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MISSILE WOUNDS

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When a missile penetrates a living body, the damage caused is the result of the absorption by the tissue of the kinetic energy (KE) released by the missile. This transfer of energy is related to the mass (M) and velocity (V) of the missile and is dependent on the formula $KE = \frac{1}{2} MV^2$. In the case of missiles of small mass, e.g. bullets, missile velocity is by far the most important factor.

A non-spinning bullet is unstable because aerodynamic forces cause it to move away from the line of flight increasing the angular deviation of its longitudinal axis so that it tumbles and tumbling, once started, continues. Rifling in the gun barrel gives a bullet spin and greater stability resulting in a greater striking velocity, a longer range and a more consistent trajectory.

RETARDATION

All missiles are subject to retardation which varies directly as the square of the velocity, the diameter of the missile and density of the retarding medium. The missile will stop as soon as it has released all its kinetic energy by retardation.

The more irregular the shape of a missile the more apt it will be to whirl and tumble through the air and the more it will be retarded because of the excessive area presented to the air.

YAW

The retardation effects of the missile will be aggravated by any instability, e.g. yaw in flight and in tissue.

Yaw is an instability due to the deviation of the longitudinal axis of a projectile from its line of flight. There is no yaw in a sphere. To have yaw a missile must have a length greater than its diameter. Although the gyroscopic effects of spin damp down the oscillations of a yawing projectile they are inadequate to maintain stability in media denser than air. Thus when a high velocity rifle bullet penetrates the soft tissues of the body, which approximates in density to that of water, yaw will be increased. This causes more retardation and the liberation of more kinetic energy causing extensive tissue damage.

EFFECTS OF MISSILE INJURY

The local effects of missile injury of tissue are laceration and crushing, production of a shock wave, and temporary cavitation.

Laceration and crushing: Laceration and crushing occur in the path of a penetrating missile. The track cut out is called the permanent cavity. With missiles of *low* velocity, i.e. less than 1000 ft./sec., such as revolver bullets and metal fragments, the damage caused is usually confined to the missile track.

An entrance wound is usually an accurate record of a bullet's presentation at the moment of impact but neither entrance nor exit wounds, especially with high velocity missiles, will give any idea of the destruction caused in the underlying tissues by yawing.

Shock wave effects: Another effect of the passage of a missile when it strikes and compresses the surface of a medium is the creation of a shock wave which moves ahead and radially at a velocity greater than sound in the medium and it may produce hydraulic effects in gas-containing viscera.

Temporary cavitation: Temporary cavitation is the most important feature of all high velocity missile wounds. High velocity missiles have an enormous strike energy which is absorbed by target tissue particles causing their momentary centrifugal displacement and creating a temporary pulsating cavity in which pressure is subatmospheric. Air is successively sucked in and blown out of the cavity through both entrance and exit wounds until the cavity finally collapses. The area of tissue damage caused by the temporary cavity can be quite extensive. There can be tissue pulping, blowing asunder of fluid filled viscera, remote damage to blood vessels, fracture of bones untouched by the missile, and shattering of bone into splinters. The phenomenon was demonstrated photographically in target media in 1941 by Black, Burns and Zuckerman by firing spheres and bullets at varying speeds through both gelatine blocks and rabbits' legs. This has since been demonstrated (Harvey *et al* 1945) with modern high speed cinematography combined with micro second surge radio-

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graphy. *It has also been shown that the cavitation phenomenon could be produced in a vacuum* (Harvey *et al* 1962). The shape of the temporary cavity depends on the shape and presentation of the missile and it is generally fusiform in longitudinal section.

Unstable irregularly-shaped metal fragments from exploding devices such as mines, grenades, bombs and shells will cause multiple ragged wounds of varying size. These will tend to lodge in the body carrying in with them bits of clothing, dirt and foreign matter not to mention the secondary effects from the scattering of bone splinters.

HISTOLOGICAL FEATURES OF THE UNCONTAMINATED MISSILE WOUND

The histological features of a bullet muscle wound from injury to healing were studied in sheep by Hopkinson and Watts (1963). They fired a 0.22 inch bullet at 1600 ft./sec. through the quadriceps femoris muscle of an anaesthetised sheep and produced a non-fatal wound. Using intravenous Indian ink perfusion a zone of muscle corresponding roughly to the area of temporary cavitation was shown to be ischaemic and it increased in size up to 12 hours. With Geimsa stain which stains normal muscle pink, they showed that damaged muscle was coloured blue in varying shades. Over the next three months, and in the absence of major blood vessel damage and infection, phagocytosis of dead muscle took place and some muscle regeneration, and the wounds healed leaving a thin fibrous scar. By way of contrast, Matsumoto *et al* (1967) showed that spraying experimental wounds in living rabbits with methylene blue stained nonviable muscle within one hour, the effect lasting up to 3 days. In viable muscle, however, the dye was rapidly disseminated by an efficient circulation.

