Of these, some 30,000 (about 25%) were victims of landmines. A deplorable loss of limbs has also been reported. ICRC figures[6] show that every month, over 2,000 people are killed by mine explosions. Most are civilians who step on mines after hostilities have ended. A study from Nairobi, Kenya[7] showed that bullet wounds were the eleventh leading cause of death in Nairobi town accounting for 3% of total non-transport trauma deaths between 3rd July 1991 and 9th August 1991.

This group of patients is usually characterized by high morbidity and mortality rates.[2,8] A study from Nigeria[2] between June 1984 and 1995 showed that the mortality rate for all cases of gunshot wounds was 53.6% while that of those arriving alive in the emergency and those hospitalized were 23.8% and 11.1% respectively. Data from Tanzania is scarce, a fact which partly justifies conduction of the current study.

However, data from the Tanzania Police Department shows that between 1995 and 1999 countrywide about 693 people were reported to have died through missile-related injuries, and that this figure has been increasing gradually.(see graph below). This is an average of approximately 121 reported deaths per year or 10-11 deaths per month. The leading motives behind these deaths were homicide followed by suicide.

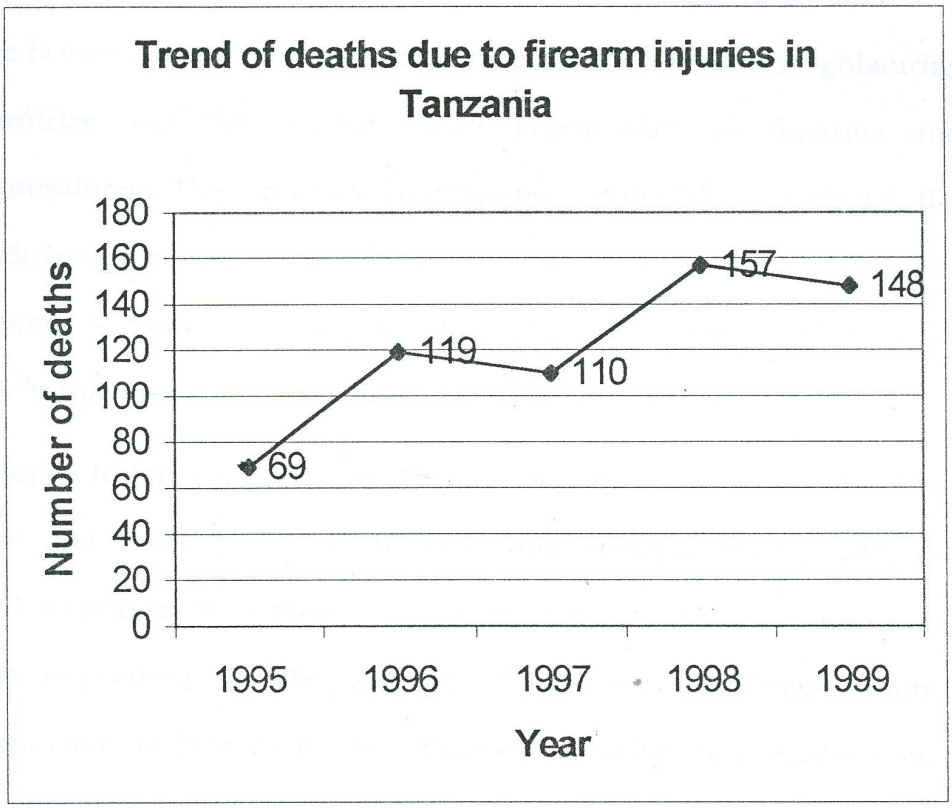


Fig 1. Showing the gradual increase in firearm related deaths in the country from 1995 to 1999.

In the year 1995 and 1996 between 20 and 30 patients were operated annually for gunshot wounds in the orthopaedic and trauma wards of Muhimbili Medical Centre (MMC theatre register), these having sustained gunshot wounds to the etremities only. These figures do not include patients admitted in the other surgical wards (e.g. general surgery, neuro-surgery,ENT etc.) with other types of gunshot wounds, or the number of deaths resulting from gunshot injuries. A number of amputations were also carried out. This figure is probably bound to rise because of the increasing rate in crime, civil wars in neighbouring countries and the current easier accessibility to firearms and ammunitions. The recent terrorist bombing of the US embassies in the traditionally peaceful East African countries of Tanzania and Kenya is another testimony to this truth. In this incident over 250 lives were lost in this attack and over 5,000 people were injured.

An open fracture is one in which there is a break in continuity of the skin and underlying soft tissues, this communicating with the fracture and its haematoma. The implications of an open fracture are that depending on the amount of soft tissue damage wound contamination by bacteria from the external environment may occur, there may be stripping, crushing and devascularization of soft tissues rendering these tissues and the bone they cover more susceptible to infection by the contaminating bacteria or may result in bone death. Furthermore, there may be destruction or loss of bone or soft tissues. Open fractures have continued to constitute a significant proportion of recorded injuries. Even as there is an absolute increase in the number

of open fractures, so there has been an apparrent increase in the magnitude of the injuries incurred.[9] As it has been demonstrated by various studies[10,11,12] the reported infection rate of 3-25% plus the healing complications in these fractures make them a challenge to every surgeon treating these kind of injuries.[9]

Missile fractures are a particular form of open fractures where, due to the high kinetic energy of the missile, are usually associated with significant tissue damage and contamination, factors which to a great extent determine their prognosis.

Classification of Open Fractures

It is important to classify any fractures because there are advantages in doing so[9]:

1. It allows the surgeon to determine the best form of treatment because the classification will determine the extent of and type of fracture plus its associated soft tissue injury
2. Analysis of the fracture pattern gives the surgeon an idea about the amount of energy imparted to the extremity and the stability of the fracture after reduction
3. It alerts the surgeon to higher risk patterns of injury
4. It enables the surgeon to monitor results and to compare treatment results in scientific publications
5. It provides basis for the evaluation of new treatment modalities

6. It gives guidelines for prognosis and permits us to make some statements about methods of treatment.

Numerous classification systems have been designed and used in the past and at present: Further details of these classifications can be sought in the references provided.

1. The AO (Albeitsgeimeinschaft fur Osteosynthesenfragen) classification of fractures is based on the morphological characteristics,and the location of the fracture. A separate classification has been proposed for muscle, tendon and neuromuscular injuries for open fractures. This classification is to be used in conjuntion with the AO/ASIF alpha-numeric fracture classification system. The soft tissue grade incoporates the degree of injury to the integument IO, Muscle –tendon injury MT; and neurovascular injury, NV. This system of classification offers a detailed and potentially cumbersome system for grading open fractures that may probably be best suited for research.[13]

2. The OTA Classification by the Orthopedic Trauma Association. This classification correlates the coding of the fracture with the expanded ICD-9 codes for diagnosis and treatment.

3. The Trafton's Modified Classification. Trafton has proposed a classification for open tibial fractures, which combines elements of the Gustilo-Anderson and Tscherne classifications into minor , moderate and major injuries.This classification offers potential simplicity in classification.[14]

4. The Gustilo and Anderson Classification and the Subsequent Modification by Gustilo, Gruninger and Davis.[15]

This classification is probably the most widely accepted and quoted worldwide.

Table 1: Classification of Open Fractures By Gustilo et al [15])

Type	Wound	Level of Contamination	Soft tissue injury	Bone Injury
I	<1cm long	Clean	Minimal	Simple, minimal comminution
II	>1cm long	Moderate	Moderate,some muscle damage	Moderate comminution
IIIA	Usually >10cm long	High	Severe with crushing	Usually comminuted, soft tissue coverage of bone possible
IIIB	Usually >10cm long	* High	Very severe loss of coverage	Bone coverage poor, usually requires soft tissue reconstructive surgery
IIIC	Usually >10 cm long	High	Very severe loss of coverage plus vascular injury requiring repair	Bone coverage poor, usually requires soft tissue reconstructive surgery

* Traumatic amputations, farm injuries, fractures occuring in highly contaminated environment, high velocity gunshot wounds, close range shotgun wounds, high energy trauma, segmental fractures and frctures with loss of bone irrespective of the size of the wound, all auotmatically are considered as grade III open fractures. [15]

Increasing Rate of Missile Injuries

Since the time when firearms became readily available, surgeons have had to deal with the firearm wounds which presented for treatment. In middle Europe, in peace time, gunshot wounds accounted for only a small percentage of the total of trauma cases seen. Baumer et al[16] reported a mere 0.065% of cases associated with such injuries Numerous studies have demonstrated the increasing rate of firearm missile injuries in various societies.[17,18,19] The current study has demonstrated that our society is no exception from this trend. Studies have also shown that most civilian firearm injuries are caused by the so called low velocity mechanisms which are not complicated as opposed to high velocity mechanisms occurring in military or war situations. Our experience through this study is that even in a civilian setting serious injuries can happen with high rates of complications.

2.0. LITERATURE REVIEW

2.1. Background History

Firearm missile wounds were an unknown problem to the surgeon till the introduction of firearms in the 14th century.[20] Before this time experience with penetrating wounds had been limited to those resulting from more cleanly cutting, much lower velocity missiles and weapons in which the path and presence of a penetrating object were usually obvious and the contamination of the wound usually less.

The history of the management of firearm missile wounds has developed hand in hand with the history of the development of

firearms, the history of their military use and the history of trauma surgery. As Hippocrates long ago (460 – 377 BC) rightly said: "War is the only proper school for surgeons"[13] ; interest, innovation, understanding and treatment of firearm injuries have always peaked through military experience in wartime. The prominent innovations and writings on this subject have also come through the experience of military surgeons. [20,21,22] During the war years several important concepts were learned, abandoned and relearned.[22]

Until the end of the 19th century the treatment of gunshot wounds was largely restricted to wounds of the extremities and to superficial wounds of the trunk, head and neck because wounds to the body cavities and joints were regarded as inevitably fatal.[23] The earliest publications on the treatment of gunshot wounds were made by the poorly educated and highly specialised 'wound surgeons' of Northern Europe,[24] notably Pfolspeundt (1447), Brunschwig (1497) and Von Gerssdort (1517) as well as by classically educated, more generalised surgeons of Italy such as da Vigo (1514).

In those days most notable about gunshot wounds was their relatively greater inflammation and suppuration as compared to previously encounted penetrating wounds[24]. This was attributed to greater amount of contaminated foreign matter iatrogenically introduced through the wound as a mode of treatment or in a heroic attempt to remove bullets. In those days heroic methods were employed at removing the bullets in an erroneous belief that bullets or gunpowder

poisoned the tissues. Copious suppuration was thought to have a favourable outcome in combating and withdrawing the poison from the wound. Amputation was indicated for extensive tissue destruction by gas gangrene but there was much disagreement as to whether the incision should be through the gangrenous or through healthy tissue due to fear for haemorrhage.[24] The ancient Greeks had recommended incision through the healthy tissue but the surgeons of the renaissance placed their incisions in the gangrenous tissue or at its margin with viable tissue. The principle of the tourniquet had not been introduced.

In the mid 16th century, Maggi in Italy[8] (1542) Ambroise Paré in France (1545) refuted Hippocrates doctrine of cauterising wounds.[25,26] They recognised that wounded tissue was crushed rather than poisoned or burned. They showed that the prevailing heroic methods of extracting poison and promoting suppuration were more harmful than beneficial to to the tissues. They believed that the body had a greater capacity for natural healing of wounds than previouly thought. Paré's insight into avoiding harmful interference in surgical treatment has been epitomised by an inscription „I treated him, God healed him."[22]

In the 17th century Paré, followed by Paracelsus, John Hunter in the 18th century and Larrey in the 19th century each published classic

contributions on the nature and treatment of gunshot wounds, each indicating the natural healing capacity of wounded tissue and the feasibility of primary closure.[25]

Before the 18th century amputation was approached with dread and was used only in gas gangrene or in fatal situations. In the 18th century, after the introduction of the tourniquet by Morel in 1674 the treatment of gunshot wounds was characterized by a bolder and earlier use of amputation.[20] Ligation became more precise and less massive. Coupled with the development of prostheses, these factors contributated to a less discriminative and earlier resort to amputation especially in the face of large numbers of battlefield casualties and limited facilities for transport and hospitalization. Along with this trend there developed an enthusiasm for wide, deep and multiple incisions of the wound in order to remove the bullet and promote drainage.

In 1794,based on his 3 years military experience in Portugal (1761-1763), Hunter,[27] came up with a conservative and influential publication on inflamation and gunshot wounds. Hunter , acredited by Billroth as being the father of modern (i.e. 19th century English and German) surgery, limited the indications for surgery to the following:[27]

1. Haemorrhage and the need for ligation
2. The removal of bony fragments
3. The removal of a dangerous foreign body

4. The replacement of eviscerated organs and

5. Relief of pressure imparing the function of a vital organ

However, the wake of the 19th century saw a resurgence in the use of amputation for gunshot wounds of the extrimities. Dominique Jean Larrey (1766-1842) who was the Chief Surgeon of Napoleon's army believed that in the context of large battles and massive casualties of the Napoleonic wars, primary amputation within a few hours of the injury was the most important surgical operation.[28] It is said that Larrey performed 200 amputations in one day at the basttle of Borodinoin 1812.[23,28] Larrey also popularized the use of "debridement" earlier defined by his teacher Joseph Desault, who defined it as „ a deep incision into the wound for exploration and provide drainage". Larrey used the term to describe the removal of bullets, bits of cloth, loose bits of bone and soft tissue – a procedure much less extensive than the thorough wound excision that we know today. Another British surgeon during Larrey's time was Guthrie. He also treated war casualties in the Peninsular Wars and at Waterloo.[29] In the face of limited transport and septic conditions in rear hospitals, Guthrie and Larrey advised prompt amputation on or near the battlefield for all open fractures of the extrimities and all gunshot wounds of the thigh.[30]

During the 19th century terminal ballistics and tissue damage became recognised as being a function of distance along the bullet track. The replacement of black powder by smokeless powder in the 19th century and the introduction of rifled gun barrels brought a knew

phenomenon into gunshot wounds – a more destructive feature which at first was thought to be due to „explosive" bullets.[20]

Later on in 1898, Woodruff,[31] recognised that this new destructiveness was secondary to a phenomenon called cavitation. This phenomenon has come under intensive study and analysis and has grown in importance within the past 3 to 4 decades.

The introduction of the science of bacteriology by Louis Pasteur and Koch in the later half of the 19th century brought a new turn in the management of wounds. This was reinforced by Lister's recognition that wounds were infected by micro-organisms and his introduction of antiseptic surgery when he in 1865 successfully applied carbolic acid as a chemical antiseptic to an open fracture and obtained satisfactory healing.[32] However this antiseptic solution suffered severe limitations because besides destroying the pathogenic organisms, it destroyed the normal soft tissue as well.

At the beginning of World War I H.D. Dakin[33] introduced a neutral hypochloride solution, which retained its antiseptic properties while being nonirritating to the soft tissues. There were other workers like Winnette Orr[34] , who faced with the problem of transporting wounded soldiers to the US applied a cast just over the wound before transporting them to America. He devised the following principles of management of open fractures:[34]

1..Complete primary debridement

2. Primary reduction utilizing adequate traction to achieve reduction

3. Complete immobilization

4. Provision of drainage beneath the cast

5 Frequent dressing

These principles of treatment were continued by Trueta[35] who put special emphasis on early debridement of the wound. He applied these principles during the Spanish War of 1935-1938.

During World War I W.S. Boer[36] reported his pleasant surprise on the use of maggots in his practice for the treatment of open fractures and cases of chronic osteomyelitis. So by World War I surgeons had gained substantial control over the wound infection.

Knowledge acquired though wartime experience from the management of combat casualties of the US troops in World War II, the Korean War and later in the Vietnam War indicated that ligation of major arteries was no longer the treatment of choice as earlier thought of by Guthrie,and that whenever possible reconstruction of the injured vessel was preferable. During the Korean War autologous saphenous vein interposition grafting was introduced as an additional technique for major arterial reconstruction for vascular trauma secondary to war wounds.[37] During the Vietnam war, US military surgeons made an additional modifications in the then existing protocols in the management of vascular trauma. They recognised that injury to concomitant veins should be treated with primary repair.[38]

2.2. AETIOLOGY

Open fractures are caused by a variety of factors to the human body and knowledge of the mechanism of injury is important in that it enables the surgeon to determine the optimum mode of management as well as it alerts him to seek evidence of obscure injuries known to be associated with such mechanisms.[39] Missile injuries are injuries caused by weapons of war either in civilian setting or in military situations. Missiles by definition are projectiles including bullets, pellets, landmine and grenade fragments and explosive shells.[40] The bullet is certainly the major cause but mines, bombs, explosives and artillery shell shrapnels are also a frequent cause. A firearm is a weapon which uses the energy of powder gases to project a bullet (or shell) out of the barrel bore. A weapon which fires bullets is called a gun as opposed to a rocket weapon which fires rockets (self propelled) projectiles. For almost all practical purposes and in a civilian setting, the weapon is basically one of three types: Handgun, rifle, or shotgun.[41]

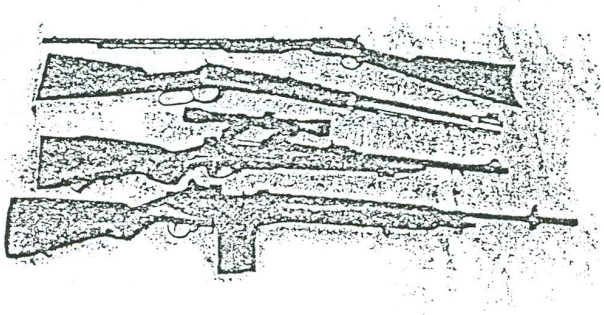


Fig.2 Various types of rifles with different firing modes

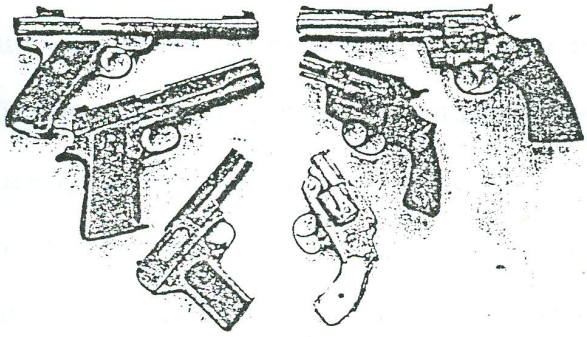


Fig.3. Various models of automatic pistols (L) and revolvers (R).

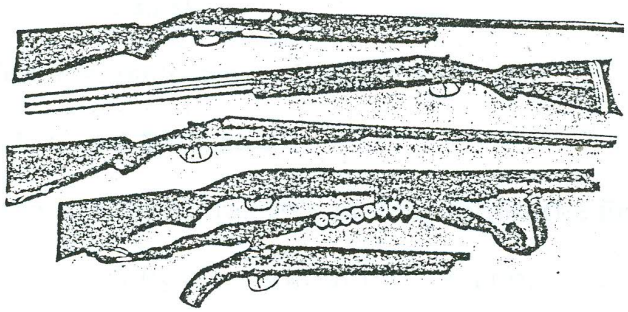


Fig.4. Different types of shotguns. Top to bottom: Semiautomatic, over and under, side by side, pump riot gun and sawed off single shotgun.

It is important that a relevant knowledge of the technical and physical attributes of firearms is known so that with this understanding, the formulation of a treatment plan is made easier. Principles of wound ballistics are also crucial to the evaluation of firearm injuries and their treatment. This is becoming more and more apparrent as the development of weaponry in recent decades has moved towards projectiles with increasingly higher velocites.[20]

2.2.1 BALISTICS AND MECHANISM OF WOUNDING

Ballistics is the science of the firing, the motion of a projectile in flight, and the effects of these projectiles in the target tissues.[41] Ballistics can be classified in three subgroups:

i) Internal ballistics

ii) External ballistics

iii) Terminal ballistics or Wound ballistics

2.2.1.1 Internal Ballistics

This is the science of projectile motion within the firing weapon. It tells about events taking place within the weapon.

Structurely the firearm will usually incoporate three main components:

a barrel

b) bullet (projectile)

c) propelling (powder) charge

Besides, the firearm may be provided with other additional mechanisms like locking, firing, extracting, feeding, sightling equipment and other mechanisms. Others include a fixture buttstock, bipod and mount, for convenient handling of the weapon and for making the latter stable during firing. A firearm weapon may be reloaded manually in which case it is called non-automatic weapon. A weapon which is reloaded through the use of energy of powder gases is called automatic. Automatic weapons are subdivided into:

Self loading weapons and

Self firing weapons

A self firing weapon is one which is capable of firing in bursts and continuously, while a self loading weapon is one which is capable of firing single shots only.

(a) The Internal Ballistics of Rifles

Despite advances in bullet design and introduction of more powerful and automatic weapons, firearms continue to operate on long established principles. Rifles and handguns operate on the same basic principles: that of a metallic case having an explosive primer in its base, and containing a measured amount of gunpowder, has a projectile (bullet) fitted into the mouth of the case by means of a press. This entire unit is called the cartridge or round. This is fed into a chamber of weapon or firearm capable of containing the pressure of the issuing explosion. When the trigger is pulled or released, the hammer strikes a metallic firing pin, driving it into the primer. This

produces a spark into the gun powder, igniting it and proppelling the bullet down the barrel. As the bullet separates from the catridge case and enters the barrel, it encounters grooves cut into the barrel called rifling, which cause the bullet to spin as it traverses these grooves machined into the barrel.These grooves help to stabilize the bullet in flight. The greater the rate of spin, the more stable will be the bullet's progress through the air. The presence of these grooves or rifling are important in wound production.

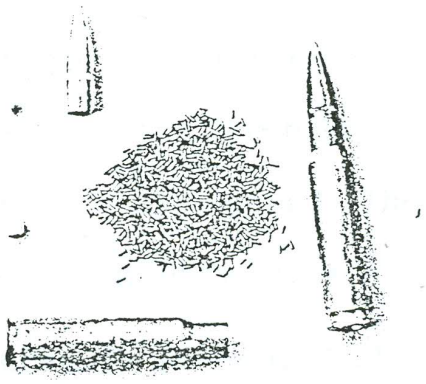


Fig.5. Intact rifle cartridge (R) and component parts (L) : Cartridge case, bullet, powder and primer.

As the bullet travels down the barrel it accelerates continuosly since the gunpowder explosion is not instantaneous, but continues as it pushes the bullet through the barrel. However, once the bullet leaves the barrel, the gases, no longer contained by the barrel, disperse, and the bullet is at its maximum or muzzle velocity.

The bullet may exit with smoke, burning gas, and some unburned powder, but the bullet is the only intact component to leave the barrel. Depending on the type of weapon, the catridge case is either retained in the weapon for later removal, or is automatically ejected at the rear of the weapon.

After its exit from the muzzle the bullet does not continue acceleration for a short distance and then starts to slow down. Once the gas pressure is removed, forward motion is decreased by the unopposed forces of air resistance and gravity. The bullet continues to decelerate until hitting the target or the ground. There are three basic determinants of the exit velocity of the bullet.[42]

(i) **The mass of the bullet**: the greater the bullet's mass, the harder it is to propel with the same amount of gunpowder.[43]

(ii) **The amount of gunpowder in the catridge**: the larger the amount of gun powder the greater the explosion. The frequently used term of Magnum version of weapons in reference to either rifles or handguns implies an improved version of an already existing catridge. Magnum version of weapons are those that use the same size, diameter, weight bullet and the same type of gun powder but

with their catridge case made longer and containing more gunpowder.[44] The amount of gunpowder placed in a catridge is limited, however, to the strength of the barrel to withstand the increased chamber pressure generated and the the amount of recoil produced. Excessive recoil may make a weapon difficult to use.[45] The velocity of a magnum version of a weapon is therefore greater and the total kinetic energy KE is also greater. Usually the magnum weapon will shoot both the magnum and the regular catridge, however, the longer magnum catridge case length prevents it from being accidentally loaded in the lesser powered weapon.

(iii) The length of the barrel: The maximum velocity of a bullet may be reduced from 5 to 40 feet per second for each inch of decrease in barrel length.[46] As soon as the bullet exits the firearm, gaseous pressure that propelled it forward quickly dissipates. The bullet then decelerates as it faces the effects of atmospheric drag[41] This is one of the reasons that rifles with their longer barrels are able to attain significantly higher velocities than handguns.

Most rifles and handguns are designated by caliber which is the approximate bore/bullet diameter in inches. For example the .22 caliber weapons may have bullets with a diameter of 0.222, or 0.224 inches, a .30 caliber weapons have bullets which which include diameters of 0.300, 0.308 0.312 or 0.323 inches etc. This classification helps to differentiate specific guns but tells nothing about their power or effectiveness.[47] European weapons are designated by millimeters which is a metric estimation of bullet/bore

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diameter. Handguns generate chamber pressures of up to 40,000 pounds/square inch (lb/sq/in) and KE up to a maximum of approximately 1,300 foot pounds (ft/lb). They are built to be shot with one hand. Rifles generate chamber pressures of up to 70,000 lb/sq/in and KE up to 8,100 ft/lb.[48,49] They are designed to be held with two hands and shot resting against the shoulder and cheek.

Rifles are the most powerfull of the three main types of small arms weapons. Rifles are capable of producing considerable tissue damage. Even smaller caliber weapons such as the .22 caliber rifle (which shoots the same catridge as the .22 caliber handgun) is capable of considerable damage because of longer barrel. The longer barrel allows an increase in the muzzle velocity from approximately 950 ft/sec in the handgun to 1,687 ft/sec in the rifle. The KE rating in the rifle is 202 ft/lb compared to only 80 ft/lb for the handgun.[50] Rifles are designed in a variety of firing modes. Among these are the pump rifle, bolt action, level action, and semiautomatic, all with a variety of calibers. Rifles come in two main classifications:

1. Those for civilian use
2. Those for military use

Today, it is important to understand both military weapons and ammunition as well as civilian weapons for several reasons:

1. It is highly likely that surgeons will continue to treat military gunshot wounds in the ever increasing wars all over the world.

2. As old military weapons are replaced by improved models, these earlier weapons become surplus and are sold to civilians.
3. In some countries there is a new trend in rifle manufacturing in that paramilitary and military versions of modern assault rifles are becoming available to both the public and the military almost simultaneously.[51,52]

Most military weapons have the capability of being fired either semiautomatically (i.e. as fast as one can pull the trigger) or on full automatic mode (i.e. the weapon continues to fire until the trigger is released). Paramilitary weapons are exact copies except for the lack of fully automatic mode. However with paramilitary weapons utilizing magazines holding from 20 to 50 rounds of ammunition, the amount of firepower produced is enormous. The disadvantage of these weapons is that although they are inherently more accurate than handguns, their weight, length and recoil make them difficult to master and are difficult to conceal.

The early military rifles were modeled after the larger caliber rifles of the times. The recent trend in military weapons has been towards projectiles of very high velocity and light weight. A good example of this is the American M-16 rifle which shoots a projectile weighing 55 grains with muzzle velocity of approximately 3,240 ft/sec. All the NATO weapons are following this pattern.[41] Militarily,this type of weapon is sensible for a number of reasons:

1. It is easier to train a soldier to shoot it because the catridge is smaller, producing less recoil
2. An infantry man can carry more extra rounds of ammunition with the same weight of combat gear because the rifle is much ligher than the conventional large – caliber military weapon.[53] The disadvantage of this type of cartridge, however is that it is not effective at ranges of more than 300 yards. Due to its light weight, poor ballistic coefficient, and high drag effects, the M-16 projectile loses velocity in air rapidly. In the M-14, for example, at 300 yards the velocity of the 55-grain projectile is reduced from 3,240 ft/sec to 2,186 ft/sec, and its KE has dropped from 1,250 ft/lb to 583 ft/lb. This now puts it in the handgun category. The older M-14 rifle with 150-grain bullet has reduced its velocity at 300 yards from 2,700 ft/sec to 2,052 ft/sec with a reduction in KE from 2,428 ft/lb to 1,403 ft/lb. This is more KE at 300 yards than the M-16 has at the muzzle. At 1,000 yards over 300 ft/lb of energy is left, which is enough to kill.[54]. The M-16 will not have enough energy at this distance to insure penetration through clothing and skin.

However at shorter distances, due to the same ballistic properties the M-16 has got unique effect on tissue destruction.Its light weight and poor ballistic coefficient cause the M-16 bullet to have very high drag and retardation effects in air. This means rapid deceleration which is equivalent to release of KE in air. Since tissue is 800 times as dense as air, energy release in tissue occurs at an even faster and higher

rate.This allows the projectile to give up a greater percentage of its energy (and greater total energy) to the target than heavier slower moving projectiles.[54] Berlin et al[54], studying on firing projectiles into anaesthesized pigs at 100 meters , found that the M-16 projectiles with a total muzzle energy of 1,224 joules, released 23.4% of their total energy or 288 joules, to the target. The M-14 projectiles, with a total muzzle energy of 2537 joules, released only 10% of their total energy or 254 joules to the target. Besides the greater total energy release, the M-16 projectile, with its high yaw angle due to its poor coefficient of essential stability and overturning moment, tumbles more quickly in the target thus causing the maximum wound channel to be formed.near the surface. Therefore at close ranges, the M-16 projectile tends to form huge, shallow, jagged or stellate wounds

At similar ranges the M14 projectile with less yaw and more energy retention due to better ballistic coefficint and less drag, causes smaller, less damaging wounds. On trunk wounds, the M-16 may have its maximum effect deep within the body cavity and destroy substantial amounts of tissue. The M-14 may not start to tumble until near the exit, thus causing still serious but less total damage. On extremities the M-16 round, because of its early tumbling effect, may completely pulverize and destroy the extremity, whereas the M-14 projectile may cause a through and through type of wound. At ranges greater than 100 meters, however the M-16 projectile loses so much energy due to drag that its wounding abilities are altered to that of a much lower powered weapon. Tikka et al[55] found that at 30 meters all

wounds caused by the M-16 projectiles were more severe than the M-14 projectile wounds, but at 100 meters the M-14 caused more severe wounds two thirds of the time.

It is interesting to note that while the military continues to modify and develop newer firearms, the trend in modern warfare has been away from wounds inflicted by small arms fire and towards wounds due to other types of weapons. In one study of arterial injuries treated in Vietnam, Rich et al[56] found that only 34.5% were due to rifle fire, 60.1% were due to fragmentation devices, and 4.4% to miscellaneous causes. Studies from the 1973 Arab-Israel war[57] showed that only 15% of all wounds were due to rifles or pistols, but 63% were due to fragmentation devices such as mines, grenades, artillery and tank shells, rockets, bombs or missiles. Statistics from the Croatian-Bosnia-Herzegovina War[58] showed that 87% of the injuries were due to mine bomb or artillery shell shrapnels, the percentage of gunshot wounds being very low. In accordance with the Hague Convention, military weapons usually shoot full metal jacketed bullets. These bullets are designed not to expand.

