■ ANNOTATION

Winner of the Frank Horan essay prize: The effect of war on the evolution of the treatment of open fractures

P. Hindle

From the Royal Infirmary of Edinburgh, Edinburgh, United Kingdom

This paper outlines the history of advances made in the treatment of open fractures that have occurred during wartime.

Military conflict has been responsible for numerous advances in the treatment of open fractures. Trueta noted that, "Throughout the ages, the progress of general surgery has been intimately related to that of military surgery". With ongoing conflicts in Afghanistan and around the world, and the risk of terrorist attacks, the treatment of open fractures caused by blast and ballistic injury is pertinent to both civilian and military surgeons. The history of the treatment of open fractures shows that many of the complexities faced by surgeons today have been encountered by our predecessors. The patients of today owe much of their improved care to both the military surgeons and the injured servicemen who went before them.

Historical overview

The first documentation of the treatment of fractures is from Egyptian manuscripts¹ attributed by some to Imhotep, a physician to the Kings of Egypt, and dated c. 2800 BC. The concept of open and closed fractures was introduced and the determination that they should be treated differently is described. If a wound communicated with the fracture it was deemed not worth treating. If the wound did not, then it should be dressed daily. In the case of contaminated open fractures the severity of the soft-tissue injury was apparent and the advice of Hippocrates was that one should "avoid such cases... for the favourable chances are few and the risks many". He summed up the problem concerning the treatment of open fractures as "... not to reduce it is to incur the reproach of ignorance, to reduce it is to increase the chance of death".²

It was not until the introduction of gunpowder into warfare in Europe during the fourteenth century that complex wounds incorporating open fractures presented in large numbers. The first recorded case report of a

gunshot wound was in 1460, by Bavarian Army surgeon Heinrich Prolspeadlt. He included a discussion incorporating his thoughts on the management of gunshot injury.³

Ambroise Paré (1510–1590) was a French Army surgeon. He initially treated open fractures with boiling oil, in line with the current thinking of the day. Due to a shortage of oil supplies he began to use a paste containing egg yolks, oil of roses and turpentine. After noting superior results with the new paste he changed his practice.⁴ This was a move away from the notion of 'laudable pus'. He recorded an account of the treatment of his own open tibial fracture, stressing the importance of extending the wound to remove contamination and to allow adequate reduction.⁵ His approach was not universally accepted. On 22 April 1676, Admiral De Ruyter suffered a fatal open fracture of the right lower leg during a naval battle near Mount Etna. The fleet doctor, Jan Manhart, and the two ship's surgeons treated the wound with brandy and prescribed rest, but fatal gangrene developed a few days later.

In the run-up to the American War of Independence (1775–1783), John Jones (1729–1791) of King's College, New York, published a textbook that was principally for the use of young military and naval surgeons in North America.⁶ Many of his principles for the management of open fractures had been gathered from work in the United Kingdom and from his own experiences in the French Indian War (1754–1763). Jones' chapter on compound fractures articulated the principle of 'life over limb' and the surgeon's decision to undertake primary amputation. This is still considered in every military field hospital around the world today. Regarding wound debridement, Jones stated that wounds should be extended to allow reduction and removal of all bony fragments. Splints and daily dressings were recommended.

■ Squadron Leader P. Hindle, MB, ChB, MRCS(Eng), RAF Trauma and Orthopaedic Department
Royal Infirmary of Edinburgh,
51 Little France Crescent,
Edinburgh EH16 4SA, UK.

Correspondence should be sent to Mr P. Hindle; e-mail: phindle@doctors.org.uk

©2010 British Editorial Society of Bone and Joint Surgery
doi:10.1302/0301-620X.92B12.25698 \$2.00

J Bone Joint Surg [Br]
2010;92-B:1632-5.

Interestingly, he comments that “Young surgeons from a principal of timidity are too apt to omit openings,” showing that debridement performed inadequately by junior surgeons is not a new phenomenon. Jones noted that transverse fractures did well when reduced as the position could be held more easily than oblique fractures in which reduction could often not be maintained. The importance of his guidance for the war surgeon was the emphasis of life before limb and the need for adequate debridement.

