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Management of small fragment wounds in modern warfare: a return to Hunterian principles?

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Treatment of ballistic wounds involving only the soft tissues remains controversial, with differences between civilian and military protocols. The conventional military approach has been to treat penetrating war wounds by exploration, excision of dead tissue and delayed primary closure; conservative treatment has largely been regarded as inappropriate. There are, however, many supporters for a non-operative approach, especially among those with experience of ballistic trauma in a civilian setting *(1)*. Developments in fragmentation weapons warrant a review of military surgical treatment protocols, to determine whether current treatment regimens might safely be modified to allow non-operative treatment of selected wounds. Such a policy would be similar to that of John Hunter for the wounds of war prevalent in his time.

The work presented here consists of:

- A brief review of Hunter's description of gunshot wounds and his recommendations for their treatment;
- An outline of the weaponry causing the majority of wounds on the modern battlefield;
- A synopsis of experimental work examining the terminal ballistics and wound ballistics of a modern antipersonnel fragment;
- An account of the clinical management of numerous small fragment wounds in a war surgery hospital.

Hunter's treatment of war wounds

Hunter obtained considerable surgical experience during his period of service with the Army Medical Department from 1761 until 1763. He clearly appreciated the nature of a ballistic wound arising from a musket ball:

> ". . . in general contused wound, from which contusion there is most commonly a part of the solids surrounding the wound deadened . . ." *(2)*

Hunter recognised the dynamic character of these injuries:

> ". . . it is at first, in many cases, impossible to know what parts are killed . . . till the deadened part has separated which often makes it a much more complicated wound than at first was known . . ." *(2)*

As a result of his observations he developed ideas on the management of war wounds which ran counter to the contemporary treatment. Hunter believed that these wounds should not be *routinely* explored:

> ". . . dilating them as a general rule should be rejected at once . . ." *(2)*

His views on the management of war wounds were controversial at the time, and have attracted more recent criticism. Whipple expressed surprise that Hunter had not mentioned wound débridement or the removal of blood clots *(3)*. However, it should be appreciated that treatment of ballistic wounds in war in the twentieth century has largely derived from the experiences in the Great War, based on rifle bullet wounds sustained in "the well-manured fields of Flanders" *(4)*. It was with these wounds that the importance of wound surgery, based on incision, extension of the wound and excision of non-viable tissue (Fig. 1) was relearnt *(5)*.

Other surgeons have acted as Hunter's apologist; they consider his relative conservatism to have been appropriate given the nature of the weaponry, the wounds and the circumstances in which they would have been managed *(6,7)*. A previous Hunterian Professor has maintained that: "in the surgical environment of his time Hunter's management of gunshot wounds was quite justified" *(6)*.

Ballistics of modern weaponry

Fragmenting antipersonnel weapons have caused most wounds in the major armed conflicts of the latter half of the twentieth century *(8)*. These weapons range from large artillery shells and rockets through to hand grenades

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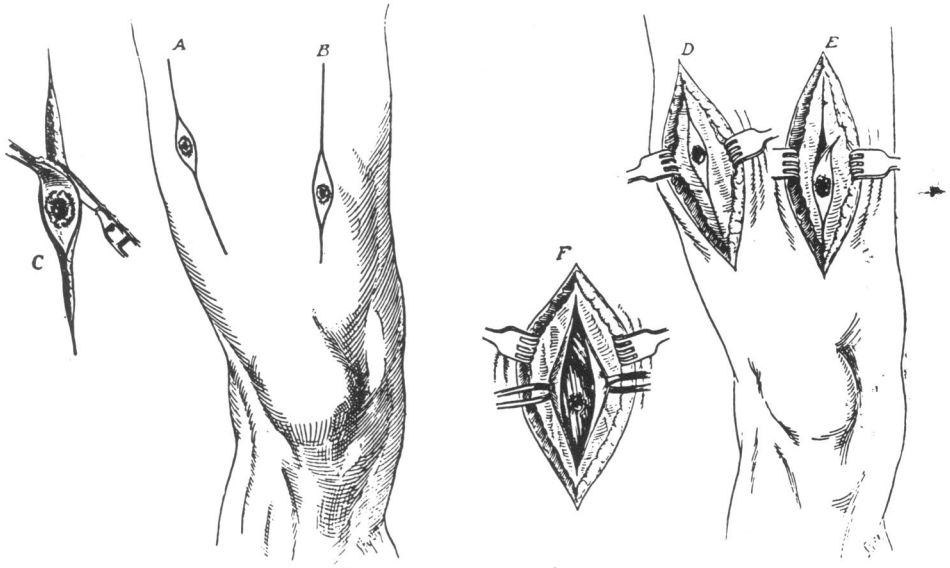