Rifles of civilian use, or their paramilitary counterparts, shooting civilian expanding or deforming ammunition , would cause a much greater amount of damage.The purpose of these bullets is usually to kill large, often dangerous game animals. This is accomplished by destroying as much tissue as possible to ensure a quick, one-shot kill. De Muth[45] noted in dog studies , using bullets of the same weight and

caliber ,and fired from the the same weapon, that expanding soft-point bullets produced wound volumes up to 40 times as large as full metal jacketed military bullets. De Muth used a Remington rifle and fired 150 grain .30 caliber full metal jacketed and soft-point bullet at anaesthesized dogs. He obtained the following results: The full metal jacketed bullet produced an entrance wound of 0.75 cm and an exit wound of 2cm, with a total wound volume of 23.5 cm^3. The civilian soft point expanding bullet produced a 0.75 cm entrance wound , an exit wound of 12.5 cm and a total wound volume of 917 cm^3.

Furthermore, military projectiles usually come in one standard weight. Civilian projectiles are available in a variety of weights which can increase total energy by increasing mass. The M-14 military combat projectile for example is usually approximately 147-150 grains. Civilian bullets, however can be obtained in weights from 110 to 200 grains.[59] It is thus clear from the afore said that military weapons are actually not as powefull as many other rifles obtainable for civilian use.[41] Civilian weapons with higher velocities, larger projectile masses and greater total energy ratings can inflict massive damage to the human beings on a scale not usually seen except by those who treat hunting accidents[50]. Many civilian rifles have the capability of inflicting significant amounts of tissue destruction.

(b) Internal Ballistics of Handguns

Handguns are the pistols. They are designed to be shot with one hand. They are the least powerful of the three main groups of small arms

weapons. They generate chamber pressures of up to 40,000 pounds square inch (lb/sq/in) and KE of up to a maximum of approximately 1,300 ft pounds (ft/lb).[41] These weapons have short barrels with close front and rear sites making them hard to aim, and thus are the most difficult of the three weapon groups to master. These weapons can be fired accurately usually at a distance of less than 25 yards for most shooters, even though some experienced marksmen can hit targets at 200 yards with customized handguns. Most handguns have barrels from 11/2 to 6 inches even though some handguns can be ordered with barrel lengths of up to 14 inches.[41] Shorter barrels mean less velocity, less total KE and less accuracy. Although handguns are made in more than 70 different calibers, most of the commonly used ones have calibers of between .22 and .44 magnum handguns. The majority of these do not have enough speed to reach transonic velocities and cause cavitation effects seen in rifles.The majority are therefore considered to be low velocity weapons.[60] Handguns are available in two main designs:

1. Pistols
2. Revolvers

Revolvers have a cylinder which usually holds six cartridges. They can be fired by single action (i.e. cocking the hammer manually before each shot , which is the most accurate method), or by repeatedly pulling the trigger. In the double-action method the handgun itself cocks the hammer. This is faster but less accurate. Automatic pistols usually have a vertical magazine which holds the cartridges in the

butt or handle of the gun. Once the weapon is loaded and the hammer is cocked once, it can be fired as fast as one can pull the trigger. Older model automatics usually hold from 5 to 7 cartridges. Modern models today can hold from 9 to 19 rounds of ammunition.[41] Several paramilitary automatics are capable of holding up to 32 rounds of ammunition. Handguns have one major advantage over rifles in that they can easily be concealed. They are less poweful and therefore easier to control. They have less noise, less recoil, are less expensive and lighter in weight.

Tissue Damage Caused by Handguns

Handguns are considered to be low-velocity weapons because there is not enough speed to reach transonic velocities and cause significant cavitation effects seen with rifles.[60] The damage caused by handgun bullets is usually only the tissue destroyed directly in the path of the bullet. However with conventional full metal jacketed bullets larger caliber bullets with correspondingly larger diameters will destroy more tissue. In order to increase tissue destruction, various types of projectile modifications are used. The most common one is the use of the hallow point , soft tip, expanding bullet. This theoretically allows the bullet to expand its diameter and increase tissue damage.[41] However even with soft lead hallow point bullets, most handguns, except for magnums, do not have enough velocity to induce reliable expansion with this type of projectile.[61] In low velocity non magnum guns, these bullets may deform, but usually do not mushroom.

Several other bullet innovations designed to increase tissue destruction can be mentioned just in passing:

- **The Winchester hollow point silver tip bullet-** is a light-weight, high velocity bullet with an early deformable aluminium jacket. It allows reliable expansion even in relatively low-velocity handguns.[61]
- **The Glasser Safety Slug-** the bullet consists of a lightweight hallow copper bullet filled with number 12 birdshot pellets. Because of their light weight, these bullets can approach transonic velocities. When this bullet impacts on the body, it ruptures, releasing its pellets in all directions. Because round pellets have the worst shape, they rapidly dicelerate, releasing all their energy to the target. This means huge surface wounds and massive tissue destruction.
- **The .38 Special +P caliber bullet-** is fired from a reinforced .38 caliber handgun capable of adding a few hundred feet per second to the bullet velocity. This increases its KE to somewhere near the low end of the .357 magnum spectrum.
- **The Teflon-coated bullet** – does not do more damage than any other pointed projectile but penetrates soft body armor.[41]

Despite these advances in firearm industry one important point should be borne in mind: that any caliber can kill a human being if a vital structure is hit.

The major objective in wound production is to incapacitate the assailant by inflicting a lethal wound. This objective is achieved by delivering as much KE to the system as rapidly as possible.This is attained in several ways:

1. The use of large calibers which punch out more tissue
2. Use of rapid expansion of the bullet to increase the cross-sectional diameter in the direction of motion and thus increase the drag force. This in turn increases the energy released to the target.
3. To ensure bullet fragmentation, which prevents over-penetration and maximizes energy release and tissue damage.[62]

The continuing emphasis, in ballistic science and firearm industry for large-caliber, high velocity, fragmenting or hallow point ammunition, unfortunately means for the medical science, larger and more complex wounds and fewer successful resuscitations.

(c) Internal Ballistics of the Shotgun

Shotguns are popular weapons worldwide and more of these weapons exist than the rifled type of weapon.[49] Many countries (e.g. Great Britain, Tanzania, Russia) discourage the use of rifles but allow the unrestricted use of shotguns.[49] Shotguns are the earliest form of hand-held weapons. They are called smooth-bore weapons because they generally have no rifling in their barrel. Shotguns are classified as low velocity weapons propelling missiles at a velocity of less than 2,500 ft /sec.[63] They are designated by gauge instead of caliber. The gauge indicates the number of lead balls of a specific diameter (made

from one pound of lead) that would just fit into the barrel of the gun. In other words the gauge of a shotgun refers to how many lead balls of an appropriate size are required to weigh a pound.[63] For example a 12 gauge weapon originally had a bore enabling a lead ball weighing 1/12 of a pound to enter its barrel. A 16-gauge shotgun would accept a ball weighing 1/16 of a pound etc. etc. There are two important exceptions to this rule: The 9 mm shotshell which has a 9 mm bore and the .410 gauge which is actually .410 caliber or inches in diameter.[63]

In a 12-gauge shotgun the barrel opening would be .729 inches, the size of a lead ball weighing 1/12 of a pound. Hence as gauge number decreases, the bore opening increases in size. Number 6 shot and smaller is referred to as 'birdshot ' while number 2 shot and larger is referred to as 'buckshot'.

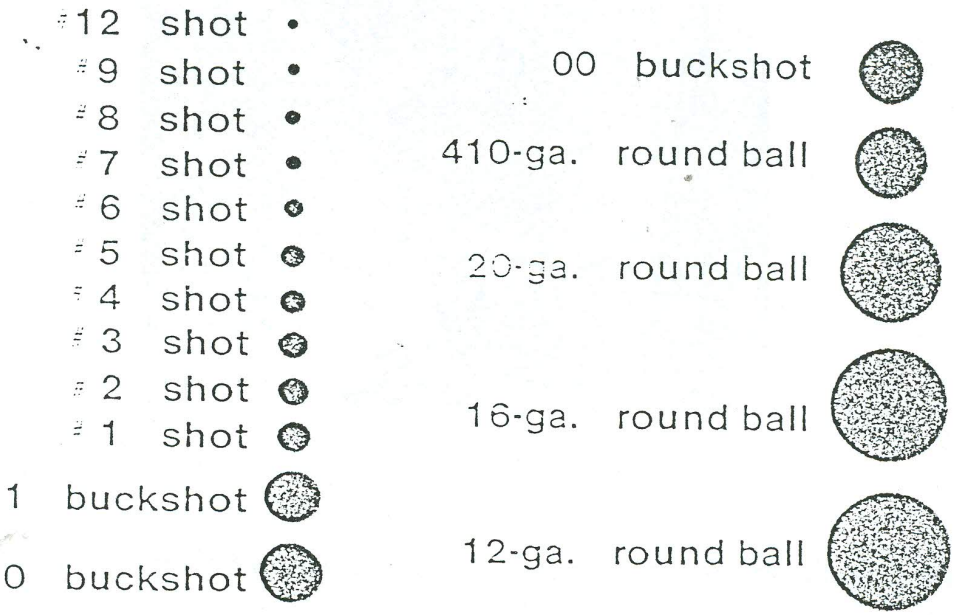


Fig. 6. Sizes of the shotgun shot in various gauges

Shotguns are also available in various forms : single shot, breech loaders, bolt action, double barrel over and under or side by side, pump action and semi-automatic.

The Shotgun Shell

In contrast to the rifle and handgun the shotgun shoots multiple pellets instead of a single bullet. The pellets of a shotgun are held in a shotgun shell, not a cartridge. A brief description of the shotgun shell make-up and its behavior may serve to clarify certain terms. (Fig.5, 6,7,8,9)

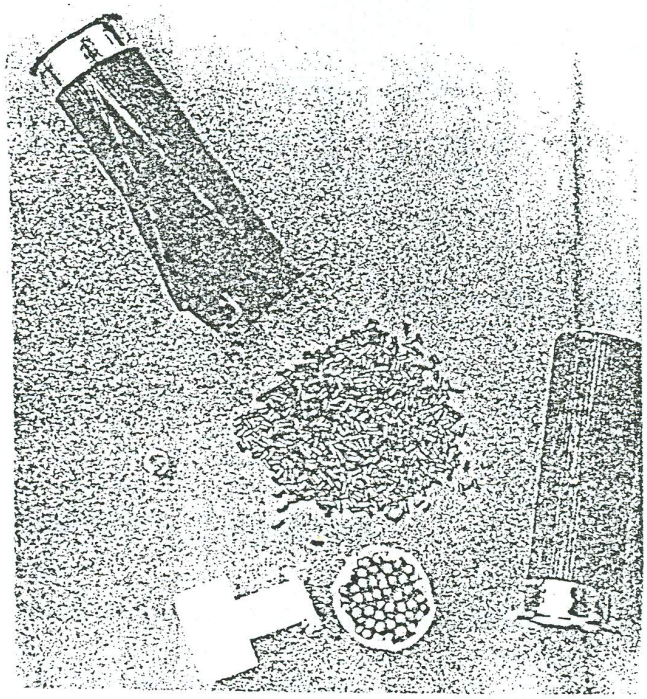


Fig. 7: Intact shotgun shell (R) and ist component parts: plastic shell with metal base, powder, primer, plastic wadding and pellets.

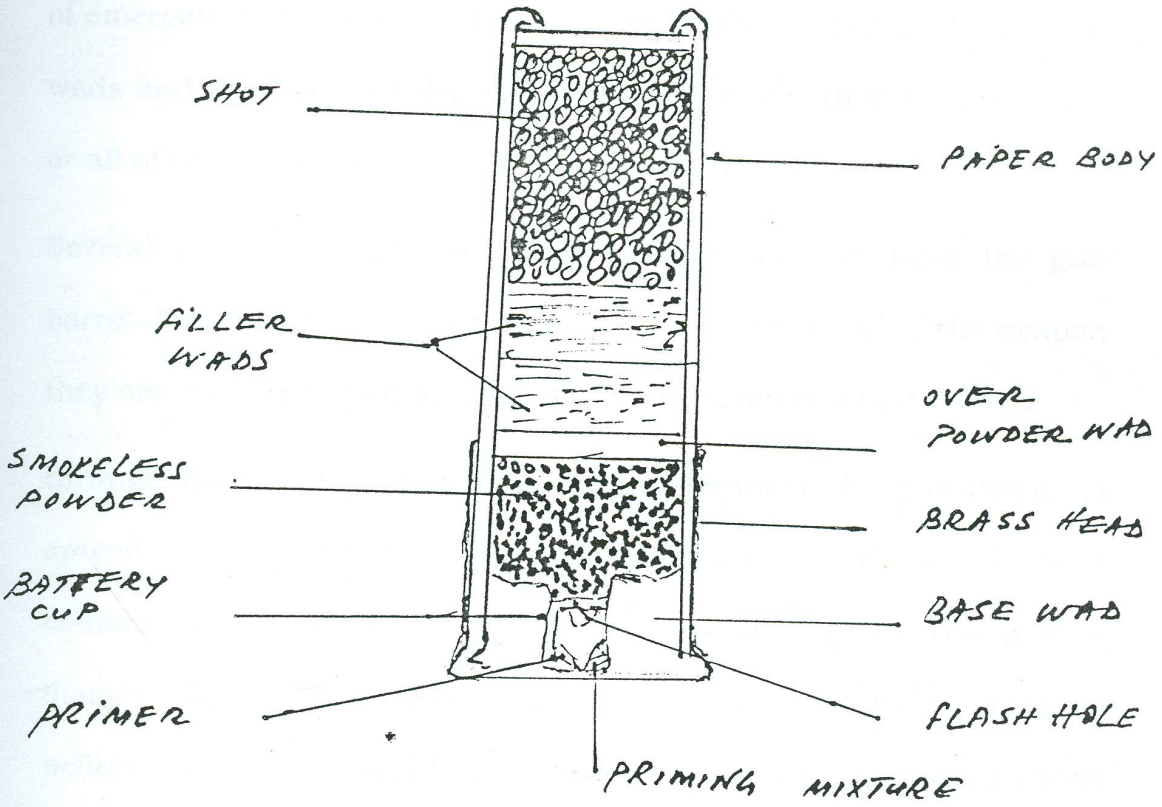


Fig.8. Cross section of a shotgun shell.

The shotgun shell consists of a paper or plastic body, brass head at one end, primer, base wad, powder charge, over powder wad, filler wads, shot charge and folded crimp. The plastic cylinder with a metal base houses the primer. Powder is contained in the metal base.

During firing the powder consumes itself creating gases that rapidly expand and force the tightly sealed nonporous overpowder wad

against the filler wads which may be porous. The crimpled end is forced open by the shot forces and the cylindrical mass of shot escapes from the shell and passes down the gun barrel. The sequence of emergence from the the gun barrel will thus be: the shot, the filler wads and the over- powder wad. At ranges of less than 6 meters any or all of these components may be propelled into the wound.[63]

Several changes occur after these elements emerge from the gun barrel. First of all as the shotgun pellets leave the barrel of the weapon they are bunched together tightly together. However as they travel

through the air they start to spread out peripherally. The degree of spread is determined by the choke of the barrel (which is a constriction at the end of the barrel which reduces the muzzle diameter by 0.003 to 0.004 inches. The greater the choke the less the pellets spread out in flight. Chokes come in various degrees; full choke , improved , modified (3/3) choke, half choke, modified (½ choke) and true cylinder or no choke. A full choke barrel may allow only 15 inches of pellet spread at 20 yards, a true cylinder barrel may allow up to 30 inches of pellet spread at 20 yards. Choke can be altered to allow maximum pellet spread by cutting off the majority of the barrel. This so called 'sawed off' shotgun affords the ability to hit multiple targets with one shot due to maximum pellet dispersion and affords the criminal ease of concealment.[65] The heavier lead of the shot cloud travels both faster and further than the wadding.

In a full choke gun 11/4 ounces of shot emerges from the muzzle as a cylindrical collection 1 inch long and ¾ of an inch in diameter. At 40 yards the collection becomes a cloud measuring from 10 to 13 feet in length and about 40 inches in diameter (fig 9).

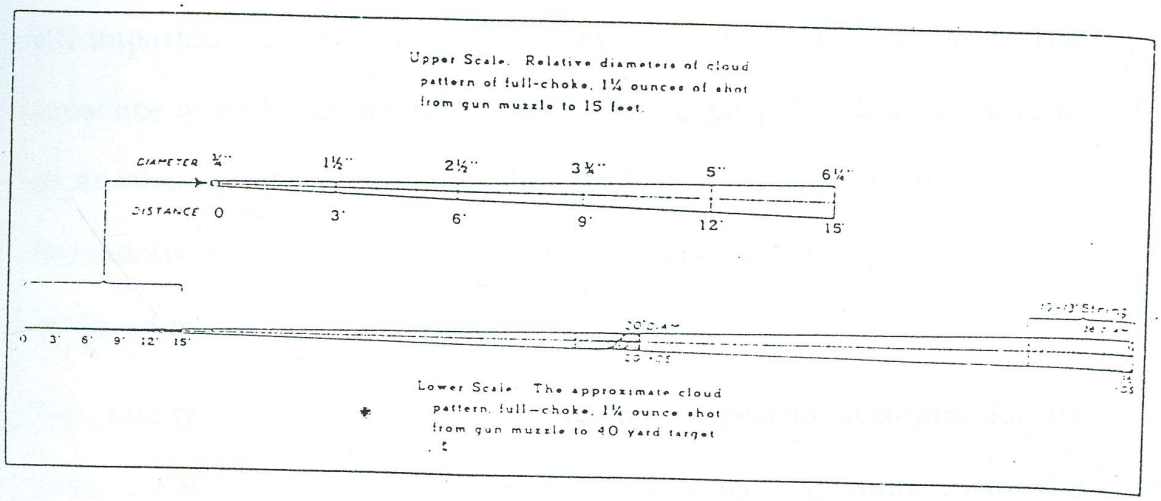


Fig. 9. The shotgun cloud pattern which increases as distance increases.

Shotgun shells also come in magnum rounds, but unlike the magnum handguns and rifles here magnum means more pellets not large increases in velocity[64]

Shotgun wounds therefore differ from those of other missiles. The spectrum of severity of wounds is large, the amount of damage varying mainly with the weapon-victim range and the type of weapon and shot used. This is accounted for by tendence of the pellets to scatter as they travel. Although shotgun are low velocity weapons, at close range the entire charge strikes the target as a single missile with a KE similar to that of a high velocity military rifle[65] At longer ranges with pellet scatter the charge acts as multiple individual missiles,with the KE imparted separately by each pellet which strikes the target[66] The presence of wadding material which can be propelled into the wound is another aspect of shotgun-shell ballistics. Due to their potential harzadous effects on tissue, wadding must always be sought and removed by wound debridement or irrigation.[63]

The ability of the shotgun to disperse its pellets accounts for its unique wounding characteristics. At close range (e.g. contact with the skin to about 4 ft from the target), the pellets stay together and act as one mass. It does not matter if the load is nine 00 buckshot pellets or 2,385 number 12 birdshot pellets as both weigh approximately 546 grains and act as one solid projectile. With muzzle velocity averaging 1,300 ft/sec., this gives a KE of approximately 2,100 ft/lb. At this range the entrance wound would be a single hole about 1 inch in diameter. Also at this range one would expect the wadding to be deep in the wound cavity. If the charge went through,glass, wood. or clothes this material would also be found in the wound[67]. At intermediate ranges of 4 to 12 ft the entrance wound could be up to 2

inches in diameter, and individual pellets would start to spread out from the single mass, producing separate holes on the borders of the main entrance wound.

Wadding and other material would still be in the wound, but nearer the surface. At distant ranges (beyond 12 feet) , the degree of pellet spread depends on the choke, barrel length and type of ammunition.[68,69]

As the pellets spread out, the total KE available is evenly distributed among the separate pellets. Now the number of pellets becomes important. When firing 00 buckshot with 9 pellets in the load , the total energy of 2,000 ft/lb is divided among the pellets for an individual KE of about 200 ft/lb per pellet. With 260 to 280 number 6 birdshot pellets, the energy averages to 7.21 ft/lb per pellet.[66]

It is obvious that a person hit with only one or two pellets will sustain greater injury on contact with the larger pellet. In fact one 00 buckshot pellet weighing 48 grains at 1,300 ft/sec. is equivalent to being shot with a .22 caliber rifle at close range. Being shot with the single number 6 birdshots weighing only 1.5 grains would do minimal damage.

As the individual pellets spread out and travel through the air they continuosly lose KE according to the drag formula. Because lightweight spheres have the worst ballistic coefficient, they lose this energy very rapidly. After travelling approximately 8 yards most pellets will not penetrate skin. The majority of the pellets will lose all their

energy and hit the ground within 200 yards. In comparison, many rifle bullets can travel 3,000 to 5000 yards before losing their energy[70,71]

The same design that gives shotgun pellets a very poor ballistic coefficient and large retardation effect ensures their ability to destroy huge quantities of tissue at close range. Since human tissue is 800 times as dense as air, these pellets will decelerate even quicker in the body than air, releasing all their energy to the target tissue. Even point blank shots rarely form exit wounds . Furthermore, as the pellets go through doors, clothes, skin etc. they tend to spread greater angles causing a type of pseudo-fragmentation[68]

2.2.1.2 External Ballistics

External ballistics is the science that describes the flight of a projectile through the atmosphere as it travels to the target. It tells about events while the projectile is in flight.

The Kinetic Energy Theory

Velocity (V) and Mass (M) are one of the major factors determining the effectiveness or wounding capability of a missile.[41] Damage to the tissue depends upon the amount of energy liberated during transit of the missile through the target tissue. The Kinetic Theory claims that the KE of a missile is proportional to the velocity squared as expressed by the formula:

Kinetic Energy (KE) = $\frac{1}{2}MV^2$

Where V = velocity in ft/sec

Mass(M)= $\frac{W}{7000\ g}$

Where W = weight in grains

g = gravity = 32.174 ft/sec

Therefore KE = $\frac{1}{2}\ \frac{WV^2}{27,000\ g} = \frac{WV^2}{450,435}$ ft/lb

The kinetic energy, KE, of a missile is hence proportional to the mass of the missile times the square of its velocity. The resulting KE, thus, provides an indication of the missile's potential for tissue destruction[72] According to this theory the degree of velocity at target impact or striking velocity is the most important determinant to wounding capability[73]

As the missile travels from the weapon to the target some energy is lost due to air resistance. The missile's KE delivery to a target is dependent upon its ability to overcome air resistance as it travels from the emiting weapon to the target[41]. The amount of energy lost depends on the ballistic coeficient of the missile which is based on the sectional density and shape of the missile. The ballistic coeficient expresses a projectile's ability to overcome air resistance and retain maximum amount of velocity and KE possible.

Thus Ballistic Coeficient (BC) = $\frac{SD}{I}$

Where SD = sectional density

And where I = the form factor for the missile shape

$SD = \frac{\text{Mass (M)}}{\text{Diameter}^2\ (d^2)}$

Therefore $BC = \frac{M}{Id^2}$

Since SD is proportional to mass (M) and inversely proportional to d^2 this simply means that missiles with large masses and small diameters have a larger sectional density. I denotes a form factor of the missile also called an Ogive.

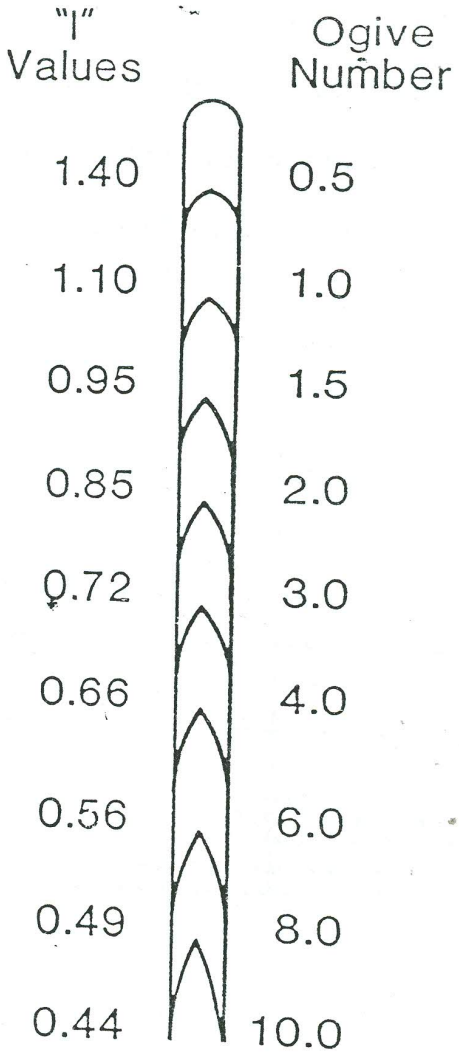


Fig. 10. Showing the relationship of .22 caliber missile nose shapes (Ogives) to the form factor I. The more pointed the nose the smaller the I value, resulting in a better ballistic coefficient.

Pointed bullets have less resistance to air , and thus have smaller Ogive values than round or flat nose bullets. The best ballistic shape , therefore would theoretically be a heavy, long, thin needle, and the worst shape would be a very light round pellet. In practical terms, of course the needle shape would probably do minimal damage to the target, while the round sphere lose most of ist energy overcoming air resistance and not reach the target at all. Projectiles with a BC of .223 or less lose up to 16% of their velocity every 100 yards, but with a BC of .410 or greater, lose only 8% per 100 yards.[33]

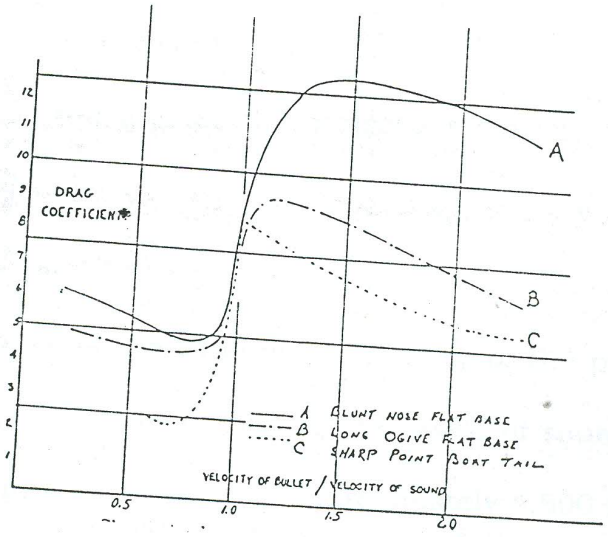


Fig. 11. Change in drag coefficient determined by plotting bullet velocity (in ft/sec.) against the velocity of sound (in thousands of ft/sec.) for three projectile shapes. Adopted from Barach E, et al. J. trauma 26(4):374-383, 1986.

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The force opposing forward motion of a projectile is termed Drag.[66] Drag is expressed in the following formula:

$D = f (v/a) k \& p d^2 v^2$

Where f (v/a) = Drag Coefficient

v/a = mach number : the ratio of the velocity of the projectile to the velocity of sound in air or tissue.

K = constant for projectile shape

& = constant for deviation from linear flight (yaw)

p = density of the medium the projectile is travelling through.

d = density of the projectile

v = velocity of the projectile.

This means that the greater the projectile's velocity the greater the drag on the projectile.

The Mach Number

The mach number is the ratio of the velocity of the projectile to the velocity of of sound in air or tissue. The speed of sound in air 1,100 ft/sec while in muscle tissue it is approximately 4,500 ft/sec[51]. It has been found experimentally that the march number is a limiting factor for drag forces, as a projectile approaches this number, drag increases rapidly until the mach speed is reached, and then plateaus off at a higher level.[67]

This occurs because molecules of air or tissue have a limited ability to absorb energy by molecular vibration. Near the transonic velocity of a specific medium, the molecules can absorb no further energy, are

pushed violently apart, and then collapse back together, as in a sonic boom from a jet plane. As seen from the figure (figs. 10 and 11) the rate of drag increase also depends on the bullet shape. Therefore as a projectile approaches the transonic velocity for a specific medium, its rate of deceleration due to drag (and thus its rate of KE release) is even greater than expected from a pure linear relationship between velocity and drag effects of the projectile[67]

Retardation

The degree to which a particular projectile is slowed down by drag is called retardation. This can be expressed in a formula. Thus:

$$r = \frac{D}{M}$$

$$r = \frac{f(v/a)\, k \,\&\, p\, d^2 v^2}{M}$$

where M= mass

D = Drag

Since $BC = M/Id^2$ it means that there is an inverse relationship between BC and retardation. At any given velocity, projectiles with larger BC 's are retarded less than projectiles with poorer ballistic coefficients.[57]

As the bullet travels through the barrel of the rifle, spin is imparted to it by the rifling in the barrel. This spin helps to stabilize the bullet during its course. If there were no spin to the bullet, it would tumble end over end in the air. However, bullets tend to be more stable in

flight.[41] However, the ability to overcome tumbling is imperfect and the bullet still possesses a degree of deviation from the axis of flight which is called yaw.

Yaw

Yaw is the deviation of the long axis of the projectile from the longitudinal axis of flight. This occurs as the projectile rocks back and forth on its center of gravity.[76] Findings from ballistic studies show that bullets fired from a properly designed rifle yaw no more than a few degrees in flight (1-3 degrees in air) regardless of velocity, and in their path through tissue, all nondeforming, pointed bullets and some round nosed ones, yaw 180 degrees, ending their path travelling base forward.[77] The severity of the yaw forces is determined by the rate of spin. Higher rates produce a more stable flight . These forces diminish the further the bullet travels, until at approximately 100 meters the bullet's flight is very stable[78].

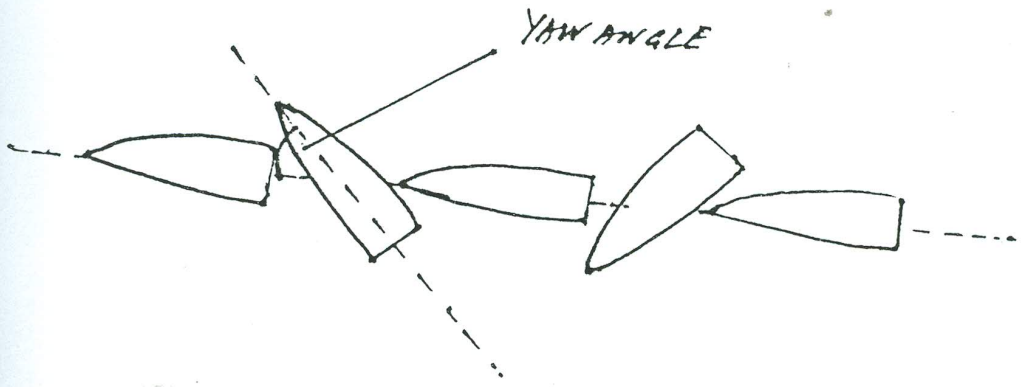


Fig. 12. Yaw and yaw angle

Tumbling

This is the bullet's action of forward rotation around the center of mass (Fig. 13).