Baron Dominique-Jean Larrey (1766–1842), the chief surgeon to the French Army during the Napoleonic Wars, (1799–1815) is credited with the introduction of ‘flying’ ambulances to evacuate the wounded for prompt medical attention.⁷ As injuries in survivors became more complex, the rates of amputation in Larrey’s practice increased. It was reported that he once undertook 200 amputations in one day.⁸ Larrey and one of his fellow surgeons, Pierre-Joseph Desault (1738–1795), are credited with naming the process of *débridement*, which was originally described as the need to extend wounds to allow for adequate free drainage. The term *débridement* is now frequently used incorrectly to include excision of contaminated and devitalised tissue.⁹

Plaster-of-Paris was first used during conflict by Nikolai Pirogov (1810–1881), a Russian surgeon, in the Crimean War (1853–1856). He originally conceived its use while observing a sculptor at work in 1851. He went to the Crimean War after hearing of inadequately treated casualties in 1854 and used it to stabilise open and closed fractures in mass casualties before evacuation from the frontlines during the Siege of Sevastopol (1854–1855).¹⁰

Following the American Civil War (1861–1865), Joseph Barnes (1817–1883), the Surgeon General of the United States Army, had a report prepared which gave details of tens of thousands of surgical cases.^{11,12} While not introducing any new practice, these volumes provided surgeons with a comprehensive account of how individual surgeons were operating and allowed the first audit of the surgical practice of an entire conflict. This is very similar in principle to the current Joint Theatre Register that is kept by the British military on injured patients from the wars in Iraq and Afghanistan.

Louis Pasteur (1822–1895) identified bacteria as the major cause of toxic effects and advanced the use of carbolic acid spray as a method of antisepsis for combat casualties, reducing mortality rates following amputation. The Franco-Prussian War (1870–1871) was the first time that antisepsis was used in war.

Although debridement had been identified as a necessity it seemed that the lesson had to be re-learned during each subsequent conflict. It was not until late in the nineteenth century that Carl Reyher (1846–1890), a Russian Army surgeon during the Franco-Prussian War, confirmed the importance of adequate debridement in conjunction with antiseptic techniques in open fractures from gunshot wounds. He observed a reduction in mortality from 66% to 23%.¹³ Unfortunately this work was largely ignored and had to be re-learned again during the First World War (1914–1918).

Before World War I, the care of wounds consisted of minimal exploration and the liberal use of new antiseptics. World War I saw the introduction of weapons which produced devastating injuries with extensive devitalisation of tissue. The standard treatment of these patients proved woefully inadequate in the prevention of life-threatening infections. Antoine Depage (1862–1925), a surgeon in the Belgian Army reintroduced the discarded French practice of wound incision and exploration (debridement) and combined it with excision of devitalised tissue.¹⁴ Through the use of debridement, excision, and delayed wound closure based on bacteriological survey, he was able to reduce the incidence of infectious complications of soft-tissue injuries including those involving fractures. He thought that wound closure should often be delayed and based his decision to close the wound on its bacteriological status. At the outbreak of World War I in 1914, Alexis Carrel (1873–1944), a French surgeon who was working abroad, was visiting his house in France and was conscripted into the French Army. He encountered a significant number of infected open fractures and was put in touch with the English chemist Henry Drysdale Dakin (1880–1952). Together they developed the Carrel-Dakin method¹⁵ of treating wounds based on a weak neutral solution of sodium hypochlorite and boric acid (Dakin’s solution) which, preceding the development of antibiotics, was a major advance in the care of traumatic wounds. Wounds were left open and instilled with the antiseptic until cultures were sterile, and then the wounds were closed. However, this was labour-intensive and associated with infections and irritation of the skin. For this advancement, Carrel was awarded the *Légion d’honneur*.