Fig. 159.—Débridement. Excision of the external wound

Fig. 160.—Débridement. Excision of the aponeurotic layer

Figure 1. Illustration of the initial stages of wound surgery (here referred to as 'débridement'), depicted in a text detailing the surgical procedures and practices of the First World War *(5)*.

(Table I). Recently there have been changes in the design of these weapons to increase their effective area. This has involved the development of scattered sub-munitions (bomblets), and controlled fragmentation of the sub-munitions (by preformed or partially preformed fragments), creating large numbers of small projectiles with a mass between 200 mg and 500 mg. These small fragments have a relatively low energy, and limited range—but large numbers are produced leading to a high probability of hitting a target in an area.

The preponderance of these low-energy fragments has brought about a particular wounding pattern: the incidence of casualties with multiple wounds has increased, with soft tissue wounds to limbs predominating *(9)*.

Terminal ballistics of small fragments

The interaction of a fragment with a target (terminal ballistics) was investigated using a 200 mg steel fragment-simulating projectile (FSP). This FSP may be regarded as

Table I. Data on modern fragment-producing munitions

Weapon	*Range*	*Fragment mass, number, type*	*Initial fragment velocity*	*Effective area*
Hand grenades, eg M26 (US Army)	~20 m	100–200 mg >1000 (PPF)	>1000 m/s	Casualty radius ~15 m
Rifle grenades, eg AGS 17 (Soviet)	1200 m	200 mg (PPF)	>1000 m/s	Casualty radius ~5 m
Mortar bombs, eg 81 mm SMI (Austrian)	5800 m	More than 50% @ 300–500 mg Total >3500 fragments (NF)	>1000 m/s	
Artillery shells	Some >20 km	Modal fragment 150–300 mg (NF)	About 1000 m/s	Casualty radius ~25 m
Bomblets (can also be loaded in artillery shells)	Depends on delivery system	100–300 mg (PPF)	About 1000 m/s	

NF = Naturally fragmenting
PPF = Partially preformed fragment

'typical' of a fragment from modern weaponry. Experiments included:

- Measurement of penetration distances into gelatin targets;
- Measurement of the size of the temporary cavity in gelatin;
- Assessment of the degree of contamination of the track when the FSP was fired through clothing;
- A comparison of the penetration of gelatin and skeletal muscle.

Full experimental methodology and detailed results are reported elsewhere *(10)*.

Summary of results

Target penetration

Penetration of the target ranged from 10 to 15 cm at the velocities employed (400–1000 m/s).

Track contamination

A scanty distribution of tiny fibrils (<5 mg total) was produced along the length of the track through the target, the majority being found at a depth of about 2–3 cm.

Cavitation

High-speed cine film analysis showed the size and duration of the temporary cavity in gelatin blocks varied with impact velocity: at 400 m/s this was ~25 ml, rising to 100 ml at 800 m/s.

Validation against muscle

Cadaveric pig thighs were shot during the FSP. A comparison between penetration of the FSP into gelatin and into muscle showed that, for impact velocities in the range 500–900 m/s (of primary concern in military wounds), there was very close agreement.

Conclusions

These experiments confirm gelatin as an appropriate medium for the study of fragment terminal ballistics. They show that a 'typical' small fragment from a modern munition can be expected to penetrate more than 10 cm of skin and muscle, producing a small temporary cavity which draws in a sparse amount of shredded clothing material.