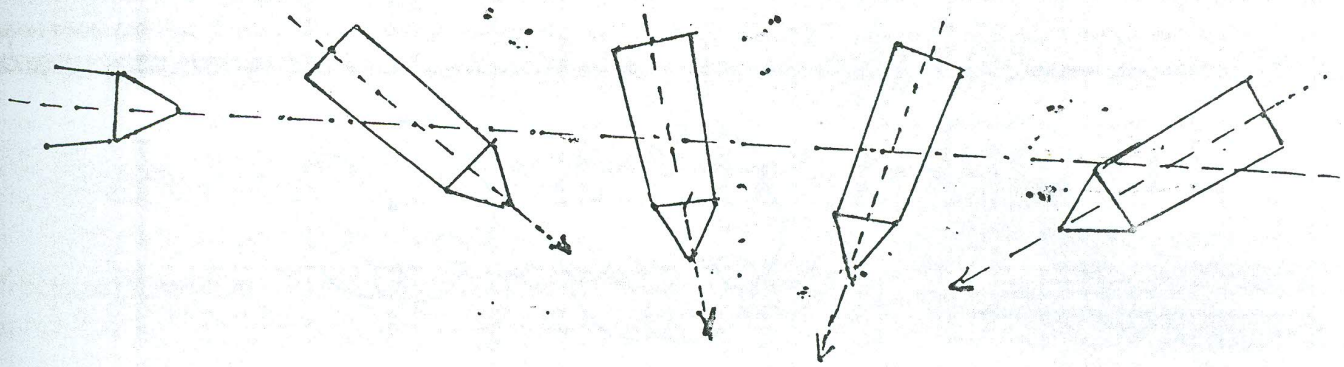


Fig. 13. Tumbling of a missile

Procession

The bullet also possesses properties called procession, which is a circular form of yaw in which the bullet nose traces gradually smaller circles in the air.

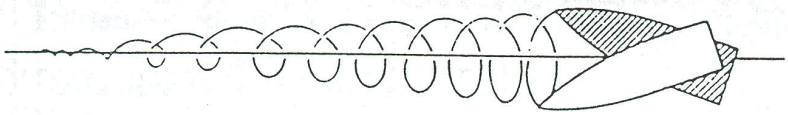


Fig 14. Procession of a missile

Nutation

Nutation is bullet motion in which the bullet nose traces a rocette pattern in the air.

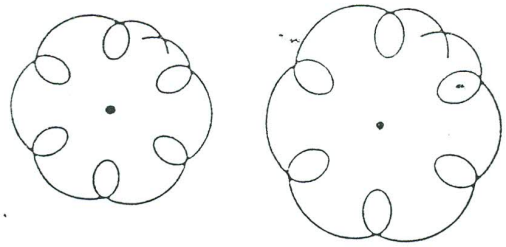


Fig. 15. Nutation of a missile

2.3.3 TERMINAL BALLISTICS AND TISSUE WOUNDING

Terminal ballistics is the study of a projectile's action in the target medium. It tells about events at target impact until rest. When the target medium is human tissue this is more properly called wound ballistics.[41]

Factors Affecting Tissue Wounding Capability

1.The Kinetic Energy (KE) Release

All the forces acting upon the bullet in air play an important role in the production of the wound channel. But one of the classical

determinants of tissue damage is the release of kinetic energy to the target.[45] Tissue wounding is proportional to the KE the missile has upon impact on the target and that on exit. The total energy released to the target tissue can therefore be represented by:

$KE = 1/2MV^2$

KE = KE (at entry) - KE (at exit)

From this formula it is evident that a higher entry KE (by increasing missile mass or velocity) has a higher KE and thus a higher potential for wounding.[79] However, if the KE on exit of the missile is still high, then relatively minor tissue damage may result. For example, a bullet that passes cleanly through the target and exits with a significant amount of its velocity will not cause as much damage as a bullet with similar entry KE that completely decelerates and comes to rest within the target.[80]. Also, projectiles with a higher impact velocity have a greater drag within the tissues, and hence have a greater KE.[64] The design of bullets has been directed towards maximizing this difference between the KE of impact and that of exit, thus increasing the damage that these bullets inflict.

2. Other Factors Affecting the Wounding Capability of a Missile

Several other factors play a role in determining the wounding capability of a missile:

(a) The Importance of Yaw in Wounding Capability

When the projectile impacts upon the body (which has an average density 800 times that of air) the spiraling force imparted to the bullet by the barrel of the weapon is insuficient to maintain bullet spin.[81]

Residual yaw becomes very important once the target is struck. Projectiles with a greater degree of yaw start to tumble inside the target much sooner than projectiles with a smaller yaw angle at impact.[64] The degree of yaw at impact is also contributed to by the projectile mass.

Bullets with lighter mass are less able to overcome yaw in the air, even with the same spin rate as heavier projectiles. This ability of a bullet to overcome yaw in air is called Coefficient of essental stability.[82]

Another factor determining the tumbling effects in the target is the overturning moment of the bullet which simply means that a shorter, higher velocity projectile tumbles more quickly in the wound.

Bullet yaw in tissue is an important consideration in wound production and should not be confused with bullet yaw in flight which is of negligible consequences.[77] Data from ballistics studies show that bullets fired from a properly designed rifle yaw no more than a few degrees in flight regardless of velocity (1- 3 degrees) and that in their path through tissue, all non-deforming, pointed bullets, and some round-nosed ones, yaw 180 degrees ending their path travelling base forward.

(b) The importance of Tumbling in wounding Capability

There are two major reasons why tumbling of a projectile in the body is important in wound production:

(i) Tissue displacement: As the projectile tumbles 90 degrees perpendicular to the axis of forward motion, it displaces much more tissue.

(ii) Facilitates the Release of KE to the target Tissue: Tumbling is one way by which KE is given up to the target, hence producing tissue destruction.

Recalling the retardation formula that retardation is directly proporional to the square of of the diameter one can see that as the bullet tumbles 90 degrees to its axis of flight, its forward diameter is greatly increased. This in turn increases the retardation force on the bullet and bullet decelaration in the target is equivalent to the energy given up to the target. This release of KE at 90 degrees of yaw can be up to 20 times the energy release rate at 0 degrees of yaw.[54]

(c) The importance of Site of KE Release in Tissue Wounding

The exact site of KE release is also important. The bullet which tumbles quicker and reaches 90 degrees of yaw sooner, releases more KE near the surface. The more stable bullet which tumbles more slowly, releases its KE later and deeper into the target tissue.[83] This could mean the difference between a huge surface wound with little internal damage, and a deceptively small entrance wound with massive destruction to the deep organs.

(d) The Importance of the Velocity at Impact in Tissue Wounding

Recalling again the retardation formula we note that velocity squared directly affects the degree of retardation. We can see that as striking

velocity is increased the retardation is also increased, the bullet decelerates faster, and more KE is released to the target tissue.

(e) The Significance of Missile Mass in Tissue Wounding

Looking back again at the retardation formula we see that as mass of the projectile increases, retardation decreases, less energy is given up, and the bullet penetrates further. This is important when designing a bullet to kill large, thick-skinned animals. But this same bullet when used on a smaller animal will tend to overpenetrate and exit the target.[64]

(f) Interactions Between Projectile and Target Tissue

Interactions between the projectile and the target tissue play a major role in influencing the resultant amount of destruction.[77] There are 4 major tissue phenomena which occur when the target is struck.[56,69]

(i) Temporary cavity formation

(ii) Permanent cavity formation

(iii) Sonic waves

(iv) Pressure waves

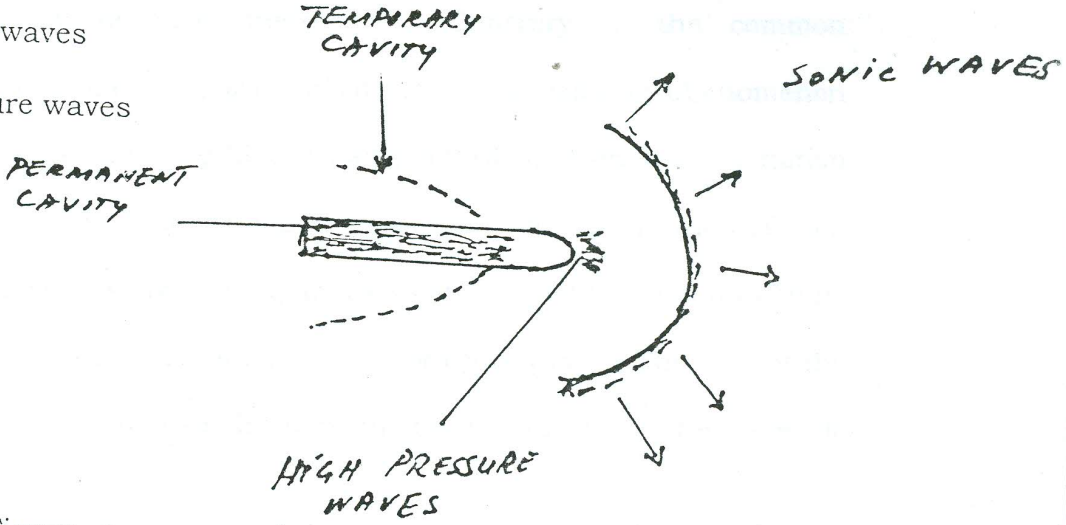


Fig. 16. Tissue pressure phenomena caused by bullet entry into tissue.

Cavity Formation

A projectile produces tissue wounding by two mechanisms.[84]

1. By crushing
2. By stretching

Crushing

A projectile crushes the tissues it strikes during penetration. Tissue crushing produces what is commonly called the permanent cavity or permanent cavity formation.

Stretching

A projectile also stretches surrounding tissue outward from the missile path. This is responsible for what is called the temporary cavity or temporary cavity formation.

(i) The Temporary Cavity Formation

Temporary cavity formation is a critical factor in the wounding mechanism of a missile. Temporary cavity formation is due to the stretching of the tissues, their elastic recoil and trapped air sucked into them by negative pressure.[60] Contrary to the common misconception that temporary cavitation is a ballistic phenomenon associated only with very high velocity missiles, temporary cavitation is not exclusively a phenomenon associated with projectiles of high velocity. All bullets produce temporary cavitation[64,77] Even handguns of very low velocity form a small temporary cavity.[64] The size of the temporary cavity enlarges dramatically as the velocity of the projectile increases.

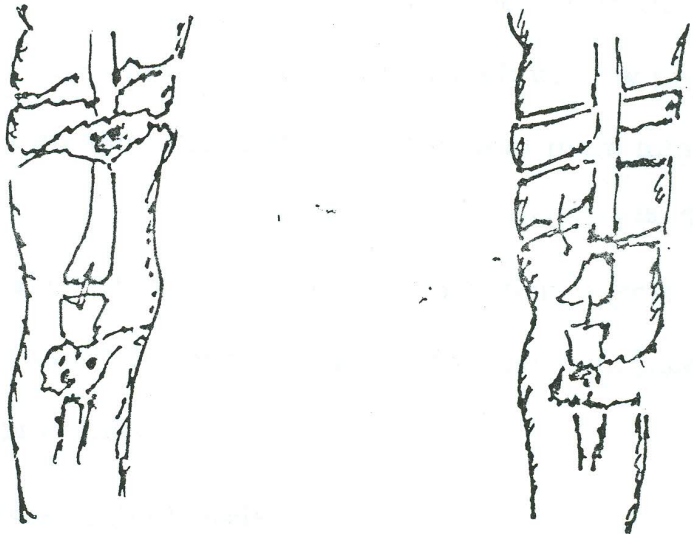


Fig. 17. Examples of wounds due to high-velocity missiles, some of which may appear deceptively harmless.

Temporary cavitation stretches tissues and therefore blood vessels near the wound tract can be lacerated without direct penetration. Similarly nerves near the wound channel can be damaged or destroyed producing sensory neuropathies or loss of motor function.[85] The exact location and size of this temporary cavity depends upon several factors, namely: the projectile's velocity, shape, mass, design, tumbling and fragmentation effects of the missile.

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a) The missile's Velocity

The greater the velocity, the greater the retardation and thus the greater the amount of KE released to the tissue. Several studies have shown that very high velocity projectiles release a greater percentage of energy and more total energy to the tissues than slower moving projectiles.[55] This energy is released sooner, due to retardation effects, and thus the wound formed is closer to the entrance site of the projectile.[86]

b) Mass of the Missile

According to the retardation formula, the smaller the mass of the missile, the greater the retardation. The greater the retardation the greater the energy release which is equivalent to the rate of deceleration in tissues. The bullet of the M-16 for example is not an expanding projectile. Low mass is necessary for it to produce cavitation effects. In order for it to form a large wound cavity it has to obtain maximum drag due to its light weight according to the retardation formula.

Rifles shooting soft-tip expanding bullets act differently. In this case more mass is beneficial. From the drag formula drag force is directly propotional to the diameter squared of the projectile. By expansion of the bullet, a larger bullet diameter is obtained in the direction of flight and more mass means more metal available for expansion. As the bullet

'mushrooms' out, small pieces fragment off the edges causing a loss of total mass.[64]

c) Tumbling Effects of the Missile

Tumbling is very important in the production of the temporary cavity because the temporary cavity spreads outwards from the nose of the bullet. This means that at 90 degrees of yaw its forward diameter is effectively increased, this greatly increases the temporary wound cavity diameter. The actual size of the cavity is modified by the type, density, elasticity, contractile state and thickness of the tissues.[64] The sooner the bullet tumbles and achieves 90 degrees of yaw the sooner the maximum cavity size will be reached. Studies have shown that the maximum cavity size occurs near the point of maximum projectile retardation.[87]

d) The Missile Design

As already discussed above missile interaction with the tissues plays a major roll in determining the wounding capability of any firearm. Bullets used for military purposes for example, form different kinds of wounds than those for civilian use. The design of military bullets is bound by the Hague Convention regulations of 1899 which mandated that these bullets be surrounded by a full metal jacket.[41,64] An inner core of lead and various other metals is completely surrounded by a hard outer shell of copper, cupro-nickel

steel, or other metals with high melting point. This sort of composition serves two major purposes:

First, it allows for higher weapon velocities, since unjacketed lead cannot be fired faster than 2,000 ft/sec, because of stripping of the lead within the barrel of the gun.[76] Secondly, this prevents expansion of the bullets on impact and theoretically prevents bullet break-up, although at very high velocities even full metal jacketed bullets can fragment without hitting bone.[45]

Civilian ammunition design is not governed by the Hague Convention and hence bullets do not have to be jacketed. Many of these are therefore of the expanding type. The bullet core which is soft, very pliable and exposed at the nose, rapidly expands on impact. The expansion can be further enhanced by the use of hallow point bullets where a depression is made in the bullet nose which increases the bullet's surface area presentation to tissue and further increases expansion.[88]

With the expansion of the bullet, there is constant increase in its diameter in the direction of flight. This also increases the wound channel. Since retardation is dependent on diameter squared, and retardation is equivalent to energy released to the target, expanding bullets release a continuously increasing amount of energy over the wound course. Both the permanent and the temporary cavities are greater. De Muth[45] has shown that using bullets of the same weight and caliber, fired from the same weapon, expanding bullets produce a

wound volume 40 times larger than military ammunition. Because bullet fragmentation can have a significant adverse effect on the tissues, it is often quite possible to see much more devastating wounds with weapons fired from civilian firearms.[89]

New bullet designs have been introduced by bullet manufacturers. These are designed to either deform or fragment within the target. These designs provide maximum deliverence of KE and increase in the size of the permanet cavity. A few examples :

The hallow-Point Bullets- Already mentioned, these expand to double their bullet diameter on impact.[90,91]

The 'Glasser Safety Slug'-These are shot shells which contain pellets in the bullet tip which disintegrate into the tissues upon impact.

The 'Devastator' – These bullets explode upon impact and can produce massive internal damage.

The last two types were designed for use by law enforcement agents in situations where innocent bystanders near the target victim may be endangered by passing of the bullet through the intended target. Even though little is known about the risk of in-vivo retention of undetonated exploding bullets, it is advised that extreme care must be taken during their removal because simple manipulation can cause them to detonate.[90]

(e) The Missile Shape

Missile or bullet shape has an effect on the velocity at which cavitation due to transonic flow can occur. At approximately 4,260 ft/sec

pointed projectiles moving with their noses in the direction of flight will form transonic flow.

Blunt nosed projectiles begin cavitation at approximately 2,625 ft/sec. Any projectile at 90 degrees of yaw can induce pressure waves at only 1,968 ft/sec.[84] Many rifles shoot at least 2,000 ft/sec. Hence they all have some degree of cavitation due to tumbling action. Many rifles in civilian use have even higher velocities, larger masses, and utilize expanding bullets. The cavitation effects they can produce can be much greater.

(f) Fragmentation Effects of the Missile

Fragmentation of a projectile is an important factor in wounding capability. Expanding bullets lose mass as they mushroom out, with multiple small fragments breaking off and reducing the overall bullet weight up to 77 % of its total.[93] These fragments act as secondary missiles which can further lacerate tissues and form their own miniature wound channels. They may lacerate tissues at multiple sites causing complete dissection of the tissue, thus increasing the wound size.[93] Even though military bullets are jacketed and do not expand, at the high velocities encountered today (3,240 ft/sec muzzle velocity for the American M 16 rifle) they can deform and fragment even in soft tissue.[93,60]

If the bullet hits and shatters bone, these bony fragments also become secondary missiles and destroy tissue.[93]

The Effects of Temporary Cavitation on Tissue

The effects of temporary cavitation will depend on the tissue struck, namely on the density and elasticity of the tissue struck.[64] Highly elastic tissue like the lung, with a specific gravity of 0.4-0.5 will easily accomodate the stretching created by the temporary cavity and will thus suffer least from cavitation effects. Fat with a specific gravity of 0.8 fares worse than lung. Muscle with a specific gravity of 1.02 sustains some damage from cavitation but due to its inherent elasticity , the damage is not that great. Other less elastic structures, such as the liver, spleen, with average specific gravity of 1.01-1.02 or a structure contained by an inelastic tissue such as the brain may be seriously damaged by this wave. Bone including the skull is inelastic and high velocity projectiles produce secondary missiles by fragmentation.[94,95]

Due to the variability of damage secondary to temporary cavitation, clinical judgement must be utilized in determining the actual tissue damage. For most part, the surgeon should concentrate on tissues that are clearly not viable and perform a re-exploration of the tissues that may have been injured by secondary effects. With the often massive size of the temporary cavity produced by modern day firearms, excision of the entire cavity is not only unwarranted but also often impossible.[96] According to Fackler, the widespread dogma that high velocity missiles cause wounds that must be treated by extensive excision of the tissue around the missile path whereas those caused by low velocity missiles need little or no treatment needs to be taken

with caution.[96] He argues that cavitation is after all no more than a transient displacement of tissue, a stretching, a localized blunt trauma, elastic tissues such as the bowel wall, the lung.and muscle, are relatively resistant to damage from such stretching, while solid organs such as the liver are not.[97] It has been demonstrated that most muscle stretched by temporary cavitation survives and this survival has been verified in every case in which muscle was allowed to remain in situ and healing was followed to completion.[77]

(ii) The Permanent Cavity Formation

The permanent cavity which is produced by bullet entry consists of the tissue which is crushed or punched out directly in the path of the bullet. All bullets produce a permanent cavity. Its actual shape and size depends on the bullet's diameter and if and when it tumbles.[64] Fackler et al have experimentally demonstrated that different permanent firearms can produce markedly different permanent cavities, depending on the interaction of the bullet with the tissues.[77,84]

Since the wound that a penetrating projectile causes is characterized by the amount of and location of tissue crush (i.e. permanent cavity) and stretch (i.e. temporary cavity) produced, .Fackler performed experiments by firing various weapons into a gelatin tissue 'simulant' that had been calibrated to reproduce the projectile penetration depth, deformation and fragmentation observed in living animal tissue. He then examined the resultant damages. These data were presented as wound profiles which illustrate the amount, type and location of

tissue disruption, projectile mass, velocity, construction,and shape (before and after the shot, as well as projectile deformation and the projectile fragmentation pattern. [84,93,97] (Figs. 18-22)

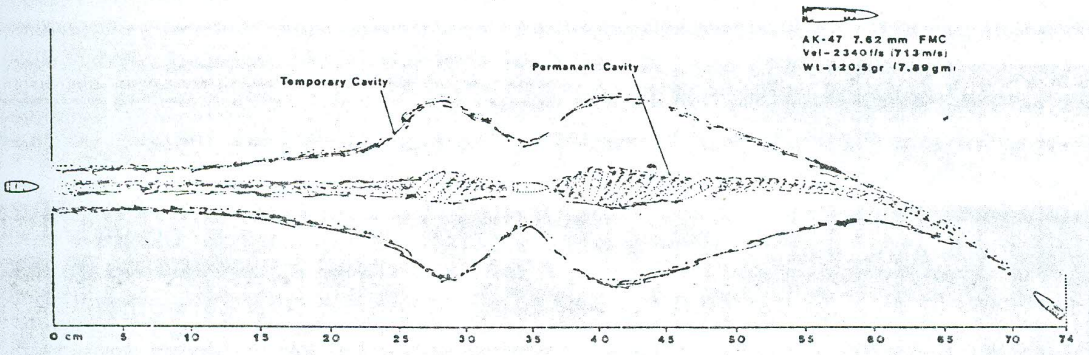


Fig. 18. Wound profile of the popular AK-47 rifle bullet. The 25 cm path through the tissue before rapid yaw begins, generally causes nondramatic wounds in the soft tissue.

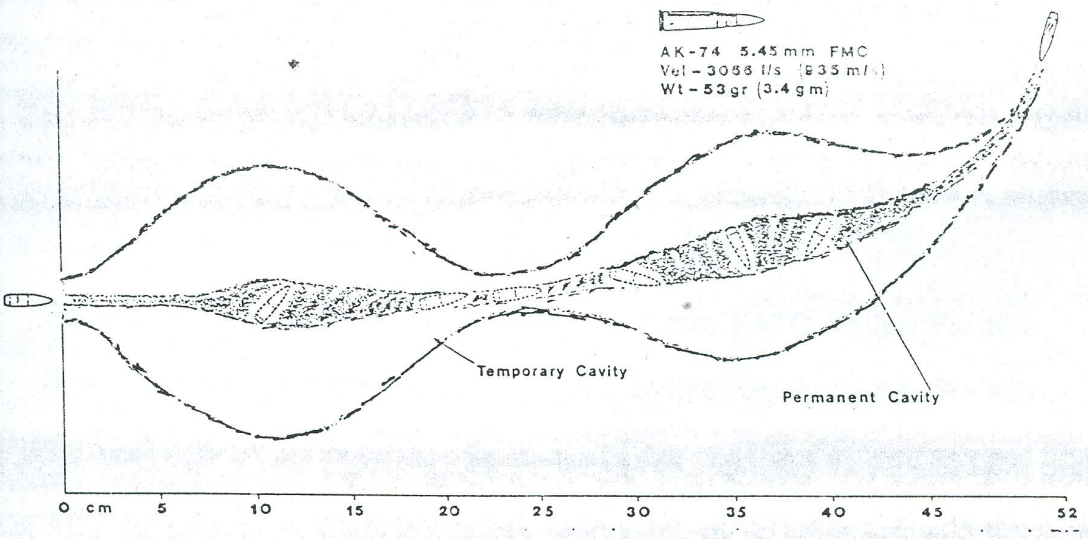


Fig. 19. Wound profile of the Russian AK-74 assault rifle. The rapid yaw, generally within 8 cm of penetration sharply contrasts it with ist predecessor, the AK-47 above.

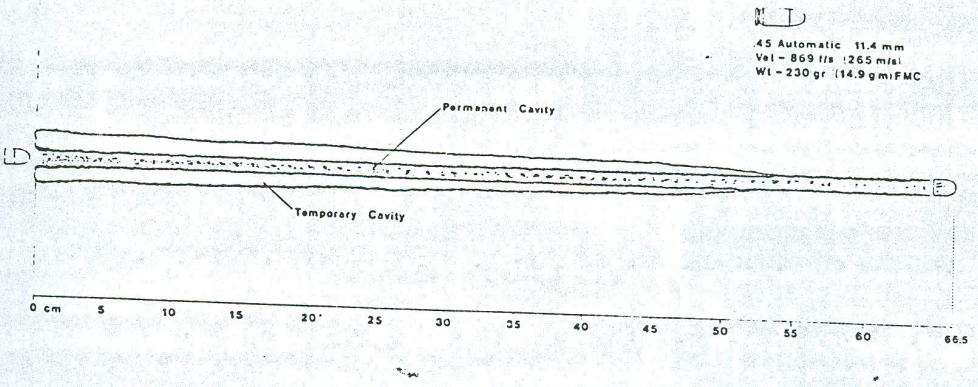


Fig.20. Wound profile of the handgun with minimal permanent and temporary cavity formation.

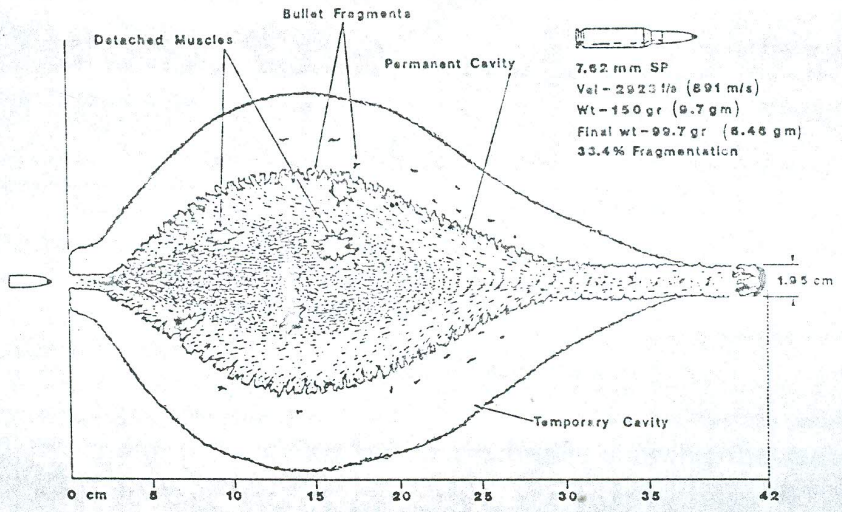


Fig. 21. Wound profile of the military 7.62-mm NATO bullet. For the first 15 cm of penetration in which the bullet remains undeformed, the tissue disruption caused by the rifle by both crush and stretch mechanisms is no larger than that caused by the handgun. Maximum tissue disruption occurs at point of 90^0 bullet yaw (penetration depth about 28 cm) rather than at point of highest bullet velocity (tissue surface).

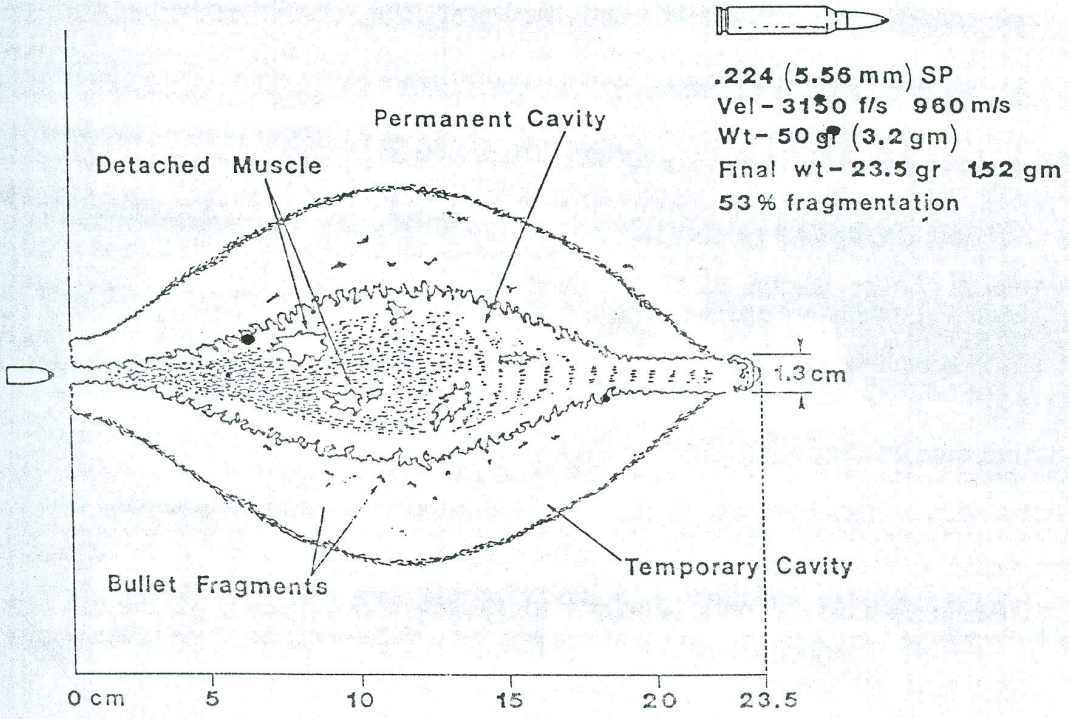


Fig. 22. Wound profile of the soft point bullet showing the massive tissue disruption potential of bullet fragmentaton.

On each wound profile is a horizontal numerical scale that also applies in the vertical dimension, which permits determination of the tissue disruption at any point along the penetration path, for comparison with other profiles, other experimental results or measurements taken from actual wounds.

Factors Influencing the Volume of the Permanent Cavity

Fackler et al [77, 84] observed that the volume of the permanent cavity was also influenced by several factors like: tissue density, yaw, tumbling, the ratio between bullet size and velocity, bullet deformation and fragmentation and bullet design.

The influence of Tissue Density on the volume of permanent cavity Formation.

When the projectile strikes its target, the stabilization effect of its spin is quickly overcome by the density of the tissue.

The influence of Yaw and Tumbling on permanent cavity formation.

The bullet can yaw to 90 degrees and often may come to rest at 180 degrees angle to its initial path. The yaw growth in the target is directly related to the yaw at entry.[98] This process of tumbling within the target significantly increases the destructive capacity of the projectile. As the bullet yaws within the target tissue, it increases its effective diameter, with a maximum reached at 90 degrees,of yaw. This is the reason why a deceptively small entrance wound can coexist with massive internal damage.

Different bullets yaw at different tissue depths. For example, faster, more stable bullets tend to yaw deeper into the target.[64]

The influence of the Ratio Bullet size/Velocity on permanent cavity fomation.

This ratio also influences tissue effects. A large, relatively slow projectile tends to crush tissues in its path with little radial dispersion of energy (temporary cavity formation). A small, fast projectile, on the other hand , tends to crush little tissue and create more transient radial tissue stretching.[77] Because of these phenomena, it is evident that two bullets of similar KE can have markedly different wounding potentials.

The influence of Bullet Deformation and Fragmentation on permanent cavity formation

These factors , as it has been seen in the temporary cavity formation are significant contributors to permanent cavity formation.

The influence of Bullet Design on permanent cavity formation.