THE MECHANISM OF WOUND CONTAMINATION

That the cavitation effect accompanying the passage of a high velocity missile could be responsible for drawing in contaminating matter from the target surface through entry and exit wounds was shown by Dziemian and Herget (1950) using coloured powders, and by Thoresby and Darlow (1967) who fired a sterile bullet through a cloud of thermolabile organisms as well as through a piece of cloth impregnated with them. Whether the cloud or piece of cloth were on the entrance wound face of the target gelatine block, or on the exit wound side, the organisms

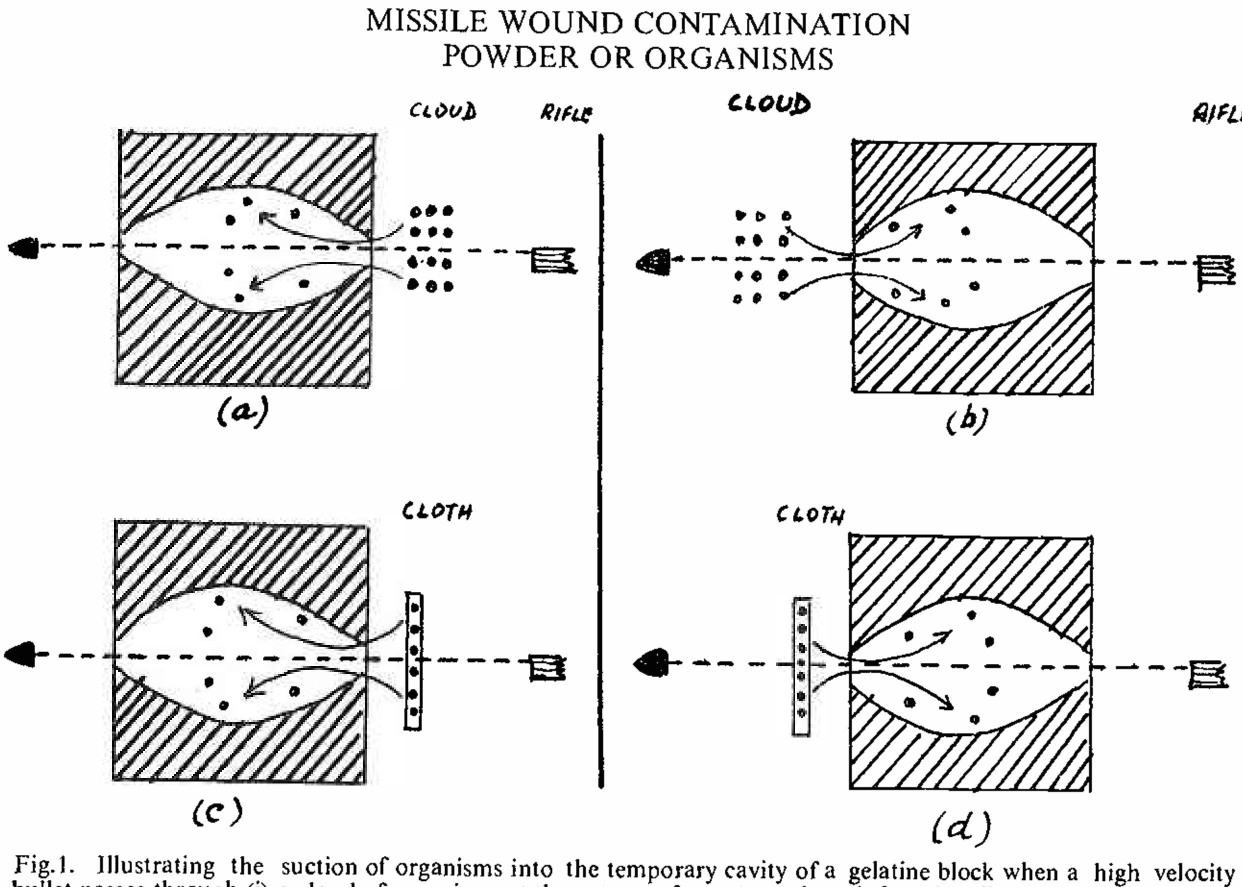

Fig. 1. Illustrating the suction of organisms into the temporary cavity of a gelatine block when a high velocity bullet passes through (i) a cloud of organisms at the entrance face (a), at the exit face (b); (ii) a contaminated cloth at the entrance face (c), and at the exit face (d).