Wound ballistics of small fragments in a soft tissue wound model

A model of a small fragment wound has been developed, using the 200 mg FSP with an impact velocity of 550 m/s to produce a single, low-energy transfer (~30 J) wound in the hamstrings of an anaesthetised pig. The wound and physiological response were examined in terms of:

- Haematological changes in the peripheral blood;
- Changes in serum creatine kinase (CK) liberated by injured muscle;
- Histopathological evidence of skin damage at the entry wound;
- Histopathological evidence of muscle damage both within the actual wound track, and in the tissue peripherally;
- Bacteriology of the wound track and related tissues (qualitative and quantitative).

These factors were studied in 28 untreated animals. Animals were allocated to one of five groups which had wounds sampled at either 1 h, 6 h, 1 day, 3 days or 7 days after wounding. The model and experimental protocol are detailed elsewhere *(10,11)*.

Summary of results

Haematology and biochemistry

The polymorph count was significantly greater at 6 h after wounding, although the levels beyond the 6 h timepoint were not significantly different from the prewounding level (t test, $P > 0.05$). The serum creatine kinase levels rose a matter of hours after wounding, reflecting muscle damage, but by 3 days they fell again to normal levels (Fig. 2).

Histopathology

The skin margins were remarkably resilient, with non-viable tissue extending only about 3 mm from the centre of the wound. Most of the wounds showed partial healing by 7 days, but one animal had formed an abscess deep to the exit wound; this animal also had an abscess within the wound track. A further two animals had micro-abscesses within the healing entry wounds.

The amount of devitalised muscle amounted to only a few hundred milligrams within the wound track for up to 24 h. Although the amount of non-viable tissue within the wound track increased up until 3 days after wounding, there was a fall in the amount of tissue damage peripheral to this non-viable tissue from 6 h onwards. The muscle damage peripheral to the track improved over 24 h, and by 7 days there was no necrotic tissue peripheral to the wound track (detailed elsewhere *(10)*). The inflammatory cell infiltrate is considered to be responsible for removing the fragmented muscle fibres, and probably accounts for the increased necrotic tissue in the track at 3 days.

These indicators suggest that the muscle damage is dynamic, increasing as fibres die over the first day, but without any increasing muscle damage after this.

Bacteriology

The skin prewounding was moderately to heavily contaminated with non-pathogenic staphylococcal species as well as with environmental faecal contaminants.

Few of the wound swabs or tissue samples yielded any bacterial growth in animals sampled up to 24 h after