Bullet design has a major influence on tissue effects. Bullets used for military purposes are non-expanding, non-deforming, full-jacketed in accordance to the requirements of the Hague Convention. They form different types of wounds from those for civilian use which are not bound by the Hague Convention regulation. Many of the bullets made for civilian use are of the expanding type. As the bullet expands it constantly increases its diameter in the direction of flight. This increases the permanent cavity . And since retardation is dependent

on diameter squared , and retardation is equivalent to energy released to the target, expanding bullets release a continuously increasing amount of energy over the wound course. Both the permanent and the temporary cavities are greater.[45]

Because bullet fragmentation can have a significant adverse effect on tissue it is often possible to see much more devastating wounds with civilian ammunition fired from civilian firearms. Because of the propensity for modern weapons to produce large temporary wound cavities, and because different projectiles tumble within the wound at different rates, it is almost impracticable to judge the severity of most rifle injuries, and some high-velocity handguns injuries, by the size of the entrance and exit wounds alone.

(iii) Sonic Pressure Waves

These are high-magnitude shock or sonic pressue waves with pressures over 60 atmospheres equivalent to 1,000 lb/sq in, generated directly by the bullet's flight.[64] These pressure waves precede the projectile following target impact velocity.[99,100] Harvey,[100] experimenting on animals in 1947 was able to isolate the sonic pressure waves from the temporary cavity effects and showed that these pressure waves although producing pressure up to 117 atmospheres lasted only a few microseconds, a duration too brief to produce destructive effects. Recently, however, investigations by Suneson et al [101] have re-examined the issue of sonic waves contribution to wounding, demonstrating that sonic waves may

contribute to the disruption of neural function even at sites of the body distant to that impacted by the bullet.[101] However ,criticisms have been raised about their data because they failed to isolate the effects of the sonic waves from the temporary cavity effects.[102]

(iv) Pressure Waves

These are low-magnitude pressure waves (4 atmospheres equivalent to 60 lb/sq/in). They are generated directly by the bullets flight as it approaches the critical transonic velocity of the target tissue medium (about 4,759 ft/sec.)

This wave is slower than the velocity of the bullet (about 1/10 the velocity of the projectile). Pressure waves are responsible for the formation of the temporary cavity and may cause damage out of proportion to the bullet's diameter.[41] Because this wave is slower than the velocity of the bullet, the maximum size of the cavity will not be reached for seveval milliseconds after the bullet has left the tissue.[86] As the nose of the projectile pushes through the tissue, the tissue directly in the path of the bullet is accelarated forward at the velocity of the projectile. The bullet nose also pushes radially against the tissue lateral to it, causing the low-intensity pressure waves to move outward at approximately 1/10 of the velocity of the projectile. This pressure wave (measured in milliseconds) may compress the lateral tissues a distance of up to 30 times the diameter of the projectile. However most projectiles produce cavities only half this size[41]

Once the cavity reaches its maximum size, it starts to collapse, and usually undergoes subsequent expansions and contractions of diminishing amplitudes.[92]

Despite the low velocity of the pressure wave causing temporary cavitation in comparison to that of the projectile (1/10 of he projectile velocity) its ability to damage tissue is indisputable.[93]

Since the threshold velocity for bone fracture is only 213 ft/sec, skin laceration 163 ft/second, and the other tissues less than skin, one can see that pressure waves even from slow-moving projectiles like the 7.62 mm rifle (with muzzle velocity of 2,800 ft/sec.) are more than adequate to cause tissue damage.[57]

As it can be seen from the aforegoing discussion the study of modern firearm missile wounds has become highly complex and the total KE formula $KE = \frac{1}{2}MV^2$ cannot be quoted as being the sole solution to understanding this type of injuries. Knowledge of multiple factors is necessary for an adequate understanding of wound production. Factors such as impact velocity, energy release rate, retardation effects,tumbling , bullet design, shape,target density , cavitation, bullet caliber and mass,type of weapon used and ballistic coefficient all play part in modifying the severity of the wound.

2.2.2 INJURIES CAUSED BY MINE EXPLOSIONS

Mine detonations inflict ravaging injuries which are usually fatal. Mines can be antitank mines designed to cause damage to tanks or

antipersonnel mines which are by design intended to disable rather than kill a person. Landmines were designed to safeguard the perimeter of a military camp or fortress from advancing foot soldiers. The early mines were improvisations of explosives in subterranean containers and were largely ineffective[103]. With the development of the easy-to-handle, powerful, and light weight explosive TNT came the first efficient and reliable mines.

The antitank mine is larger and has a 10 kg explosive charge that is carried in a flat steel cylinder and is usually surrou ded by a cluster of antipersonnel mines. The whole mine would weigh about 22 kg and would detonate when a force of 150 to 350 kg is applied to its pressure plate[103]

The antipersonnel mine which is smaller is a bounding, fragmenting mine. The fuses, charges and cast iron fragmenting projectiles are all contained in a sheet of steel case.The whole package weighs 3.7 kg and carries a little over 0.5 kg of TNT. A force of 3.6 to 20.4 kg on the firing pin is required to cause a delayed explosion after the mine has been propelled vertically about 1 meter above the ground. When the mine is stepped on, there is a delay of 3 seconds before the mine explodes and propels the 3 kg of fragmenting cast iron a d steel at waist level[103].

Today, some 250 types of antipersonnel mines have been oduced in at least 48 countries. They vary in shape, amount of explosive

It is estimated that currently there are 110 million active mines scattered in 64 countries worldwide[104,105,106], Every month, over 2,000 people are killed or maimed by mine explosions, most of whom are civilians who step on mines after hostilities have ended, women and children accounting for over 30% of the victims[104] Mine warfare is commonly used in developing countries and antipersonnel mines may injure both combatants and non-combatants during and after conflict. Furthermore, Ascherio et al [107] in a study conducted in 1995 found that between 1980 and 1995 over 3400 people had amputation because of land mine injuries in Mozambique The case fatality rate was 48%. Most of the victims were civilians (68%) and were injured by antipersonnel mines (81%).Women accounted for 16% while 7% were under 15 years of age.

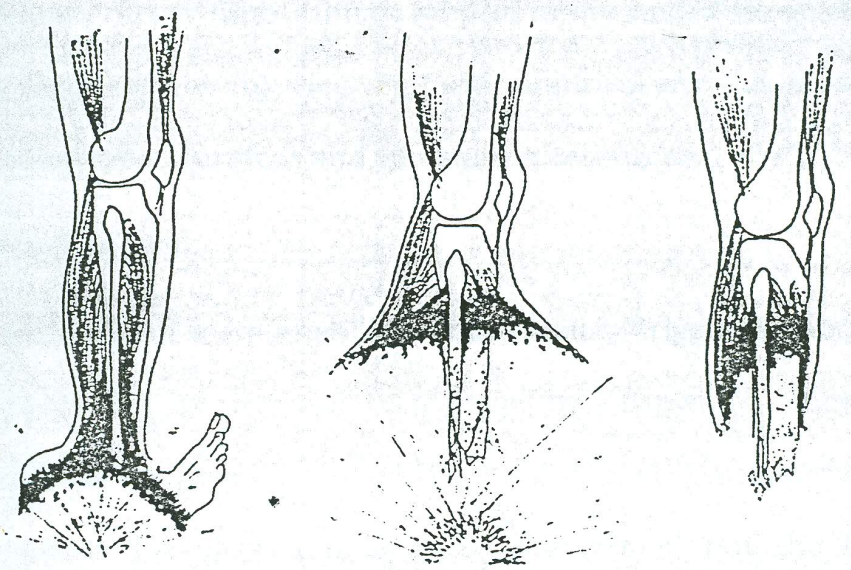
Mechanism of Injury

Coupland et al[108] have described 3 patterns of injury from antipersonnel mines:

Pattern 1 Injury

The victim triggers a burried mine by standing or stepping on the device. The blast mine results in the foot or leg being blown away (traumatic amputation) [109,110,111] with various degrees of injury to the other leg, genitalia, arms or chest. The earth and the remains of foot or shoe are blown upwards into the genitalia, buttocks, the contra-lateral arm or leg. Such mines may consist of explosive only or include fragments of metal or plastic. Many are specifically designed to

or shoe are blown upwards into the genitalia, buttocks, the contra-lateral arm or leg. Such mines may consist of explosive only or include fragments of metal or plastic. Many are specifically designed to incapacitate by traumatic amputation of all or part of the foot.Very few survive blast mines with a larger explosive charge. When the lower



(a) (b) (c)

Fig. 23. Patterns of mine explosion injuries from left to right:

a. Injury apparently confined to the foot, is associated with proximal compartmental muscle damage

b. Explosive injury with traumatic amputation of the lower leg. The mechanism of proximal compartmental injury with skin and gastrocnemius preservation is shown.

c. When the skin has returned to position, the extent of proximal damage is hidden

tibia is shattered by explosive injury there is considerable proximal soft tissue damage with the muscles of the anterior, lateral and deep anterior fascial compartments beeing severely contused and contaminated. (Fig. 23).

Coupland observed that in addition to receiving traumatic amputation of one foot or leg, the victim, if he survives, has a high chance of contralateral lower limb injury and arm injury and a lower chance of genital and central injuries. Pattern I injuries are the most severe demanding great surgical and transfusion resources.

Pattern 2 Injury

This results from a fragmentation mine beeing triggered. Such mines may resemble a grenade and be triggered by a tripwire or they may be ejected from the ground to explode at waist level. Usually the person who triggers the ejected mine rarely survives.[103] but the fragment mines are likely to injure others in the vicinity.The pattern of wounding is less severe than in type I pattern, is more random, and consists of multiple fragment wounds. The wounds may be similar to those caused by other fragmentation devices (grenades, mortar shell, etc) and can affect any part of the body. Though the lower limb is injured there is less chance of traumatic amputation or subsequent surgical amputation[108] Injuries to the head, neck, chest or abdomen are common[108].

Pattern 3 Injury

This is caused by accidental detonation or explosion while handling a mine.This may happen to anyone digging up or defusing mines, laying mines or in the case of children, playing with mines. It usually results in severe wounds of the hands, arms and face, and in some cases causes blindness.[108]

Management of Landmine Injuries

As usual life saving procedures must precede limb salvage. A thorough physical examinations is fundamental. A simple through wound may have a long or short track and be associated with little damage. It is also important to realize that the external entry and exit points can be misleading to the unwary because there can be much tissue damage inside (See Fig. 17) The wounds should be carefully examined and possible signs of internal tissue damage must be looked for. Wound debridement must be done. The wound edges are excised and any dead skin should be removed. Healthy skin should not be removed unneccesarily. An incision is made in the long axis of the limb to allow examination of the deeper structures and to allow examination of dead tissues. With a gloved finger it is possible to determine whether a cavity is present. If a cavity is present it means that much tissue has been damaged and a larger incision is required to remove it. The wound is left open and dressed with loose fluffed up gauze. It is contraindicated to pack the wound because the aim is to allow secretions to flow out.The wound can be revisited about 48-72 hours later to determine if more debridement is neccessary. Delayed

closure is done after 4 or 5 days if the wound is thoroughly clean. Large wounds with tissue loss will need muscle flaps or skin grafts. Exposed bones, tendons and vessels must be covered. If signs of compartment syndrome are present early generous epidermo-fasciotomy will prevent unnecessary tissue damage. All bone fragments which do not have periosteal or vascular attatchment should be removed. The fracture is stabilized by any appropriate method except internal fixation. Plaster, skeletal traction or external fixation are all acceptable methods.

Amputation

A wound with extensive arterial or soft tissue damage and bone may require amputation. The aim is to save life by preventing infection and gas gangrene. The decision to amputate as well as determining the level of amputation are important elements in the management of severely injured limbs. There are several factors that dictate the need to amputate and the level of amputation:[108,111,112]

1. The severity of the injury
2. The delay in presentation
3. The level of contamination/infection
4. The judgement of the surgeon
5. The capability of the surgeon
6. The type of footwear worn by the victim

It is recommended that a tibial stump of acceptable length is maintained because this may be the single factor that determines whether the patient can eventually work and therefore support his or her family.[111]

The level of amputation also needs to take into account what kind of prosthesis can be provided. If the tibial stump is too short or too long it will make the fitting of a satisfactory prosthesis nearly impossible. A through knee amputation is inappropriate if the only technology available is for below knee or above knee prosthesis. A good stump should have a pad of muscle over the bone end. A guillotine amputation can be done in cases of severe bone and soft tissue injury with contamination and sepsis. In this case the wound should be revisted in 1-2 weeks time.

In a retrospective study of antipersonnel mines victims Coupland et al[108] found that 15% of the injured lower limbs of patients with pattern I injuries were eventually amputated. In patients with pattern 2 injuries, 5% the injured lower limbs were amputated while in patients with pattern 3 injuries 30% of the injured upper limbs were amputated.

2.2.3 INJURIES FOLLOWING BOMB EXPLOSION

Bomb explosion injuries occur as a result of the detonation of an explosive charge.Bomb explosions are today usually a result of terrorist activity, usually against civilian targets, property or individuals, done in order to intimidate governments or societies for

political or ideological purposes[113,114]. Worldwide the potential for terrorist activity is on the rise, this bringing with it injuries that are usually associated with military situations, uncommon to civilian set-up, with victims sustaining injuries that do not fall within the daily routine of the attending staff.

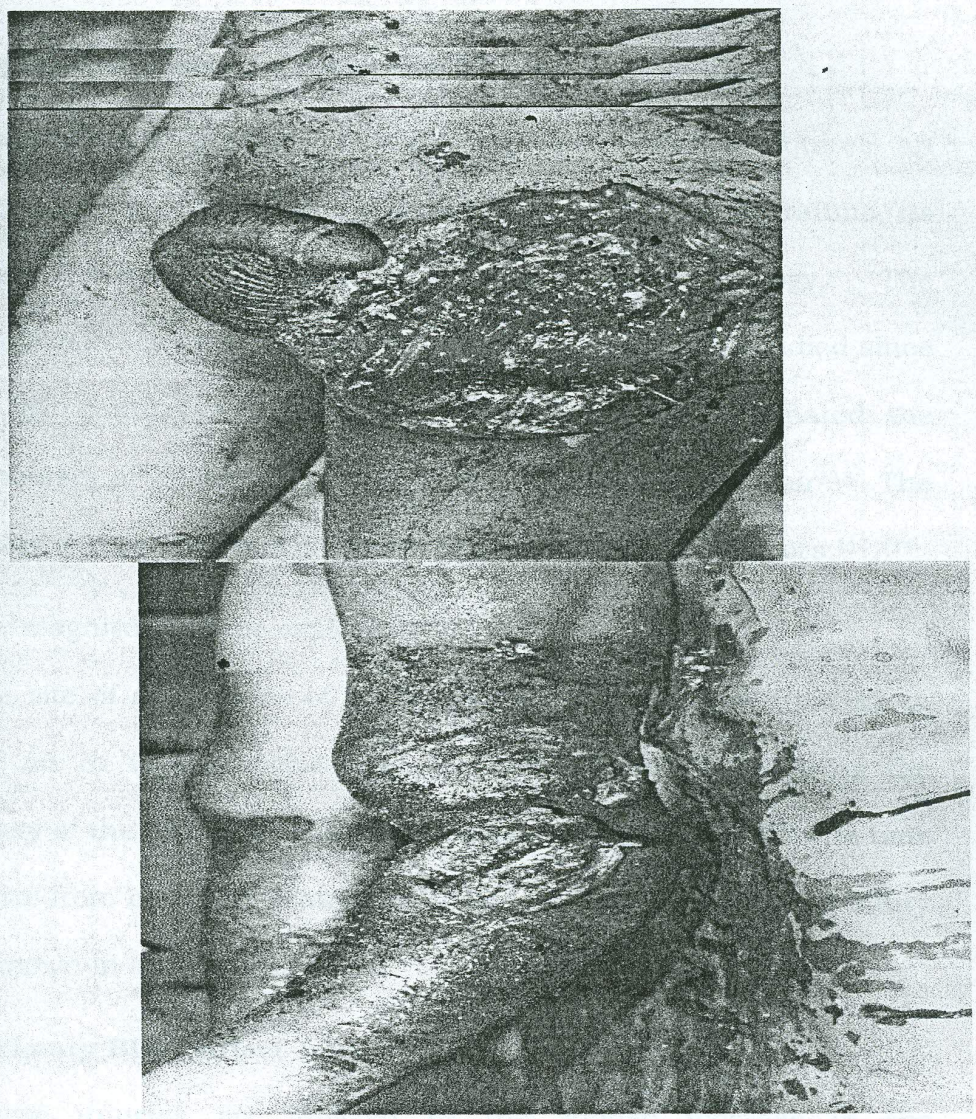


Fig.24. A victim of the American Embassy in Dar es Salaam with injuries never before seen in civilian practice in this country.

In August 1998 a bomb blasted the American embassies in the capitals of the traditionally peaceful East African countries of Tanzania and Kenya, respectively Dar es Salaam and Nairobi.Over 250 people lost their lives in this attack and over 500 people were injured[115]

The pathophysiology of Explosive Injury

Successful management of bomb explosion victims requires an understanding of the mechanism of injury of this unique trauma, its natural history, pathophysiology and epidemiology. The pathophysiology of explosive injury has been intensively studied since the 18th century when Pierre Jars first correctly delienated the mechanism of death as "la grande et prompt dilatation d'air[113] The severity of these injuries is directly related to two major factors:[113,114]

1.The magnitude of the explosion

2.The site of occurrence of the bomb blast (ie whether it occurs in open air or in an enclosed space). Other factors influencing the severity of the injury are the anatomic sites of the injury and the time interval from injury to treatment . Today several mechanisms of injury are known in a bomb explosion:

(a) Primary Blast Effect Injuries

These injuries are inflicted by the sudden increase in the environment air pressure resulting from the detonation of a high-energy explosive charge and propagated radially outwards from it at the speed of sound or greater, striking and moving everything in its

path. The degree of damage resulting from this blast wave depends upon the magnitude and duration of the peak overpressure, which in turn depends upon the explosive force, and the environment in which the explosion occurs.[113] Explosions occurring indoors tend to be associated with especially severe blast injuries because of a geometric increase in the pressure wave as it is reflected off walls, floors and ceilings.[116] Theoretically , bodilly injury from the blast wave is caused by the passage of the blast wave through the body, resulting in a disruption of tissue at air-liquid interfaces through the effects of spalling and implosion[116,113]

Air containing organs such as the ears tympanic membrane and ossicles, lungs and bowels are the most susceptible to this form of injury. Radiologically and morphologically these injuries take the form of parenchymal haemorrhage and laceration similar to those in blunt contusions [113],[116] with immediate deaths most often caused by massive coronary and cerebral air embolism[117.118] Late deaths are generally attributed to progressive pulmonary insuficiency. Primary blast injuries are rare among survivors of air blasts. Victims close enough to an explosion to be susceptible to blast injury would most most likely be killed by secondary and tertially blast effects[119]

(b) **Injuries due to Secondary Effects of air blasts**

These are injuries caused by debris in motion by the dynamic pressure of the shock wave. In the second phase, the vacuum

created by the explosion site produces an opposing, inward-moving pressure wave , which again strikes and forcibly displaces everyting it encounters. Victims sustain injuries such as penetrating wounds from flying debris, blast-driven wood, concrete and glass. These can cause a wide variety of injuries determined by the size of the fragment and the site of the injury[120]

(c) **Injuries due to Tertially effects of the Blast**

These are caused by the strong displacement force of the blast. The victim's body is displaced into other objects causing blunt and penetrating trauma. The forms of injuries predominate among surviving victims of bombing[116,119] Most of these injuries are relatively minor and non-life threatening soft tissue wounds and bone fractures[121]

(d) **Injuries due to Thermal Flash Effect of the Explosion**

These injuries are caused by the brief thermal flash of the explosion. These tend to be superficial but sometimes extensive and occur on exposed parts of the body[120,122] mainly the face and hands. Sometimes loose clothes, such as blouses and boggy trousers, are blown off the body, thus extending the area of the skin likely to be exposed. Deeper burns as a result of clothing catching fire are a possibility.[120] The occurrence of secondary fires from bombing can incur major burns with high mortalities.[113]

(e) **Injuries due to Shrapnel Fragments**

Fragments of metal from the bomb itself can cause a wide range of injuries depending on the size of fragments, the site of injury and the distance of the victim from the explosion.[120] Larger fragments can cause serious fractures and soft tissue loss mainly in the lower limbs owing to the bomb being placed on the floor.[120]

(f) Injuries due to Miscellaneous Effects of the air Blast

These include inhalation of noxious gases, crush injuries from building collapse.Building collapse is a relatively unusual but devastating sequela of bombings that likewise results from large quantities of explosive.[123] Lower extremities injuries due to bomb blast are mainly caused by high velocity, irregular fragments of shrapnel and debris that result in extensive tissue destruction and contamination.

The management of these injuries should involve aggressive thorough debridement of devitalised tissue, cleaning, stabilization of the fractures and delayed primary closure of the soft tissue wounds, regardless of how minor or innocent the wounds may appear.[124,125] Injuries associated with abdominal injuries tend to have a high mortality, hence a liberal approach to the early laparotomy is warranted for any victim with a potential for abdominal injury. Delay in appropriate treatment of critical injuries has been shown to to be a significant determinant of mortality.[113,119,125]

Experience has shown that immediate availability of experienced surgeons and surgical support personnel and facilities is crucial to minimizing the morbidity and mortality of immediate survivors of these incidents.[113]

2.3 MANAGEMENT OF MISSILE FRACTURES TO THE EXTREMITIES

2.3.1 Prehospital Management at the scene of incidence

A good proportion of patients with missile injuries to the extremities will present with other associated injuries. There appears to be a marked difference in the degree and number of associated injuries in civilian and military missile injuries. War wounds are often multisystem injuries.[125]

The major objectives in the management of firearm missile injury patients at the site of the incidence are to address to the immediate life-theatening problems, to prevent further wound contamination or infection, to prevent further aggravation of the the present injuries and ensure early evacuation or transfer of the patient to hospital.

In this respect, prehospital care has continued to play a critical role in the ultimate outcome of open fracture treatment[127] Emergency medical presonnel and paramedicals can play a critical role at the scene of the accident by early combating of shock by the administration of intravenous fluids and endotracheal intubation. Simple maneuvers which can be rapidly performed at the scene of the

incidence should be done. If there is considerable bleeding a pressure or compression sterile dressing should be applied to control bleeding. The wounds should be dressed with a large pad and bandaged. A temporary splint in neutral position should be applied for comfort and protection from further soft tissue injury. Time should not be wasted at the scene of accident and the patient should be rushed to the nearby health facility or hospital.

2.3.2 Initial Emergency Hospital Management

On reaching the hospital alive ,resuscitative measures should be continued.

At the hospital one should try to obtain a complete history as possible but when the patient is severely injured it may not be possible to obtain more than the rudiments of an adequate initial history,due to the patients serious condition or need to be taken to life saving procedures. In this case no time should be wasted to address to the ABC of initial management to ensure clear airways, to arrest bleeding and ensure a stable circulatory parameter.

After the initial resuscitatory measures and stabilization of the patient is achieved, a complete history is obtained from the patient, the relatives, witnesses, ambulance attendants, police or anyone who may have useful information about the incidence . From this information one may learn about the type of weapon used, may also acquire some idea of the volume of blood lost and if any first aid measures were done at the scene of the incidence or on the way to hospital. From the

history , knowledge of the mechanism of injury may also alert the surgeon to seek evidence of obsecure injury known to be associated with such mechanisms. In this case the distinction between low velocity and high velocity missile injury is important because it has important implications in the management of missile fractures .

The Physical Examination

When the cardiopulmonary functions of the patient have been stabilized, and the life threatening conditions have been controlled a thorough systemic physical examination of the patient should be done to detect any other injuries in addition to the obvious ones..

A patient with serious missile injury must be completely undressed so that a thorough physical examination can be made.

The state of consciousness is assesed and the CNS function evaluated. Any associated fractures must be looked for.The chest, abdomen, pelvis, the genito-urinary system and the spine must be carefully examined and evaluated for evidence of fractures, dislocation or bleeding. Careful meticulous examination of the injured as well as the uninjured extremities should be made. Detailed examination must be carried out for damage to major vessels, nerves, bones and joints. The circulation to the extremities should be noted as indicated by capillary blush, the filling of the veins and the status of the peripheral pulses. Meticulous examination for the peripheral nerve function should be made and documented. Inititial sensory examination by pressure and light touch gives a gross evaluation of the sensation in the limb, but

examination for two point discrimination is often necessary to detect more subtle losses, particularly in the upper extremity. In the uninjured limb, examination for the motor function may be difficult owing to pain and splinting secondary to muscle spasm. The injured limb should be examined in comparison to the uninjured limb and the results documented. Careful inspection of all wounds is essential to determine the type of missile used and if possible its direction of travel through the tissue. The skin around the wound is examined to determine whether it is burned or contaminated with usual or unusual agents such as dirt, dust, debris, etc. The number, dimensions, anatomical location and shape of the entrance and exit wounds should be noted and documented. Many small entrance wounds are produced by a large cloud composed of widely scattered missiles (pellets) as it occurs in shotgun injury. Multiple wounds can also be caused by a machine gun

The most common clinical signs of arterial injury are diminished or absent peripheral pulses to the limbs, pulsatile bleeding and the presence of an expanding haematoma[128,129]. Less frequently, one may find signs of distal ischaemia with pain, pallor and pulselessness[130] .In a case control study in penetrating thigh trauma Shayne et al.[131] divided the vascular clinical findings in gunshot injuries into "hard findings" and "soft findings". Hard findings included pulse abnormality, expanding haematoma or pulsatile bleeding while soft findings included neurological deficit, hypotension without an alternate source of bruit/thrill. In their series, the presence of a

gunshot injury in the form of a femoral fracture alone was not predictive of an arterial injury, but the presence of hard and/or soft findings was predictive of such an injury[131] In the case of the forearm the presence of a pulse does not rule out an isolated injury to the radial or ulnar artery. This is due to the retrograde flow through the arches of the hand[132] In this situation an Allen's test should be performed and the blood vessel in question should be palpated while the uninjured vessel is occluded.[130, 132] Occasionally an isolated neurological deficit can be associated with arterial injury[128]. This finding however has been found to be a poor predictor of vascular injury[133]

Compartment syndromes in the extremities should also be suspected or ruled out with any firearm injuries to the extremities. The reported overall rates in the literature is that of 10% in the forearm.[132 134 135 134] Moed and Fakhouri found a 36%, 0% and 6% incidence of compartment syndrome in proximal, middle third and distal third fractures of the forearm respectively[134]. Six percent of their patients had compartment syndromes without fractures.The clinical findings suggestive of compartment syndrome in the forearm include: firmness, pain with passive stretch of the fingers and decreased two point discrimination.[135] Pulses and capillary refill may be normal in the presence of a compartment syndrome. Intra-compartmental pressure measurement is a useful adjunct to the physical examination and may more accurately distinguish those patients with elevated pressures[132]. Measurements higher than 30 mm mercury have been cited as an

indication for a fasciotomy[132] [134] Compartment syndrome can be difficult to diagnose in trauma of the foot since frequently the patient has severe pain and the compartments are difficult to evaluate by manual palpation.[136] An early sign of increased compartment pressure is pain out of proportion to the insult. Injuries to the forefoot make passive flexion tests less useful. Direct measurement of compartmental pressures in the foot using a slit catheter may help to confirm the diagnosis[138] Normal compartment pressures are in the range of 4-5 mm Hg . Elevation of the compartment pressure so that the difference between diastolic blood pressure is less than 30mm Hg is suggestive of compartment syndrome and warrants a decompressive fasciotomy [134,136,139]

Nerve injury to the extremity is not life or limb theatening but can be a cause for considerable long term disability. The extent of nerve injury and its potential to recover is highly variable. Nerves are as with vessels elastic and are often pushed out of the missile path[73] When nerve injury occurs the majority are secondary to neuropraxia or axonotmesis and most studies support delayed nerve exploration because of the excellent recovery[85,140]

Radiological Examination

Several initial X-ray films are necessary for the care of the patient with missile injury but these should only be done after the general condition of the patient has been stabilized and the life threatening emergencies have been eliminated,and the wounds have been

inspected, dressed and the fractured limb splinted. A patient with firearm injuries to the extremities would minimally require good quality antero-posterior and lateral X-rays of the fracture including full visualization of the joints above and below. Special views may be required to elucidate the full extent of the injury. In patients with other associated injuries other additional X-ray films may be required according to the clinical indications. Patients may require an antero-posterior and lateral views of the cervical spine, chest and pelvis.

From the X-ray findings the extent and pattern of the bony injury can be appreciated and this may help in the pre-operative planning for adequate care of the fracture. Other useful findings could be ellicited particularly in the soft tissue. Radiopaque foreign material like retained shotgun pellets, shrapnel fragments, wadding, bullet in the joint or in the soft tissue.[135] These findings alert the surgeon to seek for them during surgical debridement. Identification of air trapped in soft tissue planes in the initial early films may reveal a much more extensive injury than originally suspected. Similar tissue gas shadows appearing several hours after the injury may raise the suspicion of gas forming bacteria in the wound [9]

Complete radiographic examination is also essential to enable the surgeon to do proper preoperative planning which is an essential element of fracture management. It also enables the surgeon to select the appropriate method of stabilizing the fracture and may indicate the need for more than one stabilization system.

In contrast to plain radiographs, the routine use of arteriography following penetrating injuries to the limbs has been challenged in recent years by several authors.[131,141,142] In the absence of arterial injury to the forearm proximity, arteriograms have been found to be positive in 20-25% of cases.[143,143] A study by Norman et al on vascular injuries due to gunshot wounds to the limbs including 11 to the forearm established that the overall incidence of occult injuries was 28% but that the injuries demonstrated an uneventful, self limited natural history. Their conclusion was that the routine use of arteriography was not justified even in the presence of a fracture. In addition, the use of angiography in the setting of a single vessel injury has also been questioned, particularly in a setting in which repair will not be performed anyway. Other workers have also challenged the routine use of arteriography following penetrating injuries to the limbs Their studies indicate that there is a low incidence of occult arterial injuries (3-6%) in patients with normal examinations after penetrating trauma.[145,146] They also maintain that the cost of negative arteriography, the complications associated with the procedure and the benign nature of occult arterial injuries challenge the routine use of angiography for these injuries. According to Norman[146] physical examination coupled with doppler studies was sufficient to identify significant vascular injury.

Arteriograms are however indicated and are mandatory in patients with abnormal examinations, penetrating injury in very close proximity to major vessels, and in patients with certain fractures and

dislocations known to have a high incidence of vascular complication, such as knee dislocation.