could be grown in the missile track and crevices left by the collapsed temporary cavity. The same effect was produced with resulting fatal gas gangrene when a bullet was fired into a sheep's thigh through a piece of cloth (simulating clothing) which was impregnated in turn with measured spore suspensions of pathogenic clostridia (Thoresby and Watts, 1967). Death took place within 60 hours whether the impregnated cloth was on the exit or the entrance side of the sheep's thigh: cloth fibres were also found in the wound.

THE SOURCES AND DEVELOPMENT OF INFECTION

All missile wounds are contaminated with a variety of flora including pyogenic cocci and pathogenic clostridia. These organisms are found on the skin and clothing of wounded men and in the soil. The origin of the clostridia is in the large intestine of humans and animals. Price and Shooter (1964) have shown that commensal strains of *cl. welchii* excreted from the human bowel are capable of forming appreciable amount of a-toxin.

The presence of these contaminating organisms in the wound is however no indication that infection will develop for they tend to disappear on subsequent days. On the other hand the presence of blood clot and foreign bodies in a wound encourages the growth and invasion of organisms. For the germination of clostridial spores and formation of their powerful toxin a greatly reduced oxygen tension is necessary: this is found in ischaemic and necrotic tissue especially muscle.

MISSILE WOUND CONTAMINATION
BULLET FIRED THROUGH SHEEP'S THIGH

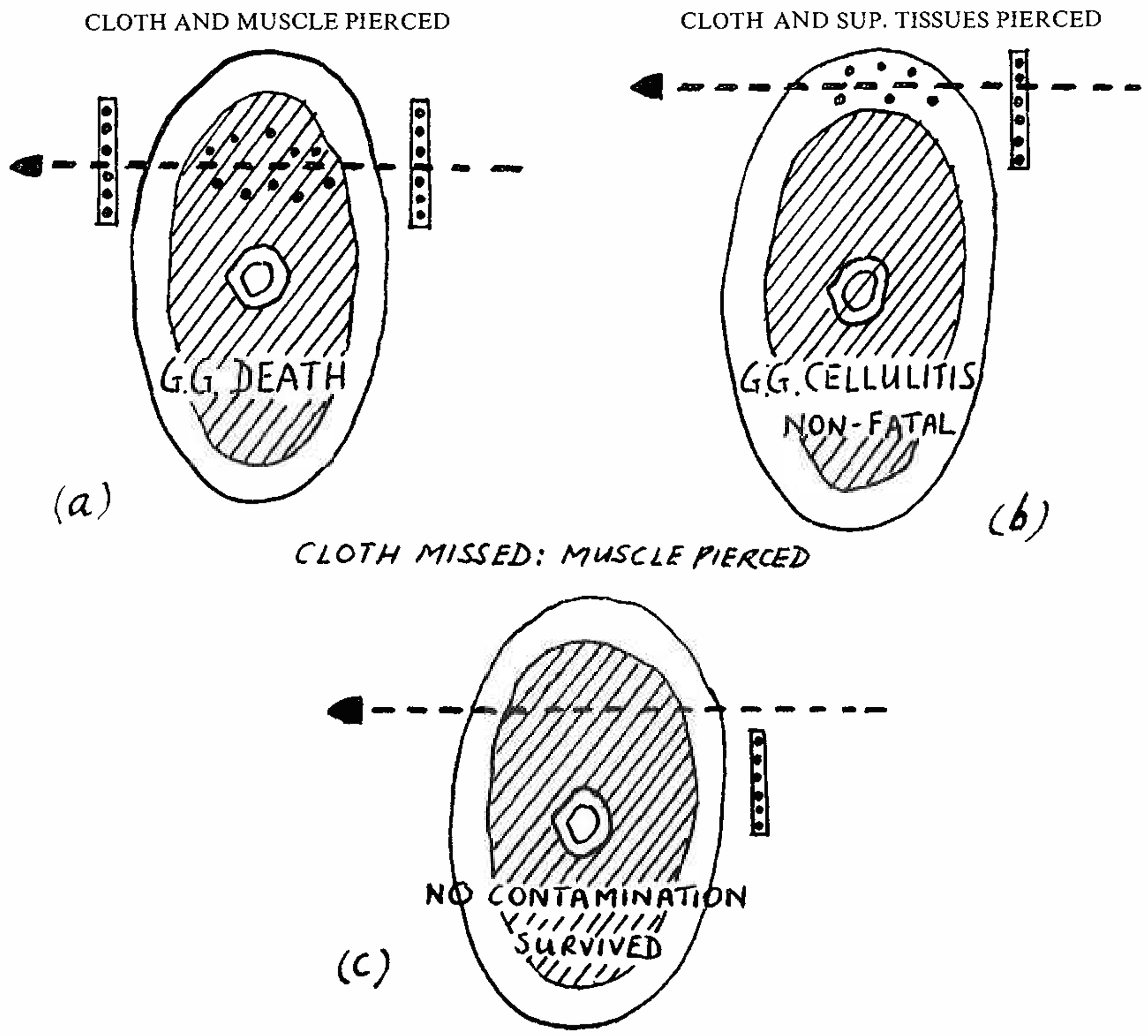

Fig. 2. When a high velocity bullet was fired through a sheep's thigh: fatal gas gangrene followed penetration of contaminated cloth (at either entrance or exit faces) and muscle (a); non-fatal cellulitis occurred if only superficial tissues were traversed (b); no contamination occurred if cloth was missed (c).

Infection from bacterial invasion can develop in contaminated wounds within 6-8 hours depending on the site, type of tissue and degree of damage. Severe wounds especially those involving muscle and bulky muscle groups such as those in the thigh, buttocks and lumbar region are particularly prone to clostridial infection.

THE MANAGEMENT OF MISSILE INJURIES

First Aid

Surgery can only be effective on living patients and therefore first aid and self aid is of vital importance to the initial survival of a casualty. The success of any medical service will depend on the efficiency of its medical organisation and on the training of combatants and medical orderlies in first aid.