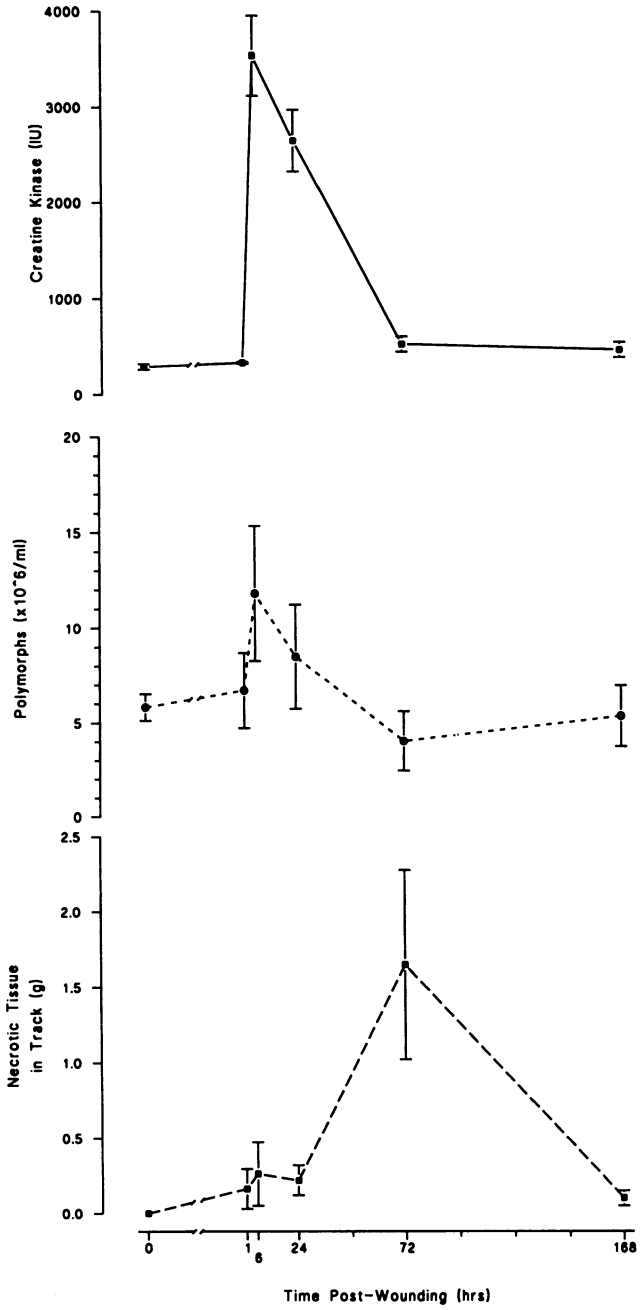


Figure 2. Serum creatine kinase (median and quartiles), mass of necrotic tissue (mean and SD), and polymorph count (mean and SD) at various timepoints in the untreated wound model.

wounding. At 3 days after wounding there was a light growth of mixed staphylococcal species (non-pathogenic) from the swabs taken from the wound track, and similar light colonisation of the tissue samples in most animals ($\sim 10^3$ cfu/g). However, by 7 days there was significant colonisation ($\sim 10^5$ cfu/g or greater) of the wound tracks in three animals, with streptococcal growth in two of these and anaerobic colonisation of another. A frank abscess had formed in the wound track of one animal.

Conclusions

This work shows that there is little potential culture medium within these small fragment wounds, and they can heal by normal responses. However, in the cases observed for 1 week, infection had become established in one case and may have been gaining a hold in the wound track of two other animals which exhibited major colonisation of the track. Two further animals had evidence of micro-abscesses within the skin at the entry wound site. Hence, localised infection may be a problem, interfering with healing in these wounds.

Small fragment wounds of soft tissue treated with antibiotics. Evaluation using an animal model

The model of a small fragment wound described above was used to assess the efficacy of two non-operative treatment regimens. Antibiotic prophylaxis, or early treatment, regimens have been aimed at preventing the major early threats to life, the streptococcal or clostridial infections. Benzylpenicillin remains the drug of choice against these bacteria and has therefore formed the mainstay of early antibiotic treatment for war wounds, particularly those affecting only the soft tissues *(12,13)*; this was the antibiotic investigated here.

Wound model and treatment

The low-energy wound was produced using the FSP as described above. Treatment was started either 1 h after wounding (ET group, 10 animals) or after a delay of 6 h (DT group, 10 animals). Antibiotic treatment consisted of benzylpenicillin (1 MUnit 6 hourly, intramuscularly) for 3 days. Animals were then followed, without further antibiotic treatment, until 2 weeks after wounding. The results are compared with a group of animals with similar untreated wounds (UT group, eight animals). The wound and physiological response were examined in the same way as described above.

Summary of results

Histopathology

The skin in the ET and DT groups was healed with re-epithelialisation at 14 days, with no signs of micro-abscesses within the dermis. This may be compared with the wounds in the UT wounds at 7 days, which demonstrated partial healing, with micro-abscesses within the healing entry wounds in two of the eight UT animals.

The muscle samples from the ET and DT groups were all histologically normal, in contrast to the UT group at 7 days, in which granulation tissue persisted and a frank abscess was found in one animal.

Bacteriology

No animal in the ET or DT group had bacteriological evidence of infection or colonisation of the wound. By contrast, in the UT group, by 7 days, there was significant colonisation of the wound tracks in three animals; a frank abscess had formed in the wound track of one of these.