2.3.3 Treatment at the Emergency

All missile fractures should be treated as emergencies and the initial treatment of these fractures often affects the ultimate outcome of subsequent management. The major objectives in the treatment of any open fracture of an extremity are prevention of infection, healing of the fracture and the restoration of function to the extremity and thus the return to normal life activity of the patient as early as possible.[147]

The initial treatment in the emergency room should include prevention of the wound from further contamination. The wounds should be covered with sterile gauze Other authors recommend irrigation or lavage of the soft tissue wounds and tracts as well as superficail or limited debridement of the grossly contaminated tissue with foreign material such as wadding or clothing in the emergency room.[148] Fractures should be splinted temporarily before the patients are transported for radiographs and definitive surgical debridement. Tetanus prophylasis should be given. The type of prophylaxis will depend on the patient's immunization history, and the degree of wound contamination.[149] A common regim includes the administration of tetanus toxoid and human antitoxin when necessary. Controversies still surround the use of antibiotics in civilian missile injuries.

2.3.4 Treatment in the Hospital

Traditionally, on the basis of their muzzle velocities at impact, missile wounds have been described as beeing of three distinct types.[150,151]

1. Low velocity missile wounds (mostly from civilian weaponry)
2. High velocity missile wounds (mostly from military weaponry)
3. Close range shotgun wounds

There is a great variation in the literature as to what constitutes a high velocity weapon. Diamond and Rich[152] quote the Wound Ballistics Manual of the Office of the Surgeon General as stating that a muzzle velocity greater than 2500 ft/sec constitutes high velocity. De Muth and Smith[153] considered anything over 1800 ft/sec high velocity and Russotti and Sim[73], use 2000ft/sec as the cut-off point . Burkhalter[151] considers high velocity agents to be those travelling more than 2000 to 2500 ft/sec at impact. Swan and Swan[5] consider low velocity anything below 1000ft/sec or 305 m/sec and high velocity anything above 3000 ft/sec or 914 m/sec Some authors[154] consider 2000 ft/sec as being the dividing line[155] Regardless of the precise definition of a low and high missile, however, the distinction has important implications in the management of missile wounds.

Studies by Hampton and separately by Brettler et al as early as 1961 showed that low velocity missile injuries could be treated in the emergency room with minimal wound irrigation and debridement.[156,157] However most authors agree that high velocity missile fractures should be treated by surgical debridement in the

operating theater. The role of antibiotic treatment in the management of high velocity missile wounds is well established in the literature, however many controversies still exist in the literature concerning their role in the treatment of low velocity missile injuries.

The Operative Debridement

There are conflicting reports in the literature concerning the origin of the word debridement. Most of the reports come from French military surgeons as early as Paré who incised or dilated the projectile path to relieve tissue tension around the wounds brought about by swelling as the body's reaction to local injury. If this engorgement caused by increased circulation and transcapillary protein and water loss is confined, as in fascial compartments of the extremities, it may cause strangulation of circulation with destruction of far more tissue than that disrupted by the inital injury. According to one report,[158] LeDran in 1737, used the term "debrider" to describe incision to relieve tension on the underlying parts of a missile wound and establish drainage as did Percy in 1792 and later Larrey in 1812.[158] In this context, the French verb "debrider", from which the noun débridement is derived, means "to remove constriction by incision"[159] As can be seen this procedure is much less extensive than the thorough wound excision that we know today. Although the term "débridement" continues to be used in this meaning by present-day French surgeons, it means wound excision to most of English-speaking surgeons.This confusion of terms is thought to have originated from the 1917 Inter-Allied Surgical Conference in Paris by

misinterpretation of texts.[158] Another report has it that the word debridement was first used by another French surgeon Joseph Desault who defined it as " a deep incision into the wound for exploration and provide drainage".[160] The term was later popularized by Dominique Jean Larrey (1766-1842), his former student and then the Chief Surgeon of Napoleon's army. Larrey used the term to describe the removal of bullets, bits of cloth, loose bits of bone and soft tissue.[160] Another report[9] describes the word debridement to mean "unbridling" and formerly used only in the treatment of infected wounds as an incision to release the purulent contents of the wounds.

In the treatment of open fractures to the extremities, one should aim for the prevention of further infection to the wounds. All firearm missile wounds are contaminated by bacteria.[102] La Grade and separately Thoresby and Darlow showed that even though the bullet can reach a high temperature in the barrel, this does not render it sterile.[102] There are several factors which encourage contamination and infection in a missile wound:[126,151]

- the penetration of the bullet itself through the tissues and wadding
- the negative pressure phenomenon of the temporary cavitation which sucks in foreign material e.g. clothing, debris and other foreign materials into the wound
- direct innoculation of bacteria can also occur in the uncovered open wound

- the creation of non-viable tissue secondary to energy transfer into the tissue enables proliferation of microorganisms into the wound.
- the disruption of the local bood supply and the increase in venous congestion
- The creation of shock with decreased immunological defence

Adequate debridement of the wounds, accompanied by copious intermitent lavage is the most important step in the management of missile wounds.[9]

A judicious use of the tourniquet is recommended. Appropriate use of the tourniquet includes intermitent inflation during irrigation and debridement as indicated but not constant inflation throughout the procedure. The tourniquet should not be inflated unless necessary to control bleeding either for visualization or to limit blood loss; because anoxia produced by the tourniquet interferes with evaluation of the viability of muscle. However one major advantage of the tourniquet is that inflation for 10 minutes or so followed by release, results in capillary flush of the skin distal to the tourniquet, which gives a good indication of the skin viability.

Debridement and irrigation has several major objectives:

(a) Detection and removal of foreign material, especially organic material

(b) Detection and removal of nonviable tissues

(c) Reduction of bacterial contamination

(d) Creation of a wound that can tolerate the residual bacterial contamination and heal without infection

Beginning with the skin and subcutaneous fat, one should do a methodical layer-by- layer debridement of the wound.

Judgement of the viability of muscles is challenging. Gregory[9] addressed four features (4 C's) as being important: colour, consistency, contractility and the capacity to bleed. [9] Scully et al.[161] in an attempt to correlate the four features with histological evidence of viability, concluded that consistency and the capacity to bleed were the most significant features. Chapman et al.[39] thought that contractility and consistency were the most reliable features because colour and the capacity to bleed are easily misinterpreted (taking in account the hypoxemia associated with the use of tourniquet or the presence of shock or injury to a major vessel of the involved limb, factors that can make the interpretation of these parameters difficult).

Debridement of Low Velocity Missile Fractures

Most civilian firearm missile injuries are due to low-velocity weapons. Since these injuries are associated with lower energy transfers most surgeons have taken a more conservative approach which includes local wound debridement of superficial necrotic tissues and copious irrigation.[135,155] Some authors think that low velocity missile wounds may be managed by local wound care , with or without excision of the entry or exit wounds.[162] Studies by Hampton[156] and separately by Brettler et al.[157] concluded that these injuries could be treated in the emergency room with minimal wound irrigation and debridement. Morgan[163] reviewed 40 low velocity lower limb gunshot wounds

managed with 5 days of antibiotics without debridement. Despite 17 patients with fever above 103 degrees F., none became infected or required readmission, antibiotics or surgical procedures. Other authors have emphasized that copious wound irrigation is even more important than debridement[164]

Debridement of High Velocity Missile Wounds

Unlike the low-velocity missile injuries, there is little disagreement regarding the treatment of high velocity missile injuries. Wartime experience has provided the scientific basis for the accepted mode of treatment of these injuries. Most authors agree that high velocity firearm injuries should be treated by operative exploration, extensive primary debridement, copious irrigation removal of foreign bodies, bullet fragments, shrapnels, the coverage with intravenuos antibiotics, tetanus prophylaxis, immobilization of the fracture , repeated debridement and delayed wound coverage.[9] Adequate wound debridement and copious intermitent lavage are the two most important steps in the management of open fractures and firearm missile wounds do not make an exception from this general principle. The critical aspect of this procedure is the removal of all non-viable and contaminated tissue by surgical debridement and copious irrigation.

However, unlike firearm injuries to other limbs, those to the forearm in proximity to the vital structures demand more caution and judgement. Studies by Fackler and Burkhalter[165] showed that the wound profiles for even the highest velocity weapons cause minimal

disruption in the first twelve centimeters of tissue penetration Because the tissue path in the forearm is often less than 12 cm, a high velocity missile frequently causes as much damage as a low velocity projectile. Bullets striking bone will, however, increase the likelihood of severe tissue damage due to additional damage from secondary missiles. In this situation the increased damage will be evident on physical examination and radiographs. The authors thus recommend that only severely traumatized or necrotic tissue be excised in the forearm. Overzelous excision can ultimately lead to increased disability by removing functional tissue.[165] A staged second surgical debridement one to three days later will allow for the reassessment of questionable or nonviable tissue.

The Type, Volume of Irrigant and the Method of Irrigation

Copious intermitent lavage with 5000 to 10,000 mls of normal saline or distilled water is recommended[147] The importance of copious irrigation was emphasized by Gustilo et al.[147] who demonstrated that in a series in which less than 10 L of normal saline was used for irrigation there was a higher incidence of infection than a series in which more than 10 L was used. The important thing that is hereby stressed is that whether 10 L of normal saline should run through every wound is less important than the fact that irrigation must be thorough and copious.[147]

The method of irrigation used is also equally important as the volume of the irrigant. Irrigation is a mechanical function and the

purpose of irrigation in orthopaedic wounds is to remove rather than kill bacteria.[166] Several mechanical irrigators that pump aseptic irrigation fluids through shower heads in a pulsatile manner provide an ideal stream of irrigation solution over a broad area. These are far more effective and are recommended. Bulb syringes or those which produce forceful streams may actually drive foreign material and bacteria into the tissue planes which is obviously undesirable.[9]

Angelen et al.[166] showed that pulse lavage with saline solution as compared with bulb syringe irrigation resulted in a 100-fold decrease in the bacterial count of a glycocalyx producing staphilococcus. Similar results were obtained when either bacitracin or neomycin were added to the irrigation fluid. Notable however was that there was a highly significant advantage to adding a detergent, castile soap, to the irrigation solution. The addition of soap decreased the residual bacteria by a minimum factor of 10 over saline alone and by 20-100 times over antibiotic solution. From this study it would appear that the addition of antibiotics to the saline used in pulse lavage provides no additional advantages.

Kellam et al.[167] in 1993 reported that irrigation of open fractures with solutions of providone–iodine (Betadine) or hydrogen peroxide resulted in irreversible decrease in osteoblastic function. According to him the practice of using these agents in the cleansing of contaminated

wounds should therefore be condemned. No adverse effects were observed with local application of bacitracin.

Debridement of Close Range Shotgun Wounds

Even though shotguns are considered to be low velocity weapons, close range injuries (less than 14 ft) can produce tissue damage similar to high velocity missiles and should be managed as high velocity injuries[12,168] Not only can the close range shotgun injury produce massive soft tissue destruction, but the presence of wadding may be introduced into the wound.[155,162,168] Wadding, which is a tightly compressed organic matter may be difficult to find, it can introduce bacteria and incite a significant inflamatory response. It must always be sought and removed. All shotgun wounds should be considered to contain wadding unless proved otherwise.[168]

There is wide agreement that these close range shotgun injuries should be treated with surgical debridement and irrigation and intravenous antibiotics. Caution, however, must be exercised in the low velocity wounds of the foot where, due to its anatomical structure, the ratio of bone to soft tissue is high. Here even low velocity missiles can cause extensive soft tissue stripping of fractures and increase the risk of infection. In this case, therefore, surgical irrigation and gentle debridement is usually necessary to prevent infection.[164] Further soft tissue stripping from bony fragments should be avoided to prevent devascularization. All loose osseous fragments not essential to the stability of the bone or joints should be debrided since loss of blood to these fragments will lead to their necrosis and wound infection[164]

Retained Missiles in the Tissue

As far as treatment of low velocity missile injuries is concerned, most authors support a conservative approach as it has been discussed above. The question arises as to what to do with the missiles retained in tissues. Most authors agree that, in contrast to retained high energy missiles where a more radical surgical debridement is indicated, retained low energy missiles will not routinely be removed because wound exploration and extensive debridement are generally not necessary.[169] The question whether or not to remove a retained missile embedded away from the site of immediate wound exploration has a multifactorial answer but depends primarily on the location of the retained missile.[169]

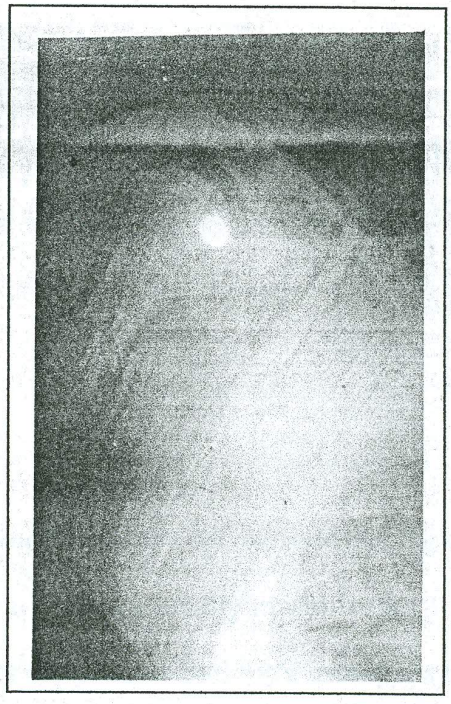


Fig. 25. A bullet embedded in the shoulder joint

Generally, retained missiles in the soft tissue or muscles of the axial and appendicular skeleton should not be removed because they usually become encased in fibous tissue, become inert and rarely have any functional impairment or systemic lead toxicity effects and the reported risk of infection is low (2-3%).[126,170,171,172]

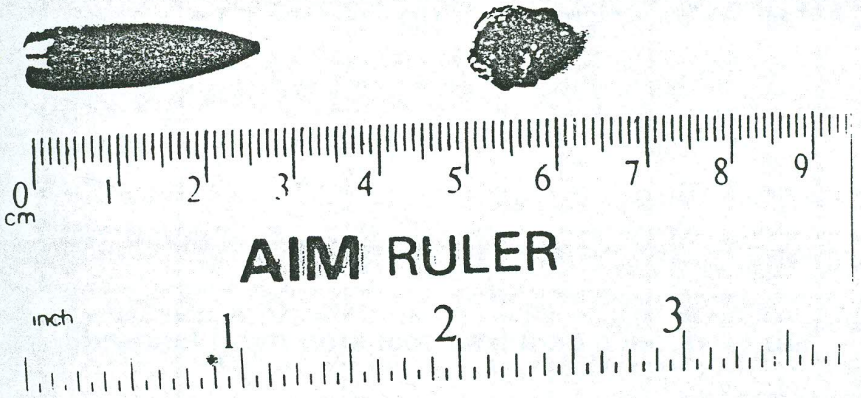


Fig. 26. Retained missiles recovered at surgical debridement: From (l) to (r) a rifle bullet, a locally made bullet for a locally made gun (gobori) recovered from a patient's missile wound to the leg sustained in a hunting accident. The patient was mistaken for a lion by his colleague.

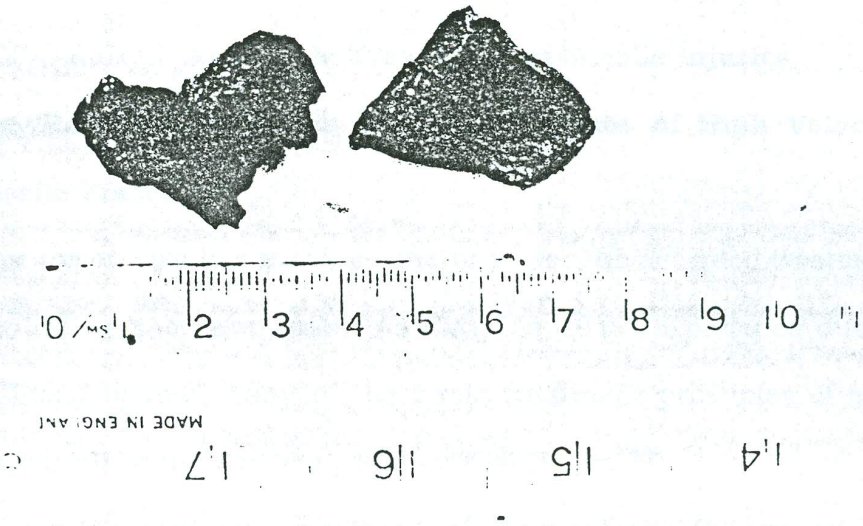


Fig. 27. Shrapnel fragments recovered from a victim of the American Embassy terrolist bombing in Dar es Salaam (see fig. 24)

In contrast to missiles retained in soft tissues, missiles retained within joints or bursae should generally be removed. Retained bullets in the joints and bursae can cause serious complications leading to destructive arthritis and less commonly systemic lead toxicity. [126,170,171,172] Other indications for surgical exploration and bullet removal is when there is a possibility of damage to a major structure by migration of the bullet fragment [126,173] Howland and Ritchey [126] found that the majority of bullet removals were done for

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pain, especially in the hands and feet. Ziperman,[174] however, advocated exploring all wounds because he noted that the depth of injury cannot be assessed from the surface.

2.3.5 The Role of Antibiotic Treatment in Missile Injuries

(a) The Role of Antibiotics in the treatment of High Velocity Missile Fractures

Wartime experience has provided the basis for the accepted treatment of penetrating missile injuries. As early as 1919, experience during World War I shaped many of the basic treatment principles of high energy missile wounds in the post -- antibiotic era[175]

The current antibiotic treatment of high velocity firearm missile injuries is quite well established and accepted. Beside operative exploration, primary debridement, irrigation, open wound management, delayed wound closure, administration of tetanus prophylaxis and broad-spectrum antibiotics are recommended. These antibiotics include parenteral cephalosporins, aminoglycosides and peniciline as prophylaxis[176] The antibiotics are administered parenterally upon presentation and for a period of up to 72 hours post operatively[177] Although staphylococci are often resistant to peniciline, the drug is effective against other potentially infective microrganisms such as streptococci and clostridia [176,177]

When treatment is delayed as it happens in wartime high velocity missile open fractures, the intramuscular administration of

benzylpenicilin has been shown to be most effective in reducing infection rates if given during the first hour and ineffective if administered after 6 hours[178]

(b) The Role of Antibiotics in the Treatment of Low Velocity Missile Injuries

In contrast to the role of antibiotic treatment in high velocity wounds which is well accepted, the role of antibiotic treatment of low velocity injury remains a controversial subjects.[154,162] The need for, the choice of and the duration of antibiotics continues to be a subject of discussion.[154162] Even though most clinicians would recommend broad spectrum antibiotics, the optimum dose and duration and type of antibiotics is not uniform. Consequently the current standards of antibiotic treatment in these type of injuries are not uniform. Antibiotic recommendations have ranged from a minimum of a week[155] to none at all.[179]

A comprehensive review of several studies in the literature is made by Miclau et al.[180] to demonstrate the controversies in the literature about the subject. Most of these studies were done on the gunshot open fractures to the extremities.

2.3.6 Definitive Stabilization of Firearm Missile Fractures of the Extremities

After adequate wound debridement and lavage has been done, an appropriate method of fixation must be chosen to stabilize the fracture. Technological advances in the operative stabilization of certain fractures have significantly improved the rate of union and the

functional results compared with those obtained by non-operative methods. There are several discernible advantages gained by achieving osseous stability in any open fracture treatment:[9]

1. It reduces the rate of infection and protects the integrity of the remaining soft tissue, hence promoting wound healing.
2. It facilitates wound care especially when patients must be transferred many times for repeated operative debridement or investigations.
3. It facilitates early mobilization of the patients especially patients with multiple injuries, hence avoiding complications related to prolonged immobilization.

Timing for the operative stabilization

The timing for operative stabilization may vary from patient to patient and the surgeon must determine the appropriate timing of operative stabilization for each patient.

a) Immediate Stabilization

In this case the fracture stabilization is done during the initial management of the wound. Immediate reduction and stabilization is beneficial in the management of intra-articular fractures for which anatomical reconstruction of the surfaces of the joint followed by early motion improves the prognosis.[181] The other advantage of immediate fixation of an intra-articular fracture is to avoid the technical problems that are inherent in late articular reduction. This has also been advocated for grade I and selected cases of grade II open fractures.[181]

Immediate stabilization of open fractures is also advantageous for patients with multiple injuries. These patients are at risk for pulmonary complications like ARDS. It is important that in these patients fractures of long bone should be stabilized during the initial operative debridement.[182]

b) Delayed Stabilization: In this case definitive stabilization of the open fracture is done on a delayed basis, seven to ten days after injury, when the risk of infection is believed to have decreased.

Devices for Fracture Stabilization

Technical advances have provided a wide spectrum of fracture stabilization devices. In general, devices for stabilizing an open fracture can be divided into:

1. External stabilization devices
2. Internal stabilization devices

The type of stabilization and the choice as to which device is appropriate to a particular fracture is guided by several factors.

1. The anatomical site of the fracture or injury
2. The degree of communition and the stability of the fracture
3. The type of wound and the degree of soft tissue damage
4. The associated injuries
5. The availability of the device or the socio-economic conditions
6. The expertise of the surgeon

There is probably no one method of stabilization that is optimum for the stabilization of all open fractures. The following are the most common devices used for fracture stabilization:

- Splints
- Braces
- Casts
- Skeletal or skin traction
- External fixators
- Intramedullary Nailing: Locked vs unlocked, flexible vs rigid, anterograde vs retrograde and immediate vs delayed insertion.
- Plate and screw fixation

Splintage, casting, and bracing can be used for stabilizing isolated nondisplaced, stable type I fractures of the long bones of the extremities. [183,184*] In the vast majority of open fractures, intramedullary nailing is used infrequently. With current techniques intramedullary nailing is suitable only for diaphyseal fractures and an occasional metaphyseal fractures. Intrarticular and metaphyseal fractures usually require internal fixation with plates and screws. [181] In the majority of type III open fractures, external fixation is the treatment of choice with plate and screw fixation commonly used in upper extremities.

Intra-articular fractures with relatively mild communition may be amenable to the use of K-wire fixation. More severe communition with or without bone loss is a prime indication for external fixation. [185]

3.0 PATIENTS AND METHODS

In the period between July 1996 and June 1999 at the Muhimbili Orthopaedic Institute (MOI) in Dar es Salaam, Tanzania 40 patients with 48 fractures to the extremities caused by firearms, namely guns, landmines and bomb blasts were treated. Of these, 38 were males and 2 were females. This was a prospective study in which the author interviewed, examined, treated or actively participated in the management and follow up of the patients.

3.1 Data Collection

All the patients admitted to the trauma ward with open fractures to the extremities secondary to gunshot landmine or blast injuries were recruited. There was, therefore no sampling necessary. Patients with firearm open fractures to other parts of the body other than the extremities were excluded from the study.

On admission all the patients or their accompanying relatives, police, were interviewed and examined by the author. The required information obtained was entered in a questionnaire specially designed for this purpose. (annexed).

From the history and physical examination the following data was obtained:-

1. The name and file number of the patient.
2. Age, sex and occupation of the patient
3. Date and time of injury

4. Date and time of admission to hospital
5. Date and time of operation
6. Time lapse from injury to admission
7. Time lapse from injury to surgery
8. Type of weapon used
9. Approximate distance from muzzle of the firearm to the victim
10. Motives behind the firearm injury
11. The anatomical site of the injury
12. The radiological classification of the fracture according to the AO/ASIF classification.
13. The wound classification of the open fracture by Gustilo classification.
14. Associated injuries present.
15. First aid treatment at the site of incidence or on the way to hospital.
16. Type of treatment given.
17. Duration to evidence of union of the fracture
18. Duration of hospital stay
19. Complications
20. Functional results
21. Duration of follow up.

From these factors it was possible to determine the mechanisms of injury and the type of weaponry used. These were divided into four groups:-

1. Fractures due to Rifle shots

2. Fractures due to shotgun shots and close range shotgun shots
3. Fractures due to handgun shots or pistols
4. Fractures due to shrapnel fragmentss from landmines and bomb blasts

The subjects were therefore tabulated in the four subject characteristics groups as shown in tables 3-6.

The energy –transfer category could also be determined from the type of weapon used, the muzzle – victims distance and the severity of the injury as to whether it was one of the two categories:-

(1). Low energy transfer category

(2) High energy transfer category

From the history obtained it was however difficult to ascertain the exact range of the victim – muzzle distance at the time of injury, this relying totally on the patients appreciation, the information given by him/her and the configuration or type of the injury sustained.

3.2 Emergency Management at the Casualty

On arrival at the hospital, the patients were initially evaluated and resuscitated at the casualty including setting an IV line with normal saline or Ringers Lactate, a full neurovascular and radiological examination. Angiography was not done in this study for lack of indication and also because it is not routinely done on emergency basis at the Institute. At the casualty the wounds were cleaned and covered with sterile dressing. A temporary splint was applied to support and stabilize the affected limb. Tetanus toxoid was also given for tetanus prophylaxis

3.3 Clinical Examianation

On admission a detailed history was obtained from the patients or their accompanying relatives regarding the history of the injury and the symptoms of the affected limb.

An elaborate physical examination evaluated the patients general and local status, the haemodynamic condition, the location of the missile wound or fracture, the number of entry and exit wounds, the degree of soft tissue injury, the degree of wound contamination and the neurovascular status. This examination was best done in the operating theatre.

Standard anteroposterior and lateral x-rays of the affected bone(s) were done for all the patients. Patients with associated injuries were requested to do the appropriate radiographs.

After examining the wounds at operation and studying the radiographs, the injuries were graded according to the amount of bone and soft tissue injury, location of the fracture, fracture configuration, degree of comminution and the degree of contamination according to the Gustilo and Anderson and the AO/ASIF classifications.

3.4 Patients Preoperative Preparation

Preoperative resuscitation continued in the ward for all acute cases in shock. Most of the patients in this study underwent surgery on an emergency basis. For these patients beside the history, physical examination and the radiological investigation, a baseline haemoglobin and full blood picture were done. An urgent blood

grouping and cross-matching was done and an informed consent for anaesthesia and surgery was obtained before the patient was sent to theatre. For patients presenting to hospital late, days to weeks after the injury, these were instructed to fast the night before surgery. On the morning of surgery preoperative preparations included operation site shaving and cleaning as well as obtaining a signed informed consent for anaesthesia and surgery.

3.5 Anaesthesia

General anaesthesia with endotracheal intubation was used. Intravenous premedication was given and an intravenous line was set and maintained with normal saline or Ringer's lactate.

Local anaesthesia was rarely used except in one patient who had a local infiltration with lignocaine 1%.

3.6 Instruments

The appliances used for stabilization of the fractures in this study consisted of:-

1. Plaster of Paris casting
2. Steinemann pin with stirrup and a Braun`s splint for skeletal traction
3. Tanzfix, AO tubular external fixators and the mini-external fixator
4. Cancellous screw fixation.

However due to the limited treatment facilities prevailing at the Institute at the time of the study it was not always possible to get the

optimal recommended type of stabilization implants. For example when it was not primarily possible to apply an external fixator on a grade III femoral shaft fracture, a skeletal traction was applied. While an external fixator was the optimal option for a grade III open fracture of the tibia, a plaster cast was the most frequently available replacement, when this was not available.

3.7 Management in the Operating Theatre: The Wound Debridement

At surgery the wounds were examined to determine the extent of bone and soft tissue damage and the presence of foreign bodies. The wound skin margins were excised. The devitalized subcutaneous tissue and fasciae were excised. The devitalized muscle tissue were generously excised using the 4 C's criteria: (contractility, colour, consistency and capillary bleeding). All foreign bodies and debris were removed unless they were far away from the missile path and did not cause soft tissue destruction or neurovascular compromise . Foreign bodies embedded into the joints were removed, the capsule was sparingly excised and closed over a drainage tube after primary surgical debridement. Small loose bone fragments without periosteal attachment were removed. Fortunately no major neurovascular injury was associated in any of the patients so that no neurovascular reconstruction was necessary. The wounds were rinsed with hydrogen peroxide and irrigated with copious amounts of normal saline. After the wound debridement and according to the geography and the configuration of the fracture, the fracture was stabilized with one of the various methods available at

the time of surgery: plaster of Paris, skeletal traction, external fixator using the Tanzfix or the AO external fixator apparatus or screw fixation. The wound primarily surgically treated in this way was left open without primary closure and was covered with sterile dressing. The patient was put on the then available antibiotic for at least five days pending culture and sensitivity results.

Definitive wound closure was done by delayed primary or secondary wound closure 5 to 10 days after primary wound debridement or by skin grafting.

The indications for amputation in this study were bone and soft tissue damage to the forefoot in one patient, irreparable injury to the axillary artery in one patient and unsalvageable serious bone and soft tissue infection to the distal leg in one patient.

Intravenous antibiotics in the form of cloxacillin in the dose of 500 mg 8 hourly was given for five days; after which antibiotics were continued only in the case of clinical signs of infection and on the basis of bacterial sensitivity pattern. In the case of large soft tissue damage associated with gross contamination metronidazole was added to the regime for the anaerobic organisms. Tetanus antitoxin was routinely given at the emergency room and where there was no data about previous antitetanus protection, antitetanus serum was administered as well.

Patients with femoral fractures treated with skeletal traction antero-posterior and lateral x-ray control at two weeks intervals to control the

effectiveness of the traction. They remained in the ward for a minimum of six weeks until the fracture site was stable or a radiological callus was evident. Daily isometric quadriceps were encouraged. Then depending on the site and type of the fracture a below groin cast was applied and the patient was discharged home to continue with out-patient care. These patients were instructed not to perform any weight bearing until radiographic evidence of healing was present, usually after 6-8 weeks. Progressive weight bearing was thereafter allowed as tolerated.

3.8 Patients Disposal

The discharged patients were followed up until fracture union had occurred.

In tibial fractures treated with casting, a long leg cast with a window for dressing was applied for four to six weeks which was then changed to a patellar-tendon-bearing (Sarmiento) cast until complete healing occurred. Antero-posterior and lateral x-rays were periodically taken and correlated with clinical signs of union.

3.9 Time to Union

The time to union was determined from the day of injury to the time of evidence of union. Fracture union was judged to have occurred when pain, swelling, tenderness or motion at the fracture site cold not be elicited, or when there was partial or complete obliteration at the fracture line on x-rays. Delayed union was considered when there was little or no radiological evidence of union 4 to 6 months following

injury with instability at the fracture site. Non-union was judged when there was no evidence of fracture consolidation 6 months or more after the injury. Malunion was considered when there was a valgus or varus deformity greater than 10 degrees and an anterior-posterior angulation greater than 20 degrees or shortening of more than 2 centimetres.

3.10 Functional Results and Complications

The functional results were assessed according to four criteria, namely: joint motion, muscle bulk, X-ray alingment and weight bearing. The results were graded as excellent, good, satisfactory or poor as shown in table 2 below.

Diagnosis of wound infection was judged according to:

1. The presence of the local signs of inflamation i.e. redness, erythema and/or swelling
2. . Presence of serous or purulent discharge
3. . Direct bacterial confirmation by wound culture.

The time required to return to work was calculated from the day of injury to the time when the patient could start working or start his usual life activities. The hospital stay was calculated from the day of admission to the day the patient was discharged from hospital. The follow-up period was averaged.