First aid includes the prompt collection of wounded men from a dangerous environment, gentle handling, the prevention of respiratory obstruction and speedy conveyance to surgical facilities. Obvious bleeding must be controlled by elevation of the part, pressure and firmly applied dressings. In general tourniquets, which are so often inefficient, should, when tightly applied, be reserved for occasions when life has to be saved at the expense of the bleeding limb. Injured limbs should be adequately splinted but wound oedema and tension must not be aggravated by constrictive bandages. Sucking chest wounds should be sealed with a dressing. These measures alone will do much to minimise wound shock. Where further trauma is inevitable, such as an ambulance journey on a poor road or across rough country, morphia in doses of not more than gr. $\frac{1}{4}$ (15 mgm.) intramuscularly, and properly, recorded, will relieve pain but it is injudicious in chest and head injuries in which its respiratory depressant effect is dangerous. Dehydration in a hot climate can aggravate a patient's condition and should be attended to but oral fluids should be witheld from those with abdominal wounds.

About 2/3 of all war wounds involve the limbs but in the remaining 1/3 wounds of the head and neck, thorax and abdomen carry a higher risk. When casualties occur in any number management must concern itself primarily with the sorting of the casualties to ensure that priority is given to those requiring urgent resuscitation and surgery, e.g. sucking chest wounds, major haemorrhage, visceral injury, massive muscle damage, major fractures, extensive burns, and severe multiple wounds.

Shock

Any significant blood loss resulting from a missile wound will cause hypovolaemic shock which demands vigorous preoperative resuscitative measures.

The assessment of wound shock is not dependent on any one particular sign: it can be assessed by noting the amount of bleeding or swelling of the injured part, the number, size and depth of the wounds, and by the blood pressure. A systolic blood pressure falling below 100 mm. Hg. indicates a loss of more than a litre of blood which requires replacement. Resuscitation should be aimed at bringing the shocked man to a peak state of fitness for operation; if operation is then delayed it is doubtful if that peak state will ever be reached again. It must also be remembered that even the safely resuscitated patient may deteriorate under anaesthesia so that the operative procedure must be speedy, precise and gentle.

Amounts of Blood Needed

The overall quantities of blood used in the field are increasing. In World War II it was 0.5 pints or units per casualty; in the Korean War it was 0.9 units per casualty; in the Borneo campaign it rose to 1.5 units per casualty and in Vietnam it may have risen to nearly 3 units per casualty. Whether blood has become too readily available and therefore been unnecessarily used and to the neglect of dextran and plasma is controversial. The fact remains that an increasing number of lives have been saved though the prospect of blood having to be provided on the scale of recent consumption is a matter which will undoubtedly cause concern to medical planners.