Table II. Protocol for casualty management in ICRC hospitals *(14–16)*, with considerable similarity to the treatment protocol for British military surgery *(12)*

Assess the patient	Identify and treat life-threatening injuries immediately: Commence resuscitation and administer antibiotics and tetanus prophylaxis.
Assess the wound	Size and extent of the wound, and the tissues involved, help to determine the surgery which is required. Wounds should be recorded and scored using the Red Cross system.
Wound surgery	Removes or reduces the potential culture medium of non-viable tissue within a wound. Wounds are not closed primarily except in special anatomical areas/circumstances. Fractures are stabilised, usually with temporary splintage or traction at this stage.
Dressing	A bulky absorbent dressing is applied by the surgeon, and left in place until return to the operating theatre.
Plan return for closure/cover	Closure or cover is planned as a second surgical procedure at about 4–5 days. Some patients will require further reconstructive procedures. Fracture fixation is applied at this stage.
Early rehabilitation and physiotherapy	Early therapy is an essential part of the management.

Conclusions

The antibiotic treatment regimens evaluated here proved effective in preventing wound colonisation and infection in all 20 cases, allowing healing to progress. This contrasts with the untreated group in which five of eight animals had evidence of infection: one abscess, two heavy growth from wound tissues, two dermal micro-abscesses. There were no differences between the results in those receiving antibiotics promptly (ET) and those starting treatment after a 6 h delay (DT).

Clinical experience of small fragment wounds: experience from the Afghan border

The International Committee of the Red Cross (ICRC) has considerable experience of treating the wounds of war. Their approach has been surgically based (Table II) *(14)*, similar to the protocol used by the British Army *(12)*. The concept of selecting some wounds to be managed conservatively (non-operatively) has, however, recently become accepted by the ICRC as part of their medical management doctrine *(15–17)*.

The ICRC maintains and staffs a war surgery hospital in Quetta, Pakistan, serving wounded from the conflict in nearby Afghanistan. This section reviews the policy of selective non-operative management of many small fragment wounds at that hospital during a period of heavy fighting across the border, when the author was working as a surgeon for the ICRC. Further details of the work and wounds encountered here have been recorded elsewhere *(18,19)*.

Background to the ICRC war surgery hospital, Quetta

Admissions to the ICRC War Surgery Hospital in Quetta averaged just over 100 per month from 1990 to mid-1993,