Table 2: Functional Results

Functions looked for	Grading			
	Excellent	Good	Satisfactory	Poor
Joint Motion	Full and Painless	Loss of less than 25 degrees	Loss of more than 25 but less than 40 degrees	Loss of more than 40 degrees
Muscle Bulk/Atrophy	No muscle atrophy	Less than 2 cm muscle atrophy	More than 2 cm but less than 4 cm muscle atrophy	More than 4 cm muscle atrophy
X-ray Alingment	Normal alignment	Angular deformity of less than 15 degrees	Angular deformity of more than 15 but less than 25 degrees	Angular deformity of more than 25 degrees
Weight Bearing	Full and painless	Full with one elbow crutch	Partial with one axillary crutch	No weight bearing with two axillary crutches

4.0. RESULTS

SUBJECTS CHARACTERISTICS

Table 3. Patients with fractures secondary to rifle shots

	PT IDENT.	SEX/ AGE	DATE OF INJURY	ANATOMICAL SITE OF INJURY	STIMATED ISTANCE FROM UN	WOUND CLASSIF.(G USTILLO)	RACTURE ASSIFICATION. AO)	YPE OF FIRST AID EASURES (PRER OSP.CARE)	URATION TO OSPITALIZATION	URATION TO REATMENT	YPE OF TREAT ENT	URATION TO NION WEEKS)	FUNCTI ONAL RESULTS	OSPITA STAY DAYS
1.	D.D B001406	M/18	23/7/97	Thigh	5 metres	IIIA	32C	-	hours	7 hours	skeletal Traction.	18	Fair	222
2.	IM B017781	M/20	7/4/98	leg	10 metres	III A	42C	-	hours	hours	casting	24	Excellent	14
3.	M.A. B014750	M/21	16/11/97	thigh	20 metres	III	32B	-	hours	2 hours	casting	16	Fair	7
4.	D.K. B013994	M/27	27/10/97	arm	10 metres	II	12B	Inj. Pethidine	hours	6 hours	casting	8	Good	16
5.	M.A. B013620	M/25	14/10/97	thigh	20 metres	II	33B	-	hours	hours	keletal traction	9	Good	44
6.	S.M. B014730	M/25	25/11/97	Thigh leg	10 metres	II II	32B 42B	-	hours	hours	keletal traction.	9	Good	42
7.	W.N B022349	M/21	3/09/98.	leg	100 metres	IIIB	42B		days	days	Casting	17	Fair	44
8.	O.S. B016841	M/51	25/02/98	Thigh leg	-	IIIA	32C 41C	-compression dressing irrigation	4 hours	4 hours	External Fix.	23	Excellent	36
9.	PCM B006846	M/22	17/12/96	leg	20 metres	IIIB	43C	-uncertain	hours	hours	asting	30	Good	92
10.	H.A. B016214	M/24	3/02/96	thigh	20 metres	IIIA	32C	-	hours	hours	keletal Traction.	18	Fair	58
11.	B015230 MPC	M/27	6/09/98	thigh	100 metres	IIIA	32C	-	days	days	asting	21	Died	-
12.	Y.A. B011408	M/27	23/07/98	leg	3 metres	IIIA	42C	-	hours	7 hours	casting	22	Poor	131
13.	M.S. B011407	M/25	23/07/98	Leg	5 metres	IIIA	42C	-	hours	hours	Skeletal traction.		Died	-
14.	M.M. B014009	F/35	28/10/97	Arm	10 metres	IIIA	12B	Bandaging	hours	hours	External Fix.	9	Excellent	13
15.	MM B008436	F/40	25/697	Thigh	15metres	IIIA	33C	Bandaging	hours	hours	External Fix.	26	Excellent	65
16.	A.S. B022781	F/40	15/10/98	Thigh	50metres	II	32C	-	hours	hours	keletal traction. aporatomy		Died	24 hours
17.	E.M. B011573	M/44	16/06/96	Leg	15 metres	IIIB	42C	Compress dressing splintage	hours	hours	asting	-	Secondary above knee amputation	365
18.	J..H B002541	M/70	30/10/96	Thigh	25 meters	IIIA	33C	Dressing	hours	2 hours	Skeletal Traction.	19	Fair	51

Table 4. Patients with fractures secondary to shotgun shots

	PT IDENT.	SEX/ AGE	DATE OF INJURY	ANATOMICAL SITE OF INJURY	ESTIMATED DISTANCE FROM GUN	WOUND CLASSIFICATION .(GUSTILLO)	FRACTURE CASSIFICATION (AO)	TYPE OF FIRST AID MEASURES (PRER HOSP.CARE)	DURATION TO TREATMENT	TYPE OF TREATMENT	DURATION TO UNION (WEEKS)	FUNCTIONAL RESULTS	HOSPITAL STAY (DAYS)
1	H.S. B012796	M/27	14/09/97	Hand	10 metres	IIIA	-	-	3 hours	Casting	18	Poor	8
2	C.A. B0016621	M/23	7/06/96	Thigh	5 metres	IIIA	32C	-	6 hours	casting	24	Excellent	45
3	H. Z B020129	M/24	6/07/98	Thigh	10 metres.	IIIA	32C	Compression dressing	10 hours	Skeletal Traction.	20	Good	60
4	H.M B023881	M/27	28?11/98	Thigh	10 metres	II	32B	Splintage	4 days	Casting	13	Excellent	43
5	A.M. B007568	M/37	4/02/97	Thigh	10 metres	IIIA	32C	Splintage	8 hours	Skeletal Traction.	22	Fair	120
6	C.N. B009245	M/46	19/07/96	Hands	5 metres	IIIA IIIA	-	Bandaging	4 hours	Casting	6	Poor	13
7	N.R. B021199	M./27	12/06/99	Forearm	100 metres	IIIA	22C	-	36 days	External fix.	17	Fair	10
8	D.M B013195	M/30	15/05//97	Thigh	5 metre	IIIB	32B	-	12 hours	Skeletal traction	18	Excellent	50

Table 5. Patients with fractures secondary to pistol shots

	PT IDENT.	SEX/ AGE	DATE OF INJURY	ANATOMICAL SITE OF INJURY	ESTIMATED DISTANCE FROM GUN	WOUND CLASSIF.ICATIO N (GUSTILLO)	RACTURE ASSIF.ICATION AO)	TYPE OF FIRST AID MEASURES (PRER HOSP.CARE)	DURATION TO HOSPITALIZAT ION	DURATION TO TREATMENT	TYPE OF TREAT MENT	DURATION TO UNION (WEEKS)	FUNCTIONA L RESULTS	HOSPIT AL STAY (DAYS)
	G.C. B005874	M/20	16/06/97	Thigh	10 metres	II	32B	-	3 hours	12 hours	screw Fix	9	Excellent	22
	M.B. B016840	M/41	25?02/98	Thigh	5 metres	II	32B	-	3 hours	6 hours	External Fix.	24	Excellent	26
	GT B024414	M/26	13/05/97	Thigh	7 metres	II	32B	-	3 hours	6 hours	skeletal traction	12	Good	11
	D.T. B017104	M/21	6/03/98	Leg	50 metres	I	41C	-	5 hours	19 hours	skeletal. traction.	9	Excellent	37
	H.U. B016575	M/32	13/02/98	Foot	10 metres	I	-	-	6 hours	10 hours	casting	8	Excellent	13
	A.M. B006576	M/33	16/12/96	Thigh	50 metres	II	32B	-	3 hours	10 hours	Skeletal Traction.	12	Excellent	47
	A.K. B022892	M/52	24/10/98	Arm	20 metres	IIIC	12B	Dressing	2 hours	6 hours	Prim ary above elbow amputation			14
	M.S 2009851	M/21	13/05/97	Thigh	50 metres	II	32B	-	5 hours	19 hours	Skeletal traction	10	Excellent	37

Table 6. Patients with fractures secondary to shrapnel fragments

	PT IDENT.	SEX/ AGE	DATE OF INJURY	ANATOMICAL SITE OF INJURY	ESTIMATED DISTANCE FROM GUN	WOUND CLASSIF.(GUSTILLO)	FRACTURE CASSIF. (AO)	TYPE OF FIRST AID MEASURES (PRER HOSP.CARE)	DURATION TO HOSPITALIZATION	URATION TO REATMENT	TYPE OF TREATMENT	DURATION OF UNION (WEEKS)	UNCTIONAL ESULTS	HOSPITAL STAY (DAYS)
	V.N B029107	M/27	END/2/99	Arm	2 metres	IIIB	13B	-	3 days	days	casting	-still in ward	-	Still in ward
	C.K. B022350	M/21	15/04/98	Arm	5 metres	IIIB	13B	-	1 month	months	Casting	-still in ward	-	Still in ward
	K.J. B020751	M/22	29/02/99	Thigh, Leg	7 metres	IIIA IIIA	32B 42B	Compression dressing	4 days	days	Casting	Still in ward	-	Still in ward
	B.N. B020751	M/32	7/08/98	Arm Leg	20 metres	IIIA IIIB IIIB`	12B 42B	-	1 hour	hours	External fix. Prim. Amputation forefoot	Died		24 hours
	H.S. B020749	M/42	7/08/98	Arm leg	10 metres	IIIA II	12C 42B	-	1 hour	hours	Casting	Died	-	24 hours
	U.M. B021161	M/	7/08/98	Thigh, leg	20 metres	IIIB IIIB IIIC IIIA	32B, 42C 42B	-	1 hour	hours	.External Fix.	Died	-	24 hours

Age sex

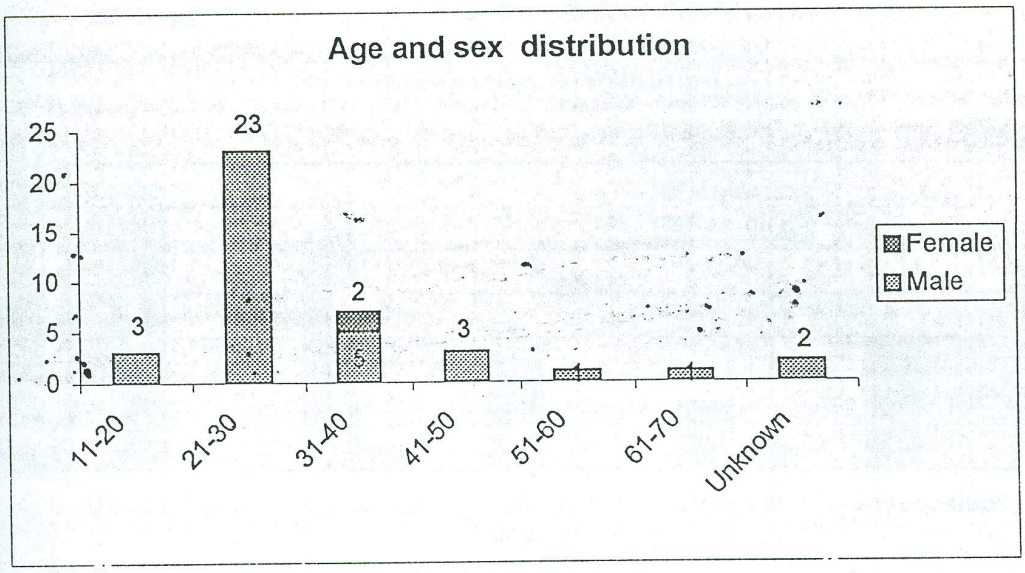


Figure 28. Age and sex distribution.

A total of 40 patients were studied. There were 38 (95 %) males and two (5%) females. The male/female ratio was 19:1 The majority of the patients 36 (90 %) were young individuals having an age range of between 11 and 50 years. Three patients (7.5%) were in their second decade while 23 (57.5%) patients were in their third decade, Seven patients (17.5%) were in their forth decade and three (7.5%) were in their fifth decade. There was one patient (2.5%) each in the sixth and respectively seventh decades.

In two patients the exact age could not be established.

Occupation

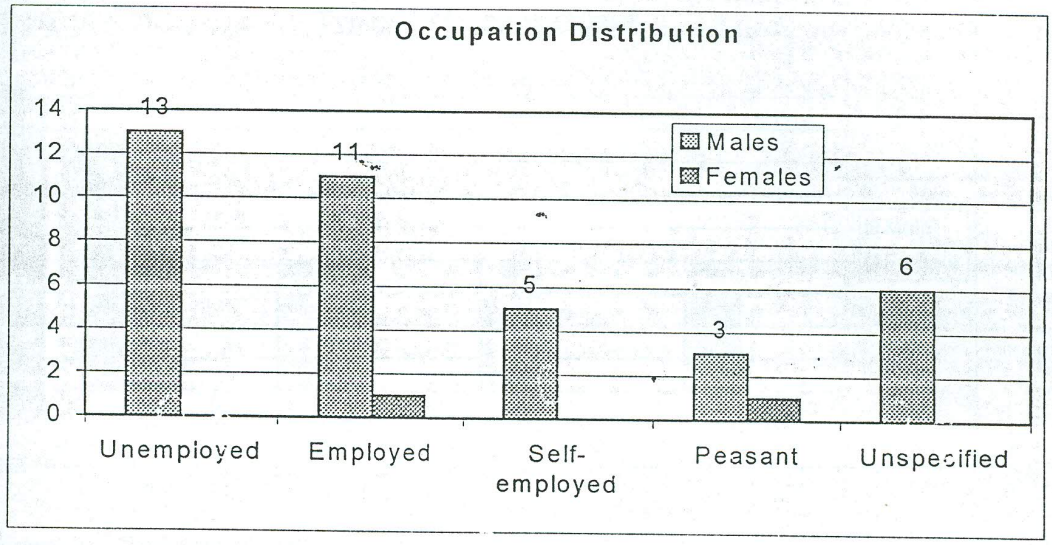


Figure 29. Occupation distribution

Thirteen (32.5 %) of the patients were young unemployed youths all of them shot at by the police, while doing some illegal activities like stealing or robbery. Most of these patients presented with rifle wounds. Seventeen (42.5 %) of the patients were employed or self- employed individuals who were innocent victims of banditry. Most of these patients presented with pistol wounds. Four of the patients (10 %) were peasants: three were attacked by bandits at their home in an attempt to steal from them. One was a peasant who was accidentally shot by hunters while collecting firewood in the bush. In six (15 %) the occupation could not be established but they were probably part of the unemployed lot.

Type of weaponry used

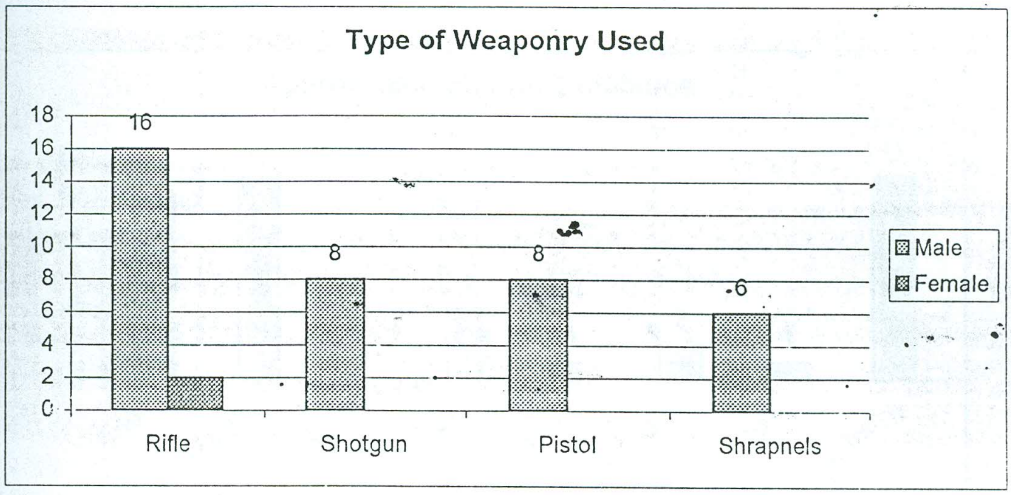


Figure 30. Weaponry used

The various injuries were inflicted by assault rifle in 18 patients (45%), shotgun shots in 8 patients (20%) six of which were close-range shotgun wounds. Pistol wounds were present in 8 patients (20%) while landmine and terrorist bomb explosion shrapnels were each present in 3 patients (7.5%)

The approximates shooting distance

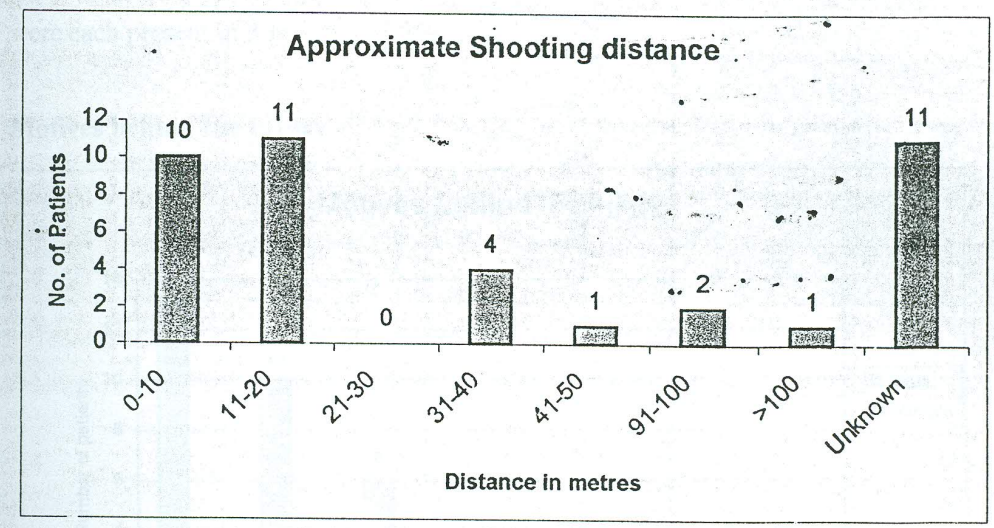


Fig. 31: Approximate shooting distance

The range was between 5 meters and 100 meters. In 10 patients (25%) the muzzle- victim distance was between 0 and 10 meters while in 11 patients (27.5%) the range was between 11 and 20 meters. Other values included 31-40 meters in 4 patients (10%), between 44 and 50 meters in 1 patient (2.5%), between 91 and 100 meters in 2 patients (5%), and over 100 meters in one patient (2.5%). The range could not be established in 11 patients (27.5%).

The various injuries were inflicted by assault rifle in 18 patients (45 %), shotgun shots in 8 patients (20%) six of which were close-range shotgun wounds. Pistol wounds were present in 8 patients (20%) while landmine and terrorist bomb explosion shrapnel fragments were each present in 3 patients (7.5%).

Motives behind the injury

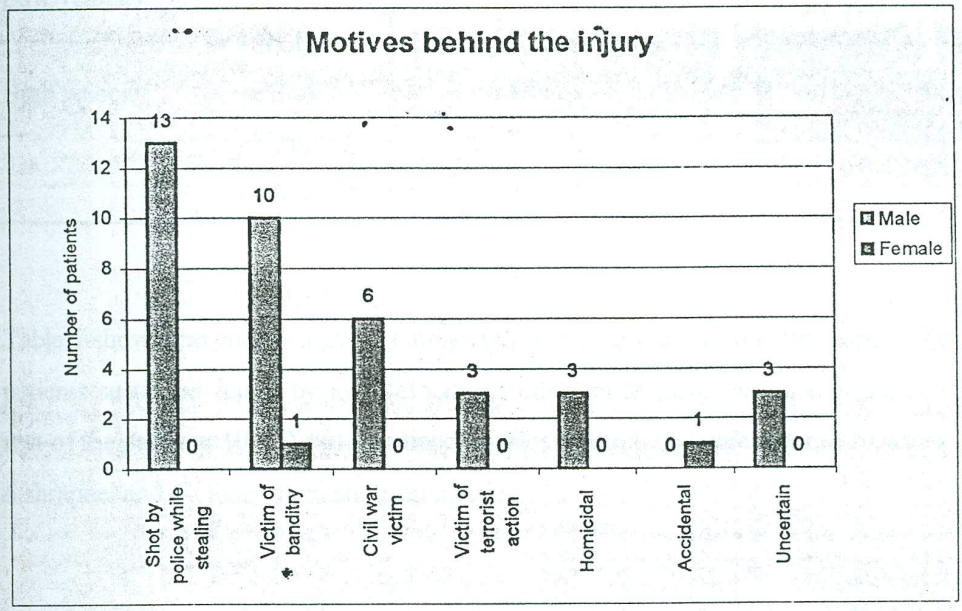


Fig. 32: Motives behind the injuries

In 24 patients (60%) the motives behind the injuries were crime related: thirteen (32.5%) were shot by the police while stealing and eleven (27.5%) patients were innocent victims of banditry. Six patients (15%) were victims of a then ongoing civil war in a neighbouring country. Three patients (7.5%) were victims of a terrorist bombing of the American Embassy in Dar es Salaam. Three of the injuries (7.5%) were of homicidal motives while one (2.5%) was due to accidental shooting during hunting. In 3 patients (7.5 %) the motives behind the shooting could not be established with certainty.

Table 7: Energy transfer category of weaponry and injuries

Mechanisms	Type of weapon	Number of Patients	
		Male	**Female**
Low velocity	Pistol	8	
	Shotgun	2	
High velocity	Rifle	16	2
	Shrapnel	6	-
	Close shotgun	6	-

Table 7 shows the energy transfer category of the weaponry used in this series. Ten (25%) patients sustained injury by low-velocity mechanism (8 pistol and 2 shotgun shots). The rest of the patients 30 (75 %) sustained injuries through high velocity mechanisms (18 rifle, 6 shrapnel and 6 close-range shotgun injuries).

Bones involved

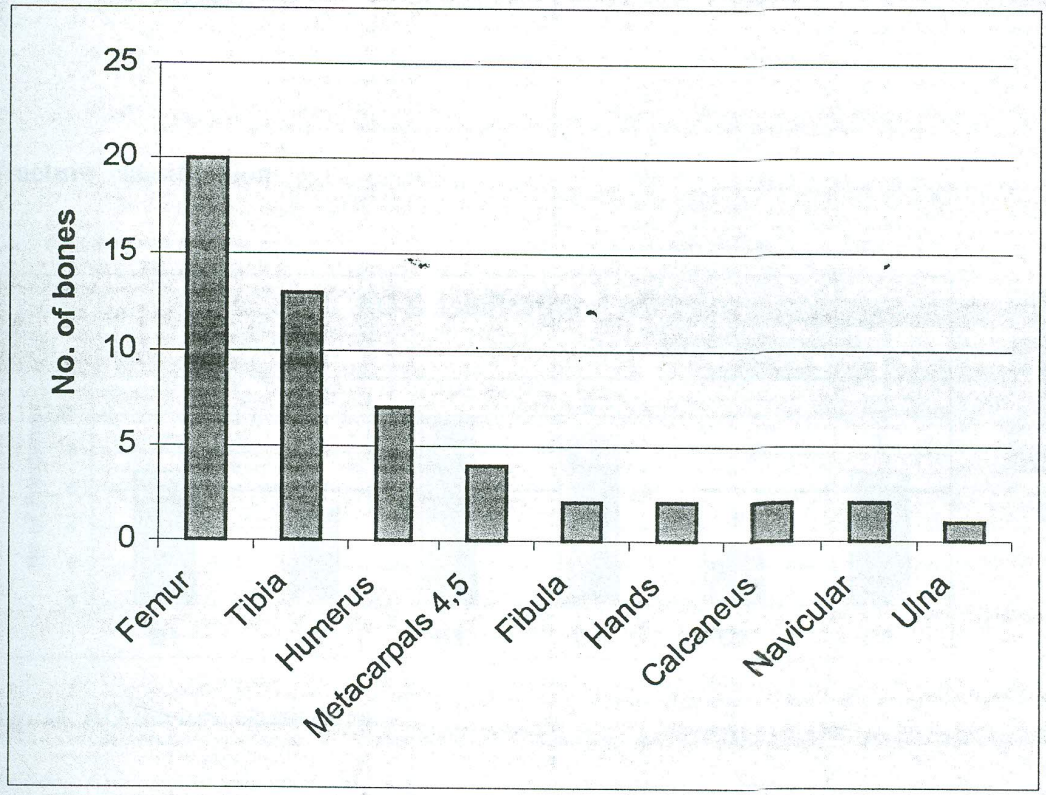


Fig. 33: Bones involved

Twenty patients had injuries to the thigh (50%), 13 patients (32.5%) had injuries to the leg, seven patients (17.5%) had injuries to the arm while two patients had injuries to the hands (5%).

There were 34 patients (84%) with a single fracture site, four patients (10%) with double fracture sites, one with three and one with four fracture sites.

There were 20 fractures to the femur (41.7) %) and 13 (27.1%) to the tibia. There were seven fractures (14.6%) to the humerus and one (2.1%) to the ulna. There were four metacarpal fractures (8.3%), two (4.2%) navicular and 2 (4.2%) calcaneal fractures. There was one (2.1%) isolated fibula fracture.

Fracture classification

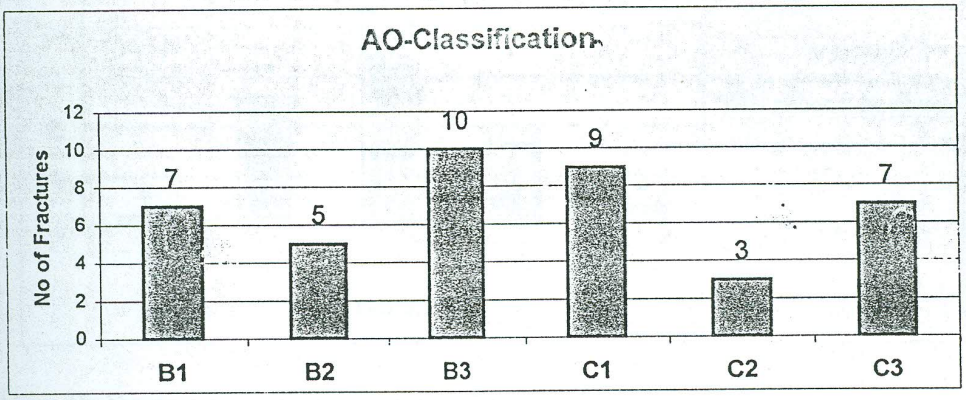


Fig. 34: AO fracture classification

Twenty two (45..8%) of the fractures were type B fractures by AO classification (9-rifle, 6–pistol, one shotgun and 6 shrapnel). Nineteen fractures were of type C by the AO/ASIF classification (39.6%) : (14-rifle, 3-close shotgun injuries and two shrapnel injuries). There were four metacarpal fractures, two navicular fractures and two fractures to the calcaneus which could not be classified by the AO/ASIF long bone fracture classification available then.

Wound classification

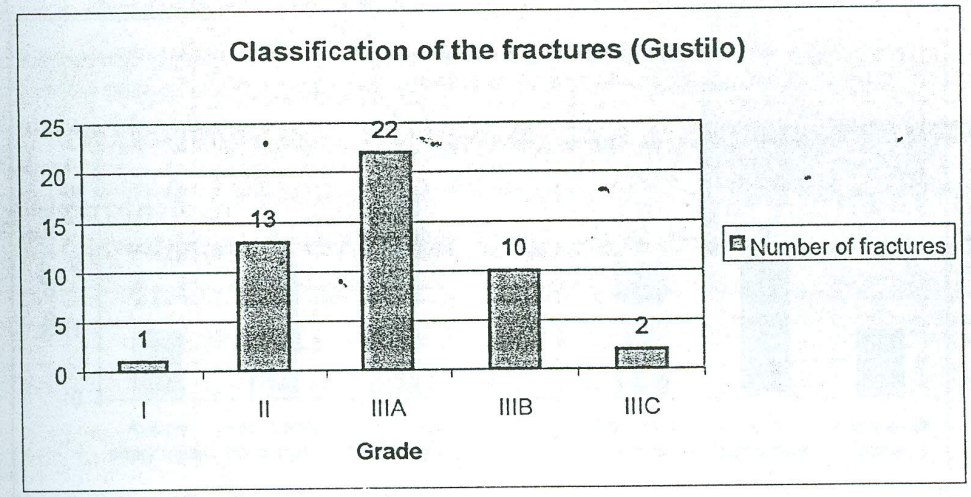


Fig. 35: Fracture-wound classification (Gustilo)

Twenty two of the fractures (45.8%) were of grade IIIA by Gustilo classification : (10 due to rifle shots, 6 due to close shotgun injury, and five due to shrapnel fragments). Ten of the fractures were of grade IIIB (20.8%): (4-rifle, and 6 shrapnel, injuries). Thirteen fractures (27.1%) were grade II (6-rifle,1 shotgun, 1 shrapnel and 5 pistol). Two of the fractures (4.2%) were grade IIIC associated with major vascular injury.

Associated injuries

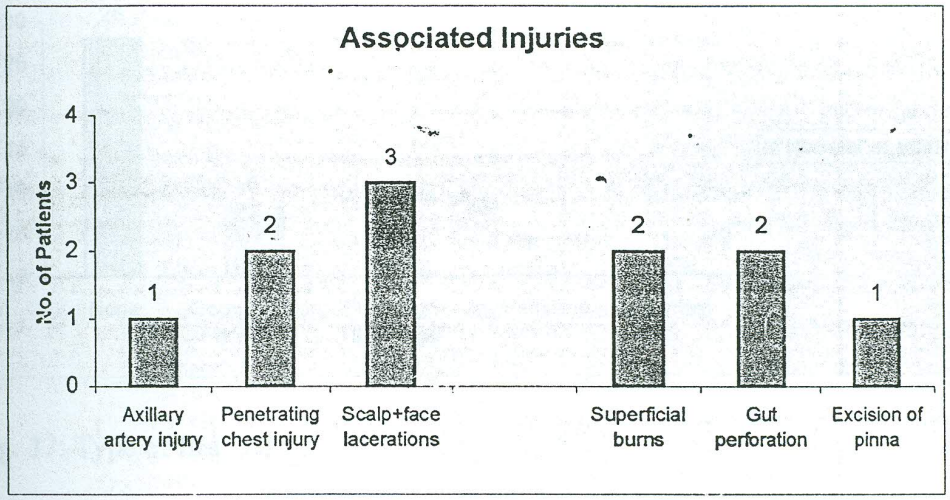


Fig. 36: Associated injuries

There were 11 patients (27.5%) with associated injuries in this series. Two patients (5%) had penetrating chest injuries with haemothorax requiring tube thoracotomy. Two patients (5%) had abdominal wounds with gut perforation requiring laparotomy. Three patients (7.5%) had scalp and face lacerations two patients (5%) had superficial burns to the body. One patient had axillary artery injury and one had excision of the pinna of one ear.