Prevention of Infection

With large open wounds muscle damage will be obvious but with wounds caused by high velocity bullets showing only small entrance and exit wounds the extent of damage can only be revealed by surgical exploration.

The uncertainty about the development of gas gangrene demands that a course of an antibiotic, preferably intramuscular penicillin, should be commenced as soon as possible after wounding. Our practice, as recommended in the Field Surgery Pocket Book (1962), is to give 600,000 units of procaine penicillin and 200,000 units of soluble penicillin intramuscularly and to repeat this dose six-hourly for five days. If the wound involves the abdomen 0.5G of streptomycin is added to each dose of penicillin. Sulphadiazine is the better drug to give in head and spinal wounds because it attains a higher concentration than penicillin in the cerebrospinal fluid.

Active immunisation with tetanus toxoid has eliminated tetanus as a complication of wounds in modern armies. Wounded men will usually be given a booster dose of toxoid after wounding. Where, however, active immunity is in doubt or absent, and especially if wound toilet is delayed more than six hours, or is inadequate, an injection of tetanus antitoxin of equine origin can be given. As, however, sensitivity reactions may occur even with test doses intramuscular penicillin is safer and equally effective in doses proportional to the severity of the wound. It should be continued until the wound is bacteriologically clear of the organisms or until active toxoid immunity has been adequately established (Smith 1964).

The Principles of Missile Wound Surgery

Surgical treatment of missile wounds is a two stage procedure. The *first* stage is the shortest procedure necessary to save life and limb and to prevent infection. It comprises early wound exploration within six hours, and involves a generous exposure in length and depth with wide fascial decompression. All foreign material and blood clot must be removed assisted by gentle irrigation and the excision of all damaged tissue especially discoloured, non-bleeding and non-contractile muscle. Serous cavities should be closed with drainage. Internal fixation of compound fractures in battle surgery will court disaster.

Primary wound suture is permissible *only* in wounds of the face, and for hands and fingers to cover exposed tendons. Otherwise primary suture should be avoided especially when the wounded man has to be evacuated to another medical unit.

After initial surgery wounds, including amputation stumps, should be left open for delayed suture, and covered, but not plugged, with a dressing. Limbs should be immobilised in well-padded but split plasters. The Tobruk splint in which plaster encloses Thomas Splint and wounded leg after operation continues to justify its well earned reputation as an excellent postoperative measure when casualties with wounds of lower limbs have to be moved.

The *second* stage is wound closure (delayed primary suture): this can be delayed until oedema subsides and the wound shows signs of clean granulations, usually within seven days. Even at this stage, and with the assistance of undercutting of wound flaps, tension should be avoided. Skin grafts should be employed to make good any remaining skin defects.

In multiple wounds of the lower limbs resulting from stepping on antipersonnel mines the smallness of the wound is misleading for the damage to muscle is aggravated by oedematous tension and anoxia of an impaired blood supply within the fascial compartments of the leg. These are conducive to anaerobic infection and although time consuming each must be explored, decompressed and excised under antibiotic cover in the same way as more severe wounds.

Intraabdominal wounds require urgent and thorough exploration. Perforating wounds of the small bowel can be sutured or the damaged segment excised. A damaged segment of colon can be exteriorised and proximal colostomy is necessary for wounds of the colon and rectum.

Repair of Blood Vessel Damage

The repair of major blood vessel damage can only be attempted in special surgical units. In addition to excision of devitalised tissue and of the damaged vessel segment under antibiotic cover at least 1 cm. of the apparently undamaged ends of the vessel are also excised because microscopic examination invariably shows intimal damage (Seeley 1960). This unsuspected intimal damage had defeated attempts at repair in the Second World War and had resulted in an amputation rate of about 55%. In Vietnam the failure, or amputation rate has fallen even further to 12% but there is still a 40% complication rate due to sepsis and thrombosis also probably due to inadequate wound excision.

Missile Wound Infection

Although missile wound infection has been significantly reduced in all campaigns since the Second World War by the use of antibiotics, especially penicillin prophylactically, it has by no means been abolished.

In the Borneo Confrontation (1963-65) when bullet wounds predominated, all wounded men were given penicillin injections as soon as possible after wounding. Wheatley (1967) recorded a very low incidence of sepsis. It was mostly superficial causing mainly a delay in wound healing. No instance of gas gangrene occurred. Wound sepsis appeared to be related to the severity of tissue damage and to preoperative delay.