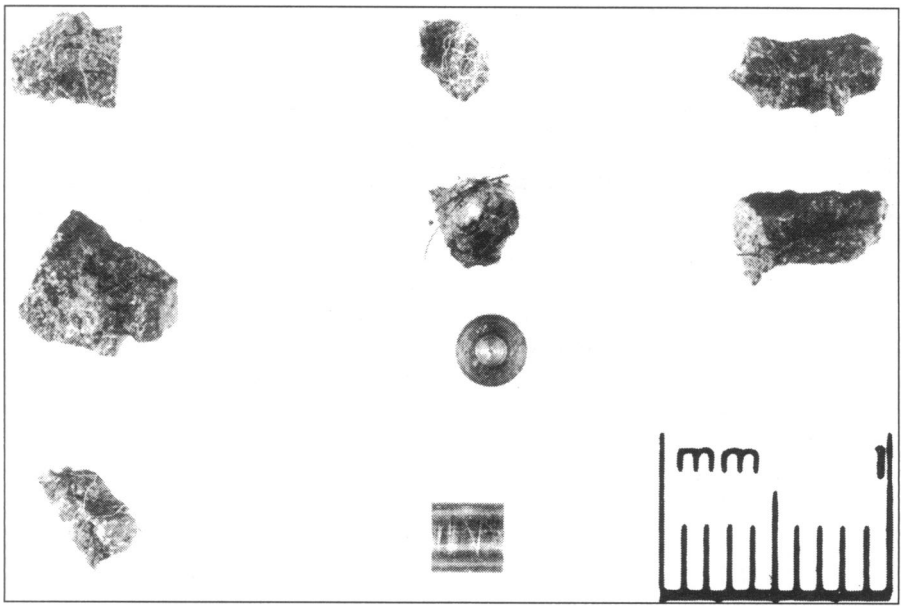
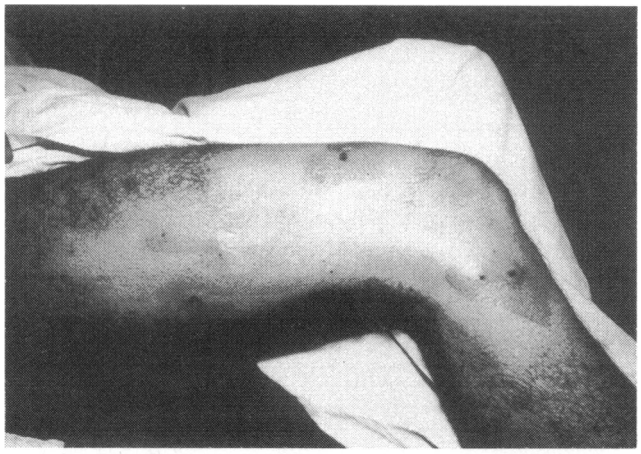
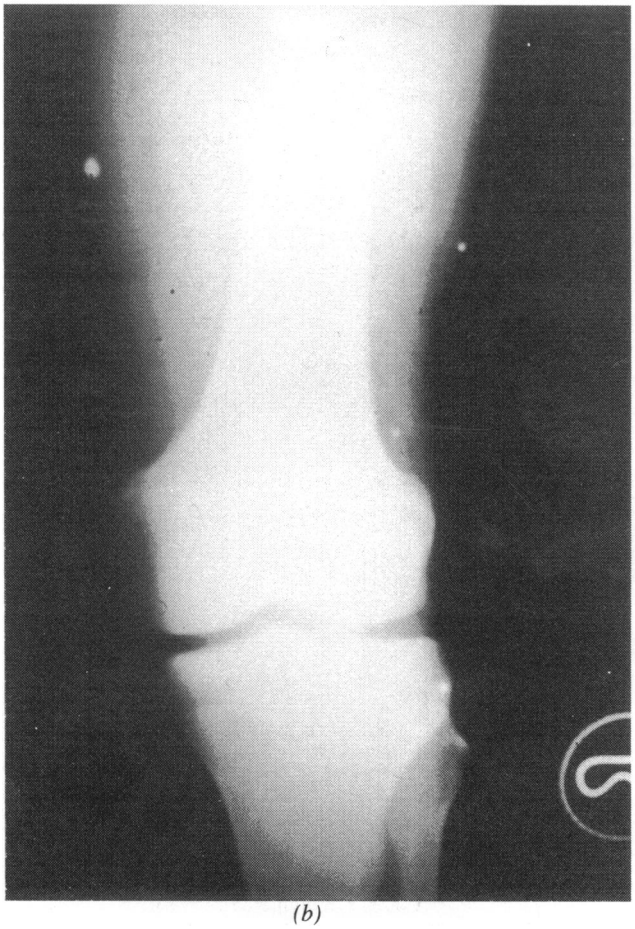


Figure 3. Fragments from modern military ammunition (shells and rockets), removed from casualties from Afghanistan. For comparison, the FSP used in the experiments described here is shown in the bottom row, alongside the scale.

but with episodic peaks when fighting between Mujahideen groups flared. The level of hostilities also had an effect on the types of injury seen in the ICRC hospital, with gunshot wounds increasing during flare-ups, and in the escalation in fighting, reported here, the number of casualties with fragment wounds increased greatly. Fragments from these weapons, recovered from patients, are shown in Fig. 3.



(a)



(b)

Figure 4. a, b. Small fragment wounds to the lower limb, without a fracture, in a casualty from Afghanistan.

Table III. Suggested selection criteria for non-operative management of fragment wounds

Consider

- Wounds affecting soft tissue only (no fractures, no breach of pleura or peritoneum and no major vascular involvement)
- Wound entry or exit less than 1-2 cm in maximum dimension
- No evidence of cavitation within the wound (wound does not increase in diameter beyond the entry wound)
- Wound not frankly infected

Exclude

- Mine wounds (these tend to have extensive contamination with in-driven mud)
- Wounds already frankly infected at presentation

Casualties and their management

The hospital was extremely busy during the influx of patients, with more than 1200 fragment wounds in 83 casualties over a 1 week period. Most had taken about 1–2 days to reach the hospital. It was considered to be both expeditious and appropriate to manage selected small fragment wounds conservatively. The criteria for non-operative management are outlined in Table III. Non-operative management then consisted of:

- Cleaning and dressing the wound;
- Administration of antitetanus serum and toxoid;
- Administration of penicillin (benzylpenicillin 5 MUnits IM/IV every 6 hours for 1 day, then 500 mg penicillin V orally 4 times daily for the next 4 days).