Type of First Aid

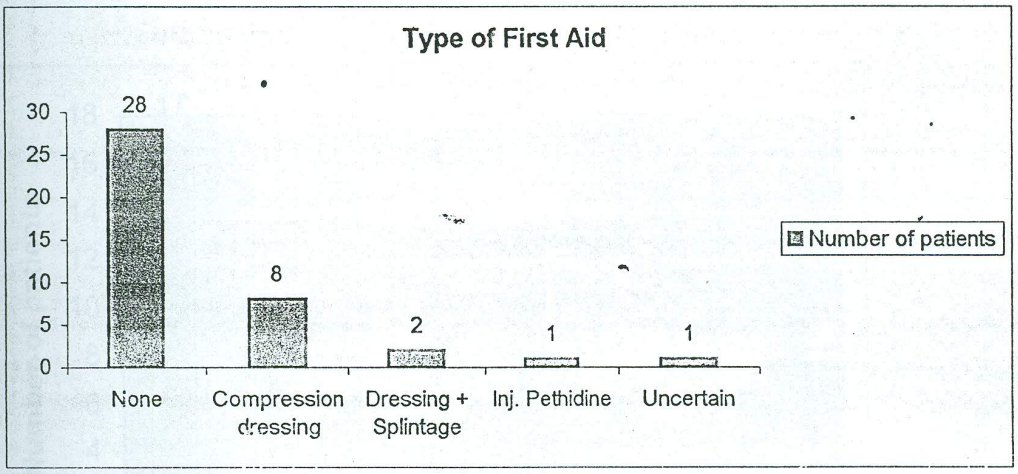


Fig. 37: Type of first aid

Figure 37 shows the types of first aid measures taken at the site of incidence or on the way to hospital. Twenty eight patients (70%) in this series did not receive any kind of first aid measures at the site of accident, or on their way to hospital other than being brought to hospital. Eight patients had compression dressing to arrest bleeding and two were dressed and splinted. One patient was given intramuscular pethidine injection for pain control.

Type of Surgical Procedure and Stabilization

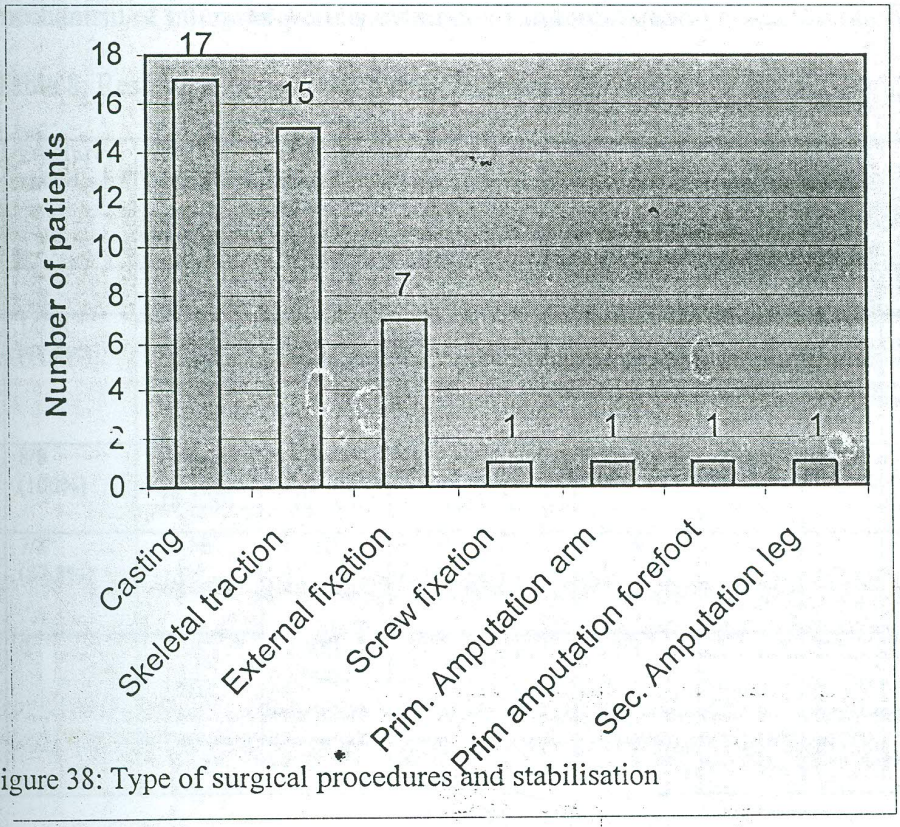


Figure 38: Type of surgical procedures and stabilisation

Figure 38 shows the type of surgical procedures performed. Seventeen patients (42.5 %) were debrided and stabilized by casting. Fifteen patients (37.5%) were stabilized by skeletal traction while in seven patients (17.5%) external fixation was applied. Debridement and screw fixation of a femoral condyle fracture was done in one patient (2.5%). Primary amputation of the forefoot was done in one patient due to severe bone and soft tissue injury secondary to a bomb explosion. One patient underwent primary above elbow amputation due to irreparable axillary artery injury secondary to a pistol shot.

RESULTS OF TREATMENT

Tables 8 and 9 show the results of treatment as well as the functional results both by mechanism of injury as well as by mode of immobilization.

Table 8: Results of Treatment by Mechanism of Injury

Mechanism of injury	Fractures united	Average hospital stay (days)	Average time to union (weeks)	Ave. time to return to work (months)	Functional Results				No. of patients returning to work
					Excellent	Good	Fair	Poor	
Rifle	14/18 (77.8%)	39 (2-365)	18 (8-30)	11 (6-16)	4	4	5	1	8/18 (44.4%) + 3 died + 1 Sec. ampt
S/gun	8/8 (100%)	38 (8-120)	14 (8-16)	8 (5-12).	3	1	2	2	4/8 (50%)
Pistol	7/8 (87.5%)	18 (1-47)	10 (6-12)	7 (3-10)	6	1	-	-	7/8 (87.5%) +1 ampt
Shrapnel	0	-	3 still in ward 3 died	-	-	-	-	-	none

Fracture Union

The fractures united in 29 patients (72.5%). Six patients died (15%). As expected fractures secondary to high velocity mechanism took longer to unite than those due to low velocity mechanism. Fourteen (77.8%) of the 18 fractures caused by rifle shots united in an average duration of 18 weeks (range 8-30) compared with 14 weeks for fractures secondary to shotgun shots and 10 weeks (range 6-12) for the pistol fractures. Three patients with rifle fractures died due to haemorrhagic shock, septicaemia and from associated abdominal injuries respectively. One patient had a primary above elbow amputation. None of the shrapnel fractures had united by the end of the study.

Hospital Stay

The hospital stay was again longer in the patients with injuries resulting from rifle shots 39 days (range 2-365) compared to an average of 38 days (range 8-120) and 18 days (range 1-47) in the shotgun and pistol fractures respectively. The close similarity between

the average hospital stay in the rifle and shot gun injury patients can be explained by the fact that a large percentage of the shotgun injuries were close range injuries which are high velocity missile injuries just like the rifle shot injuries.

Functional Results and Return to Work

Fractures resulting from rifle shots and shotgun shots had a high incidence of complications including infection, malunion and joint stiffness. In this regard the functional results in the united fractures in the rifle fracture group were graded as excellent in 4 patients (28.6%) good in 4 patients (28.6%), fair in 5 patients (35.7%) and poor in 1 patients (7.1%). These 8 patients who had excellent and good functional results returned to work in an average time of 11 months (range 6-16). The other patients with fair and poor functional results had not returned to work by the end of the study.

Comparatively the functional results of the 8 shotgun fracture group patients were graded as excellent in 3 patients (37.5%) good in 1 (12.5%) fair in 2 (25%) poor in 2 (25%) patients. The four patients (50%) with excellent and good functional results returned to work in an average time of 8 months. The other patients with fair and poor functional results had not returned to work by the end of the study.

The 7 patients (87.5%) with fractures secondary to pistol shots healed in an average time of 10 weeks (range 6-12.) The functional results were assessed as excellent in 6 patients (75%), good in 1 patient (12.5%) and none in the fair or poor result category. All the seven patients returned to work within an average time of 7 months (range 3-10). One patient had a primary above elbow amputation.

Fractures secondary to shrapnel fragments had the worst prognosis. None of the 6 patients with fractures secondary to shrapnel injury had healed by the end of this study. Three patients were still in the ward by the end of the study, three died within 24 hours of admission secondary to severe multiple injuries following a bomb explosion.

Results of Treatment by Method of immobilization

Table 9: Results of Treatment by Mode of Immobilization

Mode of immobi-lization	No of patient healed	Ave. Hosp. Stay (days)	Ave. time to union (weeks)	Ave. time to return to work (months)	Functional results				No. of patients Returning to work
					Excellent	Good	Fair	Poor	
POP casting	12/17 (70.6%)	59 (13-131)	25 (18-28)	15 (10-19)	4	2	2	4	6/17 (35.3%) 3 in ward Sec. Ampt 2 died
Skeletal Traction	12/15 (80%)	71 (44-117)	22 (14-18)	13 (8-15)	4	4	4	1	8/15 (53.3%) 2 died
ORIF by Screw fixation	1/1 (100%)	22	9	5	1				1/1 (100%)
External fixation	5/7 (71.4%)	33 (8-65)	16 (12-20)	10 (8-14)	4		1		4/7 (57.1%) 2 died

Fracture Healing

Fracture healing occurred in all the surviving 5 patients (71.4%) out of the 7 who were treated with external fixation (2 died) compared with 12 out of 15 (80%) of those treated by skeletal traction and 12 out of 17 patients (70.6%) treated by casting. This latter figure is misleading because the functional results of the patients in the latter group were far less impressive than those in the group treated with external fixation (see below).

Hospital Stay

A longer average hospital stay is noted in the groups treated with plaster cast 59 days and skeletal traction (71 days) as compared to those treated by external fixation (33 days) or screw fixation (22 days). The longer hospital stay in the skeletal traction group is partially due to the institutes regim of keeping the patients on traction for a period of at least six weeks till the fracture site stabilizes before a plaster cast or a below groin plaster cast is applied while at the same time taking care of the wound.

Functional Results

Twelve of the seventeen fractures treated with plaster cast immobilization healed without further intervention. Fractures treated by this treatment method had functional results graded as excellent in four patients (33.3%), good in two (16.7%) and fair in 2 and poor in 4 patients (33.7%). The 6 patients with good and excellent functional results returned to work in an average time of 15 months.

Among the fifteen fractures treated by skeletal traction immobilization 12 of them (80%) united within an average time of 22 weeks. Eight out of the15 patients (53.3%) returned to work within an average time of 13 weeks. The one femoral fracture treated by screw fixation of the lateral condyle united without further intervention and the results of treatment were graded as excellent. He was also able to return to work within 6 months.

Four of the seven patients (57.1%) with fractures treated by external fixation united with excellent functional results and the patients were able to return to work. The remaining 2 fracture patients treated by external fixation in two American Embassy bombing victims died within 24 hours of admission due to severe multiple injuries.

The functional results were graded as excellent in the 4 out of the 5 surviving patients treated with external fixation (80%) compared with 6/15 (40%) good to excellent results in those patients treated by plaster cast, or with 8/13 (61.5%) of those who were treated by skeletal traction.

Return to work

All the 4 surviving patients (100%) treated with external fixation were able to return to work within a significantly shorter average time of 10 months compared to 12/16 (75%) of those treated by plaster cast whose average time to return to work was 15 months. Among the 14 patients treated by skeletal traction 11/14 (78.6%) were able to return to work in an average time of 13 months.

Complications

Complications by Type of Treatment (Table 10)

In a total of 40 patients with 48 fractures, there was a total of 29 complications 29/48 or a complication rate of 60.4 % as shown in tables 10 and 11 and 12. Infection was the most common complication.

(a) Infection

From the total of 40 patients with 48 open fractures a total of 16 patients (40%) developed infection resulting in death in one patient. Among the cases treated by cast immobilization 2 developed superficial wound infection (5%) 2 deep infection (15%) and 3 osteomyelitis (7.5%).

Among the cases treated by skeletal traction 2 developed superficial wound infection, 3 deep wound infection and 2 osteomyelitis.

There was one superficial wound infection and one deep wound infection respectively among the cases treated by external fixation.

Table 10: Complications by mode of immobilization

Type of Complication	Casting	Skeletal traction	External fixation	Screw fixation
Superficial wound infection	2	2	1	-
Deep wound infection	2	3	1	-
Osteomyelitis	3	2	-	-
Malunion	3	2	-	-
Nonunion	1	-	-	-
Delayed union	1	1	-	-
Joint stiffness	3	1	1	-

All the superficial wound infections were treated with repeated debridement, daily wound dressing and administration of appropriate antibiotics according to the bacterial sensitivity pattern.

Among the patients who developed deep wound infection one patient had a grade IIIA open rifle femoral fracture and had undergone primary surgery 17 hours after injury. Three were grade IIIA rifle fractures of the tibia admitted more than 24 hours after injury. Two patients had grade IIIA open femoral fracture and were operated primarily within 12 hours following injury. The infection was treated by early excision of all infected tissue, exploration of the fracture site and removal of loose bone fragments. One was stabilized with an OA external fixator with two bar construction while the rest were stabilised with skeletal traction which was later changed to a below groin plaster cast in the cases with distal femoral shaft fractures. In these patients there was no recurrence of the infection.

Table 11 shows the culture and sensitivity results in 8 patients from whom the data could be obtained:

Table 11: Infection and Bacteriology

Patient's Identity	Day of Detection	Bacterial Flora	Sensitivity Pattern
A.M. B007568	3 days	Pseudomonas	Gentamycin Kanamycin
Y.A. B011408	5 day	Pseudomonas	Gentamycin Kanamycin
P.C.M. B006846	20th day	Proteus	Augumentin Ciproxin
K.J. B028995	8th month	E.Coli	Gentamycin Ciproxin
D.D. B011406	1 month	Staphylococcus Aureus	Erythromycin Tetracycline
H.M. B015475	3rd day	E. Coli	Gentamycin
B.M. B007240	15th day	Klebsiella	Gentamycin Cefuroxime Cotrimoxazole
M.S. B012562	25th day	Coliform	Cefuroxime Gentamycin

(b) Other complications

Fractures treated by cast immobilization had a higher rate of other complications like malunion delayed union, and joint stiffness compared to the patients in the other.types of treatment.

Complications by Mechanism of Injury (Table 12)

(a) Infection

Infection complications were more prominent in the fractures secondary to rifle shot injury. Among the patients with fractures secondary to rifle injury 10 cases developed infection (with one death due to septicaemia) as follows: five developed superficial wound infection, 2 developed deep wound infection and 3 cases developed osteomyclitis.

Table 12: Complications by mechanism of injury

Type of complication	Rifle	Shotgun	Pistol	Shrapnel
Superficial wound infection	5	2	1	-
Deep wound infection	2	2	-	1
Osteomyelitis	3	-	-	1
Malunion	3	-	-	-
Nonunion	-	-	-	1
Delayed union	2	-	-	-
Joint stiffness	3	2	-	-

Cases with fractures secondary to shotgun shots were the next in magnitude with a total of 4 cases of infection: 2 cases of superficial wound infection, and two cases of deep wound infection. No osteomyelitis developed in this category.

Among the cases with fractures secondary to pistol shots only one developed superficial wound infection.

Among the cases with fractures due to shrapnel injury 3 were victims of a bomb explosion and they died due to severe multiple injuries within the first 24 hours.

The other three cases developed deep wound infection in one patient, and osteomyclitis in one patient.

(b) Other Complications

Rifle shot fractures also presented with a high rate of complications which included malunion in 3 cases, delayed union in 2 patients and joint stiffness in 3 patients.

The average time for union was 17 weeks (range 12-23 weeks) for the tibia, 14.4 weeks (range 12-22 weeks) for the femur, 12 weeks (range 11-13 weeks) for the humerus, 8 weeks for the ulna and 8 weeks for the hand injuries. Five patients were still in the ward at the end of this study. One patient with a grade IIIB wound and type B3 fracture of the humerus following shrapnel injury developed a nonunion. He was a victim of a then on-going civil war in a neighbouring country and arrived at the hospital one week after injury with infection. He was still in the ward at the end of the study. In two patients healing was delayed due to deep wound infection. They latter required decortication and healed with good results. Malunion was seen in 3 patients with a 2.5cm. 2.5cm and 2cm shortening respectively and a compensatory shoe was offered to compensate for the shortening pending further follow-up in view of possible further surgery.

Joint Movement

No stiffness was noted in the hips. One patient with a humeral fracture developed stiffness of the shoulder joint movement in the course of his outpatient follow-up. This was due to the patient's poor compliance to physiotherapy training. The active abduction of the shoulder was 60 degrees. He gradually progressed to painless full range of motion of the joint after supervised rigorous physiotherapy. Three patients developed stiffness of the knee joints with an average range of movement of 80 degrees of flexion in two patients and 70 degrees in the other patient who had suffered severe soft tissue injury and fractures involving the tibial condyles.All except the latter patient achieved a flexion range of better

than 110 degrees flexion. The poorest results were in the two patients who had severe injuries to the hands.

One was treated with a mini-external fixator and was lost to follow-up for two months only to reappear two months after with severe contractures of the fingers.

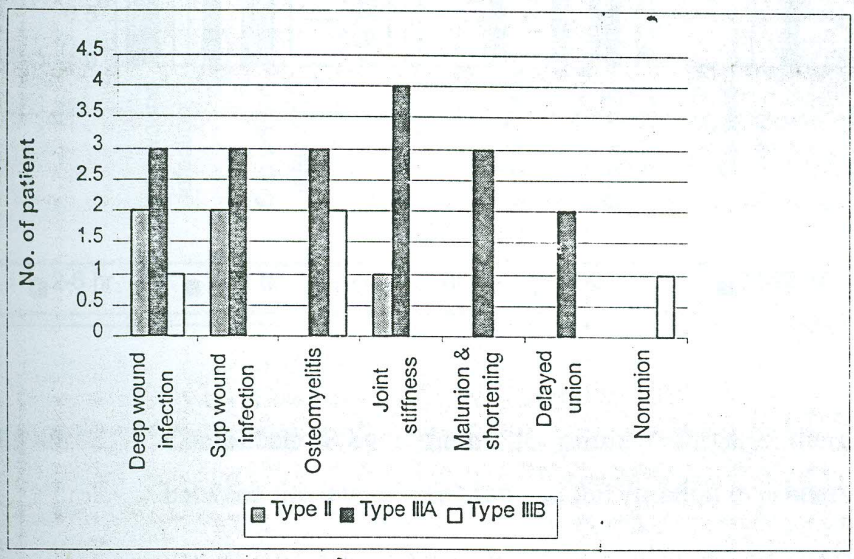


Fig 39: Complication by type of Fracture

The most common complication was infection in 40% of the patients. There was a correlation between the severity of the injury and the rate of complications. The majority of the fractures were type IIIA.

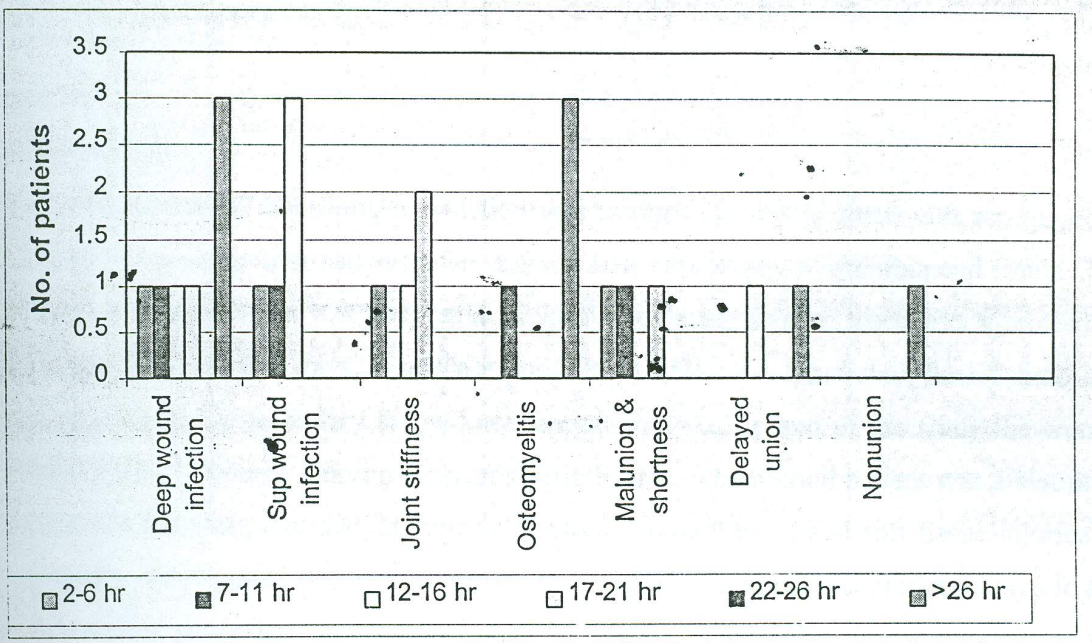


Fig 40: Complication by duration to primary surgery: there was a correlation between the rate of infection and the duration to primary surgery.

Neurovascular Complications

No neurovascular complications were encountered both in the pre- and post-operative period.

Amputations

In three patients (7.5%) limb amputation was performed: One patient with serious bone and soft tissue infection had sustained a grade IIIB rifle injury of the tibia and fibula. The initial cast stabilization was later replaced with an external fixator. Even after a prolonged hospitalization of 365 days, it was not possible to achieve a functional, healed limb. He later underwent a secondary below knee amputation. At the end of the study the wound had healed and he was training for a prosthetic fitting. The second patient was a victim of a terrorist bombing and had sustained extensive shrapnel bone and soft tissue injuries to the limbs with a grade IIIB injury to the tibia and fibula, humerus, superficial burns to the limbs and a grade IIIC (Gustilo) of the foot. He underwent primary amputation of the forefoot which was nonviable. This unfortunate patient died of haemorrhagic shock within 24 hours of injury. The last patient had a grade IIIC pistol injury to the arm with an irreparable injury to the axillary artery. He underwent a primary above elbow amputation.

Mortality

There were 6 deaths in this series as shown in table 12 constituting a 15% mortality rate.

Table 12: Number of Deaths

PT. IDENTITY	AGE/SEX	MECHANISM OF INJURY	ANATOMICAL SITE OF FRACTURE	CAUSE OF DEATH
1. MS B0011907	M/25	Rifle	Femur	Haemorrhagic shock
2. B.022781 AS	F/40	Rifle	Femur.	Associated abd. Injury
3. MPC B015230	M/27	Rifle	Femur	Septicaemia
4. BN B020751	M/32	Shrapnels	Multiple fractures	Severe .polytrauma
5. B020061 UM	M/35	Shrapnels	Multiple fractures	Severe polytrauma
6. H.S B020749	M/42	Shrapnels	Multiple fractures.	Severe polytrauma

5.0 DISCUSSSION

The purpose of this study was to identify the problems associated with treating civilian firearm missile injuries to the extremities in our civilian society. Many studies have shown the alarming rate at which these injuries are increasing in some societies.[186] This study has shown that our society is no exception to this trend, and that the treatment of missile fractures is a serious problem particularly in our societies in which the resources and options for adequate treatment are limited.

In a span of three years from July 1996 to June 1999 40 patients with 48 firearm fractures to the extremities were treated at Muhimbili Orthopaedic Institute. This figure excludes the number of patients sustaining firearm missile injuries to other parts of the body other than the extremities.

Age and Sex

The large number of young individuals in this series is noted. Thirty three (82.5%) of the patients had an age range of between 11-40 years. The evident male preponderance of 19:1 is noted. This is probably no surprise since males are the more adventurous, the bread-earners and are more aggressive than their female counterparts.

Aetiology

The history of the injury is important because it provides information to assess the amount of energy dessipated in the fracture. The history should include the type of weapon used (handgun, shotgun, rifle, landmine or bomb blast), bullet calibre and the distance travelled by the missile. These important details may influence

treatment and many patients who have sustained firearm injuries know or remember them.

Perhaps the most alarming fact is that 24 of the patients (60%) were in one way or another victims of a crime- related incidence. Thirteen (32.5%) patients were shot by the police while stealing while 11 patients were innocent victims of banditry. Most of these incidences occured within or in the areas around Dar- es-Salaam City.

The circumstances and sequalae of urban violence are well documented in several societies[187] However the identification of aetiological factors has been more difficult.[188] Some studies have incriminated socio-economic factors like, unemployment, alcohol intoxication, marital disharmony, age and broken parental relationships[189] In this study the alcohol intoxication, marital disharmony and family background factors were not investigated but a significant number of unemployed individuals was noted in 13 patients constituting 32.5% of the patients.

The terrorist bombing of the American Embassies in Nairobi and Dar es Salaam on 7th August 1998 was a completely new event in the histories of these traditionally peaceful East African countries. This event, the first of its kind in Tanzania brought new experience in the management of bomb blast injuries with patients having injuries never before seen in the civilian hospital practice in this country. Three of the patients in this study (7.5%) were victims of this bomb blast. All of them died within 24 hours of injury despite tireless efforts to save their lives.

Another 6 patients (15%) were victims of a then ongoing civil war in a neighbouring country, 3 patients were victims of a homicidal attempt and 1 was a victim of

accidental shooting by hunters while collecting fire-wood in the bush. In three patients the motives behind the injuries could not be established with certainty.

Many studies have shown that civilian type of missile injuries are usually caused by the so called low-velocity mechanisms as opposed to war or military wounds which are called high-velocity wounds caused by high velocity mechanisms. Because of the low energy transfer the civilian type of missile wounds are said to be uncomplicated.[190] However, it is well known that the muzzle velocity is not the only or most important determinant of wounding capacity.[190] Many studies have established that civilian missile wounds are as a rule caused by handguns.[190] Ordog et al.[191] found that 87% of the missile injuries of the chest injuries were due to handguns, 9% were secondary to shotgun blasts and only 3% resulted from high velocity weapons. Both bullet velocities and bullet designs have changed over the years, so that many handguns and sporting arms are using expanding or deforming bullets with higher velocities. Dugas and D'Ambrosia[192] stated that a more aggressive approach should be taken when dealing with low-velocity midrange firearms. eg the 0.38 special and the 0.45 calibre handguns. They think that these handguns are capable of delivering significant kinetic energy to the body and therefore should be treated as high-velocity firearms.

In this series a large proportion of the injuries were caused by high velocity weapons in 29 patients (72.5%) namely: rifle, landmine and bomb shrapnel fragments and close shotgun injuries. This explains the considerable bone and soft tissue damages caused in this series resulting into many Gustilo grade III type wounds and a high rate of complications. Only 11 patients (27.5%) were victims of low-velocity missile

injuries .The legality of police using assault rifle to immobilize suspected or red-handed caught thieves comes into discussion. The current discussion in the house of Parliament to liberalize the sale of firearms to the public will most probably have serious consequences to the community. In this study at least 17 patients (42.5%) were innocent victims of the illegal use of firearms. The shotgun was a causative agent in 8 patients, 5 of whom were close range shotgun injuries. Range and the type of pellet used are the most important determinants of damage inflicted by a given shotgun charge[63,168] In this study five (12.5%) out the eight shotgun injuries occurred at ranges closer than 10 meters. It was not possible to determine the size of the pellets but at this close range the concentration of pellets within the target pattern is extensive and the type of wounds produced are severe. Four of the five wounds in this category were type IIIA fractures and one was type II. When pellets, wadding and debris are blasted into the extremities with other foreign bodies and massive bacterial contamination, these wounds may be worse than the so called high velocity wounds.[190]

The Shooting Distance

The exact shooting distance could not be ascertained but a good approximation could be obtained from the history. The range was between 5 meters and 100 meters. In 21 patients (52.5%) the muzzle-victim distance was between 0 and 20 meters. We think that this also probably or partially explains the high rate of severe injuries sustained in this series. (34 grade III fractures equivalent to 85%).

There were retained missiles in 4 rifle shot patients, in 2 pistol shot patients and in 1 bomb blast patient. (See Fig. 26 - Retained missiles removed at surgery)

The shooting distance is an important determinant of wounding capacity in shotgun wounds. Due to the spreading pattern of shotgun ballistics there is a variation in the size of the shot cloud at different ranges. This implies that the total area injured grows larger as the distance from gun to target increases. At close range the tightly packed cloud of shot may blast completely through the extremity carrying with it many vital structures producing a segmental type of damage. At larger ranges the shot pattern disperses and there is less likelyhood of segmental loss of bone, vessel or nerve because the energy and the shots are dispersed over a wide area, sparing tissue between the pellet wounds.

The Bones Involved (Fig.33)

The frequent involvement of the extremities in firearm injuries is well documented. Nance et al.[193] found the extremities to be the most commonly injured area at 41% in a total of 139 cases under the age of 17 years. In a review of 122 patients with gunshot wounds at a Level II rural referral centre, Dodge et al.[194] found that the lower extremities were involved in 25% and the upper extremities in 24% of the cases.

The lower extremities are the most common site of injury in warfare. Approximately 70% of the patients treated by the International Committee of the Red Cross in Africa and Asia have limb wounds[195] El-Ezaby et al.[196] reports 55.5% involvement of the extremities in the October War in 1973 between Egypt and Israel. Carey[197] reports that 90% of the wounds incurred by U:S: Army Seventh Corps Personnel during Operation Desert Storm involved the extremities. During the Croatia-Yugoslavia war 76,6% of the Croatian patients suffered injuries to the extremities.[58]

Among the 1,129 fractures treated in the Rwandese War. 609 were fractures of the upper limb, 491 for the lower limb and 315 fractures of the hand[198]

Associated Injuries

In a large series of patients with missile fractures one might expect to find a significant percentage with other associated injuries. There were 11 patients (27.5%) with associated injuries in this series. War wounds are usually multi-system and may tend to have more associated injuries than civilian wounds both in number and in degree. Fig.36 shows the number and type of associated injuries in this series. Two patients had penetrating chest injury with haemothorax requiring tube thoracotomy, two patients had abdominal wounds which required exploratory laparotomy. The one patient who had irreparable injury to the axillary artery has already been described.

Pre-hospital Care or First Aid measures (Fig. 37)

The level of health care is determined not only by the quality of hospital care but also by the level of pre-hospital care because pre-hospital care and the early accessibility to hospital can influence the final results of treatment. Twenty eight patients (70%) in this series did not receive any kind of first aid measures other than being brought to hospital. At least thirteen of these patients (32.5%) were shot by police while doing criminal activities like stealing or robbing. The society's indifference to giving first aid to such victims is probably due to a commonly accepted attitude by society that no assistance should be given to criminals. However the medical consequences and impact of this attitude can be seen and felt in the poor treatment results and in the high rate of complications like infection.

Treatment

The principles in managing open fractures resulting from firearms include determining the amount of energy dissipated into the bone and soft tissues and in assessing wound contamination. Firearm wounds vary in the amount of energy dissipated through the tissue, the amount of contamination and the frequency of associated neurovascular injuries. Pistols and shotguns are low velocity weapons whereas rifles and shrapnel fragments from landmines and bomb blasts are high velocity missiles.