Wound sepsis has been low among American and Commonwealth forces in Vietnam. On the other hand there has been a high infection rate in wounds in which surgery had been delayed more than six hours due to unavoidable delays in evacuation from the field. Sepsis has also been significant when surgical toilet had been inadequate and when primary wound suture had been carried out. In spite of clostridia being common contaminants of wounds, gas gangrene has been infrequent.

Surgery in Experimental Gas Gangrene

In a study of the treatment of experimental high velocity bullet wounds in sheep using the deliberate clostridial contamination methcd of Thoresby and Watts (1967), the contaminating organism used was *cl. oedematiens* spores. The untreated sheep was used as a control as it usually developed fatal gas gangrene (clostridial myonecrosis) within 60 hours of wounding. Simple incision alone failed to prevent fatal gas gangrene but a significant prolongation of survival time was obtained with excision of all discoloured, non-bleeding and non-contractile muscle (Thoresby and Matheson 1967).

Systemic Prophylaxis of Wound Infection

The prophylactic control of human wound infection depends not so much on the use of chemotherapy and antibiotics as on the application of sound surgical principles.

In an experimental study of the effects of parenteral penicillin in the sheep bullet wound preparation, deliberately contaminated with *cl. oedematiens*, it was found that fatal gas gangrene could be prevented in the contaminated sheep wound with intramuscular penicillin alone. Indeed the commencement of a course of penicillin could be delayed up to nine hours after wounding with survival and without surgery. Delay beyond nine hours led to an increasing mortality rate from gas gangrene (Owen-Smith and Matheson, 1968). Similar results were obtained with intramuscular injections of tetracycline (Owen-Smith 1968).

Intramuscular polyvalent gas gangrene antitoxin alone prevented gas gangrene in sheep Owen-Smith (1968) and the wound track usually showed an abscess in the pus of which *cl. oedematiens* spores were found and cultured. The use of anti-gas-gangrene serum in humans, however, carries a risk of anaphylaxis.

Local Treatment in the Prevention of Wound Sepsis

Circumstances often arise where the evacuation of a wounded soldier to surgery may be delayed and it is in these cases that the risk of septic complications, especially gas gangrene, is greatest.

In the Second World War parenteral penicillin displaced the sulphonamides which, though they were useful in controlling the systemic effects of missile wound infection, had little effect when applied topically especially in deep wounds. Recent work has evoked renewed interest in the local application of sulphonamides and antibiotics.

Massive open wounds have been inflicted on the thighs of anaesthetised goats using a high explosive charge of tetryl (Oschner *et al*, 1958; Lindsey *et al*, 1959). Mixed flora including *cl. welchii* were found in the wounds from autoinfection. Topical therapy alone, especially with a spray of a sulphonamide preparation called sulfamylon (mafenide) was exceedingly effective in controlling the growth of organisms and contributed significantly to the survival of the animals (Mendelson and Lindsey, 1962).

In Vietnam the high sepsis rate following delay in wound surgery has been ascribed to systemic antibiotics being prevented by ischaemic tissue from reaching a sufficiently high concentration on the wound surface. Following the successful control of infection in burns with a topical water-soluble ointment of sulfamylon (Lindberg *et al* 1965; Matsumoto *et al* 1967) reported favourably on the use of an antibiotic spray in the simulated combat muscle wound in rabbits. Their experimental findings suggested that topical antibiotic therapy could do much to prevent infection developing by creating a high immediate local concentration of antibiotic. They also suggested that the fighting soldier might be supplied with a small antibiotic spray to apply to his wound to avoid the risk of delay in surgery.

CONCLUSION

1. The wounding effects of missiles and the principles of their management have been discussed.
2. More lives are being saved by increased efficiency in first aid and in field medical organisation including speedier casualty evacuation, especially by air, and by vigorous measures to counteract shock.
3. The fundamental treatment of missile wounds, especially severe and multiple wounds, consists of early exploration and and excision of dead and damaged tissue leaving the wound open for delayed primary suture.

4. In spite of antibiotics, missile wound sepsis is related to the severity of tissue damage, to preoperative delay and to inadequate surgery.
5. Prompt antibiotic prophylaxis has reduced missile wound sepsis and its complications even following delay in surgical treatment. It has facilitated earlier wound healing as well as surgical procedures, such as blood-vessel repair, previously hazardous.
6. Experimental evidence suggests that the local application of antibiotics such as with a spray may be particularly beneficial where delay in surgery is inevitable.

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