Of the 1222 fragment wounds, 866 fulfilled the criteria for non-operative treatment (an example is depicted in Fig. 4). Operations were performed on 68 of the casualties, but in 48 of these some of their wounds (fulfilling the criteria above) were managed non-operatively. Treatment was entirely non-operative in a further 14 casualties. The

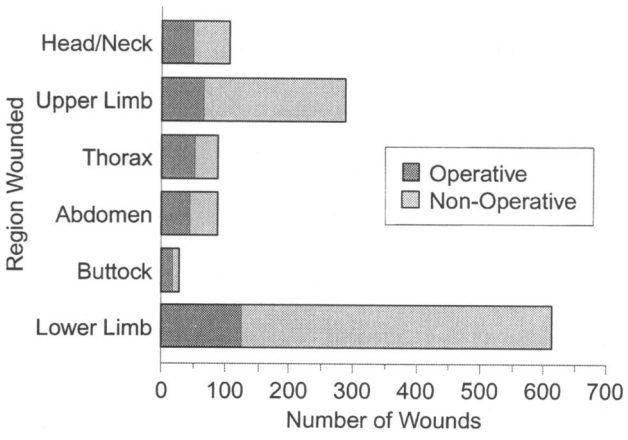


Figure 5. Distribution of wounds managed operatively and non-operatively in 84 casualties with fragment wounds.

anatomical distribution of wounds managed operatively and non-operatively is depicted in Fig. 5.

Patients remained in the hospital or attached tented accommodation following their treatment, and so were available for review. Most stayed for 4–5 days. Those few leaving early usually went to relatives in Quetta; all were offered open access for review if complications arose.

Outcome and complications

Conservative management of selected soft tissue wounds resulted in complications in just two patients; each developed a superficial abscess associated with a fragment wound to the lower limb. In one case this discharged spontaneously, in the other case a surgical incision and drainage was carried out. Both patients went on to heal uneventfully. It is worthy of note that the patient who developed the abscess requiring drainage had taken 5 days to reach Quetta, during which time she had received no antibiotics or other treatment.

All other patients with conservatively managed soft tissue injuries healed without complication over the period while they were in or near the hospital (in most cases at least 5 days). None re-presented to the hospital with a complication of their conservatively treated wounds over the following 3 month period.

Conclusions

The selective non-operative regimen, with antibiotics, adopted in this series appears to have yielded favourable results. Operative time was saved without causing life- or limb-threatening complications, or jeopardising healing.

Conclusion. Recommendations for management of small fragment wounds

The military approach to war wounds in the twentieth century has been to ensure that wounds involving the soft tissue are explored surgically and converted to a cleansed track consisting of a viable skin margin and a healthy muscle bed of bleeding, contractile muscle *(12,20)*. However, the experience of others has suggested that some soft tissue wounds might safely be managed non-operatively, if the wounds are small with little contamination *(16,17)*. The work reported here suggests that the non-operative management of *selected* ballistic wounds in warfare may be appropriate. This is based on an understanding of the prevalent wounding projectiles, the nature of the wound and the efficacy of non-operative, antibiotic treatment. This is not to propose a generalised policy of conservative management relying on antibiotics. Rather, the key is clinical evaluation of the wound, deciding which will require operative intervention, as Hunter has put it:

> ". . . it will be almost impossible to state what wound ought, and what ought not be opened; this must always be determined by the surgeon, after he is acquainted with the true state of the case and the general principles . . ." *(2)*

The views expressed in this paper do not necessarily reflect those of the British Defence Medical Services.

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