The key to success in treating any open fractures even in remote parts of the country lies in excellent primary surgery.[199] Good primary surgical care also offers the best conditions for prevention of complications such as infections. There has been some disagreement as to the nature and extent of debridement necessary in missile wounds

Considering the reviewed wounding mechanism of firearms in this series one would undoubtedly expect that most of these wounds in this series should be treated as war injuries. Many authors contend that most civilian gunshot wounds are low velocity missile injuries and that the majority can be managed with minimal debridement or with no debridement in the emergency room[183,200] .The effectiveness of limited surgery in most cases of civilian missile fractures is supported by several studies. Howland and associates[126] in a study of 72 patients with fractures resulting from civilian gunshot wounds concluded that simple gunshot fractures do not require extensive debridement or antibiotics. Feeark and associates[201] in a similar study also found that gunshot fractures do not require extensive surgery, and that cleaning of the wounds and immobilization were all that was necessary. In their group of 100

fractures of the extremities, there were no cases of delayed wound healing or deep infection, and all had satisfactory results. Hampton also reviewed a series of patients with GSWs of the extremities, some of whom had fractures, and concluded that the presence of a fracture was not an indication for extensive debridement.[156] Carr and Stevenson[202] noted that civilian and war wounds vary with respect to both environment and type of missile, but still recommended that the basic principles of management remain the same.

Our experience in this small series is that even in a civilian setting severe bone and soft tissue damage can be sustained, there is lack of pre-hospital care and the patients may arrive late for treatment. In view of these problems, the risk of infection is even greater and the complication rate much higher than that reported in the Western literature. For this reason, therefore, as opposed to accepted modes of treatment of missile wounds in the Western literature we would recommend their debridement always in the operating theatre, be them civilian or military in nature. In the operating theatre one has the advantage of inspecting and assessing the amount of damage and thus adopting the appropriate mode of debridement and fixation. The principles of debridement using the 4C's are widely accepted in the treatment of soft tissue missile wounds.[203] Also in the presence of unexpected tissue damage that requires more extensive debridement, the resources for proper care would be available in the operating room. Fackler et al.[204] did not find any valid clinical or experimental data to show that excising the injured tissue around the wound, as prescribed by military dogma, added any benefit over that obtained from simpler treatment alternatives of incising to release pressure and establish adequate drainage

In the case of close-range shotgun wounds, these are a class of wounds about which there is no dispute as to the necessity of wide debridement[168] There is also no dispute over the principle of exploration in case of doubt. Because the shot-cloud is a relatively low-velocity missile, as the range increases there may be doubt as to whether much damaged muscle or wadding is present. Under these situations, there is no substitute for exploration of the wound. Close-range shotgun wounds (20-30 yards)[168] are within the range of the wad trajectory and must be considered to have in its depth some of this foreign material and demands removal.[168] If no extensive muscle damage or wadding are found, then no extensive debridement need be done.

The other important thing to remember is that of leaving the firearm missile wounds open and closing them by delayed primary or secondary closure 5 to 7 days after wound debridement[203] This can be followed by primary or secondary covering of the wound. All the wounds in the 33 patients who underwent primary wound debridement were closed by delayed primary or secondary closure or were allowed to granulate and epithelialize. Some patients required skin grafting.

Different regimes of antibiotics are advocated in the treatment of extremity missile injuries. Antimicrobial therapy is effective in preventing infection, however, it cannot be overemphasised that antibiotic administration cannot replace good primary surgical debridement of the wound. The most common complication among missile wounds is infection, and the threat of gas gangrene should be considered even in civilian wounds.[203] Routine antibiotic administration was noted to decrease the Clostridial incidence to 0,08% in the Korean war in comparison to the incidence of

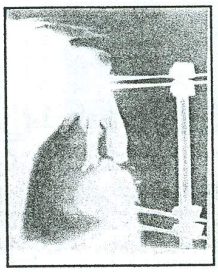
5% in World War I and 0,7% in World War II [77] Some authors[126] have stated that the use of antibiotics in the treatment of low-velocity gunshot fractures may not be necessary. However, Patzakis et al.[12] in a prospective study , showed that antibiotics are indicated in low-velocity missile injuries. Gas gangrene was not encountered in this series. Benzylpenicillin has usually been used routinely in infection prophylaxis but today there is a trend toward broad-spectrum cephalosporin derivatives like cetriaxone [203]. In this series cloxacillin or erythromycin were used because according to hospital laboratory figures most staphillococus strains were sensitive to these antibiotics. In some instances antibiotics were used according to bacterial culture and sensitivity results Whenever fear of anaerobic infections was present metronidazole was added.

The other important element in the treatment of missile fractures is bone fragment stabilization . Low velocity missile wounds usually result in lacerations and crushing with minimum diameter of the permanent cavity. Such fractures are usually stable, undisplaced but can be comminuted. Depending on the location of the fracture, these fractures can be immobilised with a plaster cast. Other suitable non surgical treatment such as skeletal traction or functional bracing have been used successfully for stable fractures. The options for appropriate bone stabilization in a developing country are limited and even the expertise to apply them may be available only in the few consultant or referral hospitals available. Standard plaster of Paris casting is still a basic way of stabilization in our country in these kinds of injuries. In this series it was used in 17 patients (42.5%) . For our surroundings Plaster of Paris immobilization has got some advantages: It is the most available item for fracture stabilization even at regional or district hospital level, it is cheap and affordable, it is

easy to use, enables relatively good mobility of the patient and ensures bone fragment stabilization. However, plaster of Paris has got some disadvantages in that it does not offer good wound control and may particularly hinder plastic surgery in early covering of the defect. Also the wound discharge soaks and stains the plaster of Paris, which presents a potential risk of additional contamination. On the other hand this manner of stabilization requires splintage of adjacent joints which is disadvantageous especially for the upper limb which is often followed by contractures. Furthermore, when a plaster of Paris is applied to a patient the dangers of cast ischaemic phenomenon and compartment syndrome should always be borne in mind and proper instructions should be given when discharging a patient with a cast. Early loss of reduction should be checked by x-ray controls. Despite these disadvantages, plaster of Paris sometimes appears to be the only available means of stabilization in some of our hospitals.

External fixation is another important option of fracture stabilization which is currently increasingly being used at the Institute.. These facilities were few at the time of the study and were used in only 7 patients (17.5%) in this series: in one patient for the humeral fracture with good results (Figs. 40-43), in 3 patients with tibial fractures 2 of whom died due to multiple injuries following bomb explosion injuries, in 2 patients for a femoral fracture who presented to hospital more than 12 hours after the injury. One patient had a mini- external fixator for metacarpal fractures of the hand. Many authors agree that external fixation is the method of choice in the management of severe missile fractures. [203] Rifle shots and shrapnels are high velocity missiles. Missile wounds from these weapons are nearly always devastating injuries with severe bone and soft tissue destruction. Close range

shotgun injuries have large cavitating entrance wounds, often with significant contamination. These injuries behave similarly to the high energy and high velocity injuries and are frequently contaminated with wadding and numerous pellets. These high velocity injuries commonly correspond with open grade IIIA, IIIB and IIIC injuries which may result in early or late amputation. In these type of injuries external fixation provides early stabilization, easy accessibility to the wound while the patient is hospitalized. Careful attention to placement of external fixator pins in an appropriate pattern should be emphasized.

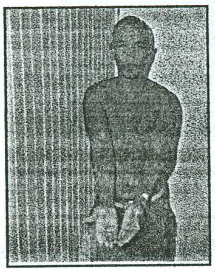
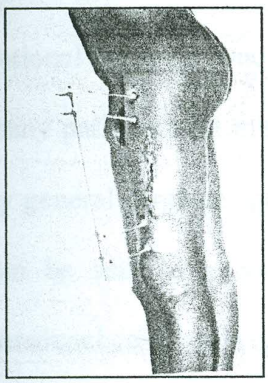


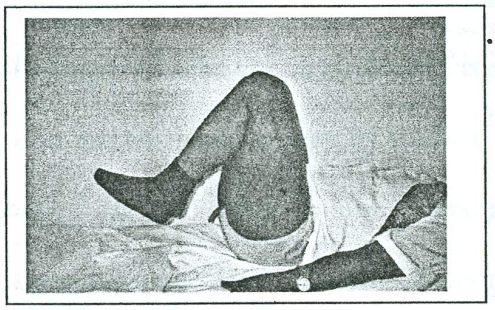
Fig. 40 Fig. 41 Fig. 42 Fig. 43

Figures 40 – 43, Showing a grade III open humeral fracture treated by external fixation with good functional results.

Immobilization by external fixation has got a number of advantages. It allows good access to the soft tissue wound and facilitates the inspection and change of dressings. Furthermore it allows early mobilization of the patient and joints adjacent to the fracture site, and indeed, a number of patients soon begin to walk with the help of crutches which is quite motivating to them. It also assures undisturbed work and

comfort for early covering of soft tissue defects. The other advantage is that the surgeon can choose to preserve limb length or to reduce the gap between bone ends if limb shortening is acceptable.





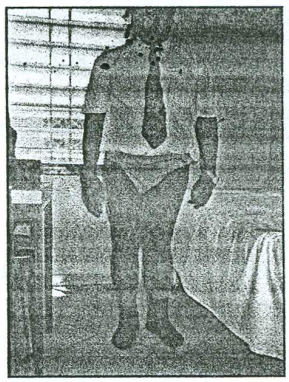


Fig. 44 Fig. 45 Fig. 46

Figures 44 - 46, Showing a grade III open fracture of the Femur Stabilized with an external fixator with excellent functional results

However, immobilization by external fixation is not without its disadvantages. External fixation device placement requires a well trained personnel because incorrectly placed pins can cause destabilization of the whole construction, stiff joints, muscle tethering with prolonged swelling, neurovacular bundle injuries with nerve palsies and pain, equinus foot deformities and pin tract infection. The other disadvantage of external fixation is the cost which may be forbiding for many of our

patients The external fixators used in this series were the Tanzfix, the AO/ASIF tubular external fixators and the mini-external fixator. The most common complication of external fixation in this series was pin tract infection which was eventually controlled. The Tanzfix external fixator is a cheaper version of external fixator with self-drilling pins introduced at the Institute since 1996. The author believes that cheaper devices could be made locally in the country to meet the national demands. Due to the current shortage of orthopaedic surgeons in the country many patients with missile injuries in the country-side will continue to be managed by general surgeons, general practitioners, or even by medical assistants before they can be sent to a consultant hospital. With minimal amount of exposure, this personnel could train on the good application of external fixators.

There has been discussions concerning the use of external fixation in children. Current thinking in civilian practice recommends the use of external fixation in children [205,206,] However Coupland[195] strongly advises against the routine use of external fixation for war wounds with fractures in children, maintaining that callus formation is very rapid by conservative means in this age group and that it can be substantially slowed by rigid fixation. Other workers think that the delayed union frequently reported after external fixation may be a feature of the nature of the fracture rather than of the stabilization technique[207] External fixators have been used widely in war surgery. Labeeu et al[198] have reported their experience from the Rwandese War in 1990/93 where in a period of less than three years they applied 209 external fixator devices to treat 4,646 patients.

Unreamed, interlocked, intramedullary nailing, fine-wire fixation and percutaneous screws in the mataphyseal bone are other suitable options that are not easily accessible in our situations.

Stabilization of fractures can also be done by the use of skeletal traction. This method was used in 15 patients (37.5%) in this series, all of them with missile fractures to the femur. Twelve of these patients progressed to healing, Two of these patients died of septicaemia and haemorrhagic shock .respectively. The average hospital stay of these patients was 71 days (range 44-117 days) and the average healing time by this method was 22 weeks (range 18-25 weeks). Ryan and associates[208] reviewed the histories of 43 patients who were treated with skeletal traction for a gunshot-related fracture of the femur. The average time in traction was 47 days, the average time in a spica cast was 98 days, and the average time from injury to union of the fracture was 144 days. There was no deep infections or non-unions. The use of skeletal traction, followed by a spica cast or cast brace, can lead to a satisfactory result, and deep infection is uncommon.[209] The disadvantages of this method is that it may be difficult to maintain axial alignment, particularly in fractures of the proximal and middle thirds of the femur. Furthermore, the patient's long-term confinement to bed with prolonged skeletal traction, exposes the patient to thromboemblic phenomenon, urinary tract infections, psychological disturbances in the elderly, development of bedsores and severe joint contractures. It is therefore suggested that this kind of immobilization should be short-time and changed as soon as possible during the phase of secondary surgery. In this series skeletal traction was changed to a below groin plaster of Paris cast after a period of 6 weeks of traction for diaphyseal fractures of the distal third of the femur.

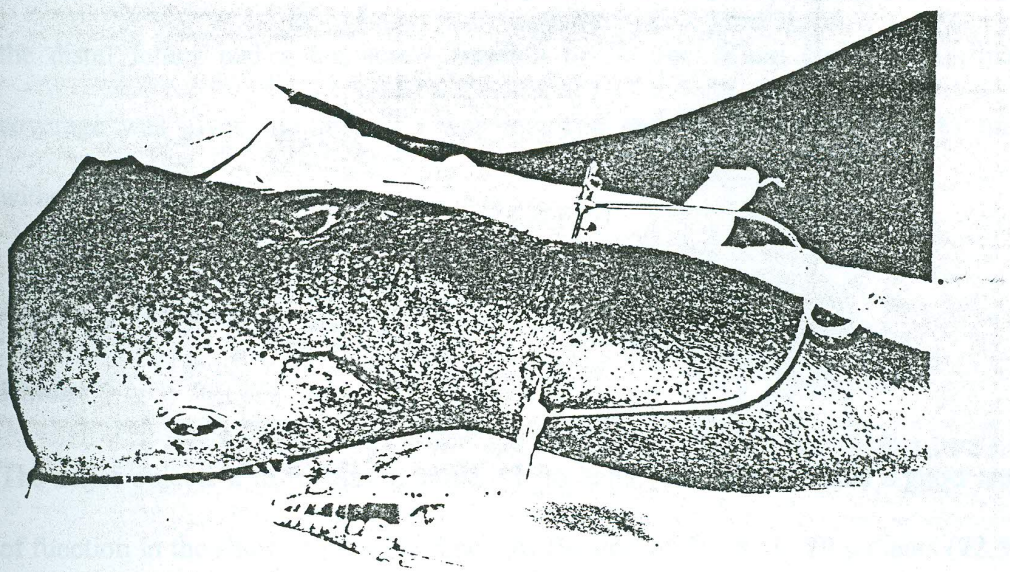


Fig. 46 Fracture femur, Stabilization by skeletal traction

Internal fixation has not been widely advocated in the treatment of missile fractures because of the risk of infection in these highly contaminated wounds except perhaps where joint reconstruction is necessary.[207] In this case minimal internal fixation technique, with well placed screws requiring no soft-tissue stripping, supported by external fixation, is gaining wider popularity in blunt injuries and may be applicable in gunshot trauma. Intra-articular firearm injuries constitute a special category of open fractures which present a real therapeutic challenge. Treatment aims to restore the anatomy (when possible) and function as well as prevention of infection. An acceptable approach would be stable surgical reconstruction of the joint followed by early exercises. In cases with severe comminution, plaster cast, traction or external

fixation is needed. In this series only one patient with a grade II gunshot fracture to the distal femur had a lag screw fixation to fix the lateral condyle. Antibiotic coverage was given, no infection was incurred and the femur went on to union without complication.

Results of Treatment

Union

The major objective in fracture treatment is to achieve bone union and a good return of function in the shortest possible time. At the end of the study 29 patients (72.5%) had healed, 6 patients (15%) died (3 due to multiple injuries following a terrorist bomb explosion, 1 due to haemorrhagic shock due to severe blood loss, 1 due to septicaemia and 1 due to associated abdominal injuries).

As expected, fractures secondary to rifle shots and close-range shotgun shots took longer average time to unite as compared with those secondary to shotgun injuries and pistol fractures. This is explained by the different mechanisms of injury, considering the severity of bone and soft tissue injury associated with high velocity mechanism injuries. Comparatively low velocity mechanism fractures like those secondary to low velocity weapons (pistols and long range shotgun shots) took shorter time to unite. The majority of the rifle shot fractures as well as the close range shotgun fractures were high velocity grade III injuries.

Fracture healing occurred in all the surviving 5 patients (100%) who were treated with external fixation (2 died) compared with 12/17 (70.6%) of those treated with plaster cast and 12/15 (80%) of those treated by skeletal traction. These latter figures

are misleading because the functional results of the patients in these groups were far less impressive than those treated with external fixation.

Hospital Stay

The hospital stay was again longer in the patients with injuries resulting from high velocity mechanism like rifle shots and close range shotgun shots, compared to that in the low velocity mechanism group. The close similarity between the average hospital stay in the rifle (39 days) and the shotgun injury patients (38 days) can be explained by the fact that a large percentage of the shotgun injuries were close range injuries which are high-velocity injuries just like the rifle shot injuries.

A longer hospital stay was noted in the groups treated with plaster cast (59 days) and skeletal traction (71 days) as compared to those treated with external fixation (33 days) or screw fixation (22 days). This is partially due to the institute's regim of keeping the patients on traction for a period of six weeks till the fracture site stabilizes before a plaster cast is applied while at the same time taking care of the wound.

Functional Results

Fractures resulting from rifle shots and shotgun shots had a higher incidence of complications including infection, malunion and joint stiffness. In this regard the functional results were poorer compared to those in the fractures secondary to the other mechanisms of injury (with the exception of shrapnel injuries which had the worst outcome). They were graded as good to excellent in 8 patients (57.1%) in the rifle shot group with 5 fair (35.7%) and 1 poor (7.1%) functional result respectively. Comparatively, there were four (50%) patients with good to excellent functional

results with two (25%) patients each in the fair and poor functional result category respectively. Seven of the 8 patients (87.55) with pistol shot fractures healed with good to excellent functional results. One had an above elbow amputation due to irreparable axillary artery injury.

The functional results were graded as excellent in 4 of the 5 surviving patients treated with external fixation (80%) compared with 6/12 (50%) of the healed fractures treated by plaster cast; or with 8/12 (66.7%) of those treated by skeletal traction. Twelve of the 15 patients treated by skeletal traction healed but with far less functional results: 8/15 (53.3%) had good to excellent functional results, 4/15 of the patients or 26.7% had fair functional results not enabling them to return to work.

Duration to Return to Work

As expected more patients with pistol fractures returned to work 7/8 (87.5%) in the shortest average time of 7 months (range 3-10) as compared to 8/18 (44.4%) of the patients with rifle fractures who returned to work in an average time of 11 months (range 6-16). All the surviving 4 patients (100%) treated with external fixation were able to return to work within a significantly shorter average time of 10 months compared to 6/17 patients (35.3%) of those treated by plaster cast whose average time to return to work was 15 months. Among the 15 patients treated by skeletal traction 8/15 (53.3%) were able to return to work in an average time of 15 months.

Complications

1. Complications by Mechanism of Injury

The most common complication in this series was infection which occurred in 16 patients (40%). Infection complications were more prominent in the patients with

fractures secondary to rifle injuries, close range shotgun injuries and in fractures secondary to shrapnel fragments. Among the patients with fractures secondary to rifle injury 10 cases (55.6%) developed infection. Cases with fractures secondary to shotgun injury were the next in magnitude with a total of 4/8 cases (50%) of infection. This high infection rate in this group could be explained by the fact that a large part of these injuries were close-range shotgun injuries. Among the patients with fractures secondary to pistol shots only 1/8 (12.5%) developed superficial wound infection. Fractures secondary to shrapnel injuries bore the worst diagnosis. Among the 6 cases with fractures due to shrapnel injury 3 were victims of a bomb explosion and they died due to severe multiple injuries within 24 hours of admission The other three cases developed deep wound infection in two patients and osteomyelitis in one patient.

Complications by Type of Treatment

Among the cases treated by cast immobilization 7/16 (43.8 %) developed wound infection compared to the 7/14 (50%) of the patients treated by skeletal traction. There was 1/7 (14.3%) superficial wound infection and 1/7 (14.3%) deep wound infection respectively among the patients treated with external fixation. Among the patients who developed deep wound infection one patient had a Gustilo grade IIIA rifle femoral fracture and had undergone primary surgery 17 hours after injury. Three were Gustilo grade IIIA rifle fractures of the tibia admitted more than 24 hours after injury. Two patients had grade IIIA open femoral fractures and were operated primarily within 12 hours following injury.

All the superficial wound infections were treated with repeated debridement, daily wound dressing and administration of appropriate antibiotics according to bacterial sensitivity pattern.

The infection rate of 40% including one septicaemia resulting into death and 4 cases of osteomyelitis is probably alarmingly high. However, there could be several explanations to this fact: First of all there was a special category of patients who had sustained war injuries from a then on-going civil war in a neighbouring country. These patients had spent three or more days in the bush without medical attention arriving to hospital several days or weeks after injury obviously with badly infected wounds. Secondly, late presentation can also be incriminated as being one of the reasons for the high rate of infection. As expected the incidence of infection was higher in patients who received primary treatment more than twelve hours post injury. In nine of the infections (22.5%) occurred in patients who were operated

more than 10 hours post injury. The reasons for the delay from the time of injury to the time of surgery were multi-facforial: first the delay in transfer of patients from the site of accident or from the referring hospital to our hospital; and secondly the unproportionally large number of accident patients requiring surgery and the limited and shared theatre facilities that required waiting. Cox and Evans[210] reporting on 66 cases of open fractures of the tibia, found no greater incidence of complications in patients treated after twelve hours as compared with those treated within twelve hours after injury. They believed that devitalised tissue was more easily identified in the latter group, contributing to more adequate debridement. Furthermore, poor pre-hospital care could also have contributed to the high rate of infection. Furthermore although the majority of the patients in this series sustained missile fractures in civilian settings, most of their injuries were inflicted with military type of weapons resulting in much severe injuries due to wound cavitation as compared to injuries with civilian weapons. The potential for infection was therefore higher. As expected the incidence of infection was higher in the patients who sustained fractures from rifle shots, shrapnels and close range shotgun injuries.

Furthermore, the increasing incidence of AIDS and HIV infection has had a dramatic increase in the number of septic complications in orthopaedic patients. In our region, according to one report by Jellies et al., [211] about 20% of adult road traffic accident victims were HIV- positive and between 35% and 45% of adult surgical admissions were HIV-positive. However, the HIV status of the patients in this series was not studied.

The reported infection rate in open fractures ranging from 3 to 25% raises a lot of challenges to every surgeon managing such injuries[177] Specifically, the incidence of infection of wounds associated with open fractures correlates directly with the extent of soft tissue damage: for type I fractures 0-2%, for type II fractures 2-7%, for type III fractures over-all from 10-25%, for type IIIA, 7%, for type IIIB 10-50% and for type IIIC,25-50%.[147] In the case of missile injuries, the type of weapon and environment are important factors determining the potential for infection[126] Woloszyn et al[155] retrospectively studied 132 gunshot fractures in 126 patients, 80 of whom were treated with intravenous antibiotics and 52 with oral antibiotics. The overall infection rate in this series was 1.5%. Only two infections were encountered, both in the oral therapy group (3.8%). He attributed the low infection rate in this study to several factors including surgical cleansing, local wound debridement, immobilization, and broad-spectrum antibiotic coverage. Wiss et al.,[209] in a retrospective analysis of 56 patients, reported no infections for low-velocity femoral gunshot fractures treated by intravenous administration of antibiotics followed by immediate or delayed closed interlocking nailing.

The efficacy of prophylactic antibiotics in the treatment of open fractures has repeatedly been discussed and conflicting reports are found in the literature. Some studies have advocated the use of antibiotics.[11] while others find it of little or no use[212] Patzakis et al.[12] in a prospective randomized study of 310 patients with 333 open fractures (255 wounds caused by direct trauma and 78 caused by gunshot) showed that there was no statistically significant difference between the infection rates of the groups receiving no antibiotics (with infection rate of 13.9%) and the group receiving penicillin and streptomycin (infection rate 9.7%). The infection rate

for the group receiving cephalocin (2.3%) was significantly lower than those for the other two groups. He showed that nearly two-thirds of direct trauma patients (64.5%) had positive bacterial cultures from a wound, obtained at any stage of initial treatment (before treatment, after lavage, or after suture) or obtained from debrided tissue and furthermore several days of bacteriological culturing were required before a culture was considered sterile. In such a situation the author considers giving antibiotics is not giving prophylactic antibiotics but is in fact treating contaminated wounds. Missile fractures are open and communicate with the external environment and as such are potentially infected. The presence of pathogenic organisms in the open fracture wound greatly enhances the possibility of infection if the patient is not receiving antibiotics. Burke[12] showed that the optimum period after wounding for the administration of prophylactic antibiotics to be effective in contaminated wounds is approximately three hours. No pre-treatment bacteriological studies were undertaken in the current study though the author thinks that interesting results would be obtained for comparison. To our knowledge no such studies have been done in this geographical region. Tikka et al.[213] in a retrospective analysis of 36 civilian gunshot fractures found an infection rate of 41.4% including pin tract infections rate of 22%. The tibia and femur were the most frequent sites of infection. Other workers have also documented the high infection rate of the distal half of the tibia in open fractures[12, 154]

The incidence of infection was higher in the patients who were treated by casting and lower in patients treated with external fixation or screw fixation. Among the 16 patients treated by plaster cast, seven (43.8%) developed infection as compared to two out of the six (33.3%) in the patients treated by external fixation. In the patients

treated by casting, this complication was due to the discharge from the wound soaking the cast and hence re-contaminating the wound. Skeletal traction on a Braun's splint provided good wound control but drainage of the wound contents was impaired in cases where a deep wound with a dead end acted like a well not allowing adequate drainage of the discharge.

The organisms responsible for wound infection in six patients whose data could be collected are shown in table 11.A large proportion of these flora are hospital infection flora probably acquired in the hospital as a result of prolonged hospital stay of the patients.

Gustilo,[11] in his analysis of 511 open fractures, found that specimen from 19 of 33 infected wounds grew coagulase-positive staphylococcus aureus. One of his recommendations for open fracture treatment was the administration of massive doses of antibiotics prescribed routinely for coagulase-positive staphylococcus aureus or specifically for the pathogenic bacteria isolated before, during, and after surgery for a 7- to 10-day period.[11]

Type IIIB or IIIC open fractures are associated with high incidences of infection and non-union due to the increased devitalisation of the soft tissues and the comminution of bone. If such wounds are left open for more than two weeks, colonization with bacterial flora from the hospital is common, frequently resulting in infection of the wound. In patients who have an open fracture, early soft tissue coverage of exposed bone (within 5-10 days after injury) considerably reduces the risk of infection.[147]

3. Other Complications



The other major complications encountered in this series were fracture healing problems and joint stiffness. These occurred among patients treated by traction and plaster of Paris casting. Two patients were classified as having delayed union, three had malunion with shortening of between 2.5 and 2cm, one had non-union and three had joint stiffness with knee flexion of less than 30 degrees. By the end of the study the patients with delayed union healed spontaneously with time after an extra three months, shoe compensation was offered as a trial for the patients with malunion and shortening pending further reassessment and further physiotherapy was recommended to improve the range of joint motion of the knees.

Judged on these results a plaster cast with a hinged knee would be advisable to enable the patient to start early joint mobilization. Similarly, skeletal traction by Perkin's traction would probably be a better alternative to traction with a Braun's splint. Further follow-up of the patients will be required to assess whether or not further corrective surgery is required in the future.

4. Amputation

Three patients underwent amputation, two primary and one secondary: one patient had an above elbow amputation due to unsalvageable injury to the axillary artery secondary to a pistol shot, another patient underwent primary amputation of the forefoot due to severe bomb blast injury. The other patient had a secondary below knee amputation due to severe bone and soft tissue infection secondary to a grade III rifle shot fracture of the tibia and fibular. The limb was amputated one year after failed successive attempts at limb salvage and reconstruction. One patient underwent a secondary ankle arthrodesis due to a severely damaged ankle joint secondary to a

rifle shot. He was referred to the Institute from the regions two days after the injury. Six other patients were still in the hospital at the end of this study.

5. Mortality

There were 6 deaths (15%) in this series. Three deaths were secondary to rifle shots while the other three were secondary to shrapnel fragment injuries. The cause of death in the rifle injury group were septicaemia in one patient, haemorrhagic shock in one patient and associated abdominal injuries in one. In the shrapnel fragment group the deaths were due to severe polytrauma.

6.0 CONCLUSION

It is concluded that as it has been demonstrated by many other studies in other societies, firearm missile injuries are on the increase. Our traditionally peaceful country is no exception from this trend. These injuries are usually associated with a high morbidity and mortality rates and since the resources for adequate treatment are limited the complication rates are high.

In ideal conditions a rational approach to fracture treatment is dictated by a critical evaluation of both the injury and the patient as well as the best treatment options at the surgeons disposal.

Unfortunately, due to the limited resources, as it occurred in the series of this study, the choice of treatment is often dictated sorely by the resources available at the time of treatment. In this regard, it is always a dilemma to choose which treatment to apply because this depends on the available facility.

It is because of this dilemma that an effective comparison of the advantages and disadvantages of each method of treatment cannot be effectively analysed and confident conclusions drawn. The other major critic of this study is that of the small number of subjects involved in the study and the short follow-up time making it difficult to make firm conclusions.

However, despite these shortcomings, our experience in this study indicates that treatment with the external fixator bears far better advantages compared to cast or skeletal traction for the treatment of severe Gustilo grade III open firearm fractures such as the majority found in this series. This is reflected in the shorter hospital stay, the higher rate of bone healing in a relatively shorter time, easier control of infection resulting in a lower complication rate and better functional results.

This does not mean that the other methods of treatment like casting and skeletal traction should be abandoned because they have and have always had their role in the management of open fractures. A large proportion of the fractures in this series were grade III by Gustilo classification. The external fixator finds an exceptionally good advantage in this type of injuries as compared to other methods of treatment. Non operative methods of treatment like plaster cast and skeletal traction can be used in stable Gustilo grade I and II firearm missile fractures mainly secondary to low-velocity mechanism.

The major disadvantages of plaster cast treatment in this study was that control of infection was difficult due to the discharge soaking the plaster and hence causing re-contamination to the wound. Other disadvantages were the higher rate of malunion and joint stiffness found. Judged on these results a plaster cast with a hinged knee would be advisable to enable the patient to start early joint mobilization. The

adequacy of reduction and stability should be judged by clinical and radiological assessment.

Treatment with skeletal traction on a Braun's splint provided fairly good wound control but the problem arose when a deep open wound with a blunt end acted like a well not providing adequate drainage of its contents. This method of treatment also had a high rate of joint stiffness and malunions as compared with the external fixation group. Skeletal traction by Perkin's traction would be a better alternative. It is simple effective and allows hip and knee motion as well as controls rotation satisfactorily.

Because of its advantages over the other treatment methods, the external fixator should continue to be the treatment of choice for the treatment of severe firearm missile fractures to the extremities. It is recommended that in our peripheral hospitals every district or regional hospital should have an external fixator as a minimum orthopaedic armamentarium to treat these types of injuries, plus a trained personnel capable of correctly applying it.

Preventive measures should include restriction of the availability of firearms and ammunitions to the public and a broad based approach to curb the current unemployment problem. We support the various peace initiatives currently taking place among the different warring factions and ethnic groups in and around our geographical region. We urge that a lot of efforts and commitment be invested in them in order to achieve a lasting peace in our region and in the world at large.

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