H. Winnett Orr (1877–1956) was an orthopaedic surgeon in the United States. When the United States entered World War I, he became a Major in the Medical Reserve Corps of the Allied Expeditionary Force, and before going to France, he worked alongside Carrel at the Welsh Metropolitan War Hospital in Cardiff. In France, Orr took the Carrel treatment further by cleaning wounds, packing them with petroleum-soaked gauze to prevent sticking, and then setting the fracture and immobilising it with plaster-soaked bandages that would harden quickly. The results were visible within three weeks, with no infection present after the cast was removed.¹⁶ Orr was credited by the British Medical Research Council as being one of three American physicians to pioneer the technique.

During the First World War, William S. Baer (1872–1931) recognised the efficacy of maggot colonisation in healing wounds. He observed one soldier left for several days on the battlefield who had sustained compound fractures of the femur and large flesh wounds of the abdomen and scrotum. When the soldier arrived at the hospital, he had no signs of fever despite the serious nature of his injuries and his prolonged exposure to the elements without food or water. When his clothes were removed, it was seen that “thousands and thousands of maggots filled the entire wounded area”. To Baer’s surprise, when these maggots

were removed "there was practically no bare bone to be seen and the internal structure of the wounded bone as well as the surrounding parts was entirely covered with the most beautiful pink tissue that one could imagine". He subsequently used sterile maggots in the treatment of chronic osteomyelitis¹⁷ and infected wounds. Baer also detailed the important principle that all war wounds should be considered infected and that they should all have contaminated and devitalised tissue removed within 12 hours. If this was done in time, he concluded, the wound could be considered aseptic and be closed primarily, converting an open fracture to a closed one. He stated that primary closure was possible in 80% to 95% of cases and that even the failures were minor. He admitted that primary closure was not practical in the majority of cases due to the large number of casualties and lack of facilities. He described delayed primary suture as the alternative. Trueta used this method of treatment in the Spanish Civil War with excellent results. He treated 1073 open fractures with 91 poor results and four cases requiring amputation. He reported six deaths, two following amputation. He presented his findings to the Royal Society of Medicine in 1939.¹⁸ This paper was read at a time when the death rate for patients with a compound fracture of the femur was 75% to 80%.

Ernest Hey Groves (1872–1944) served in the Royal Army Medical Corps in the First World War and was in charge of surgery in the British Army general hospital in Egypt. In 1918 he described the use of intramedullary rods for the treatment of gunshot fractures. These rods were passed into the medullary canal through the fracture site. They were, however, little used due to a high rate of infection.¹⁹ The use of intramedullary nails was reintroduced by Gerhard Küntscher (1900–1972) during World War II (1939–1945) for fractures of the femur.²⁰ Küntscher nails allowed soldiers to mobilise much earlier, where previously they would have been immobilised in traction for a long period. This was important due to the large volumes of casualties requiring treatment.

One of the simplest but most effective interventions in World War I was the Thomas splint. Originally designed by Hugh Owen Thomas (1834–1891) for the treatment of chronic bone disease and fractures, it may well have fallen into obscurity were it not for Sir Robert Jones (1857–1933), his pupil and nephew. The Thomas splint allowed the immobilisation of the femoral fractures of a large number of wounded servicemen to be performed by relatively untrained personnel in the field away from medical attention. The mortality associated with open femoral fractures dropped from 80% to 16% with the introduction of the Thomas splint.²¹ The rate of amputation in World War I for blast injury to the extremities was approximately 75%.

Soft-tissue flaps were first used in the treatment of open fractures following the introduction of the tubed pedicle flap by Harold Gilles (1882–1960) in World War I. They were originally used in the treatment of chronic osteomyelitis following open fractures.

Plates were first described by Hansmann in 1866²² but were popularised by a number of surgeons including Lamotte, Lane and Sherman. William Sherman used plates during World War I for fixation of femoral fractures. He left the wounds open and removed the plate after six weeks.

Immobilisation of fractures with external traction pins and plaster produced disastrous results with infection during World War II and was discontinued by the United States army.²³

The introduction of penicillin reduced the incidence of gas gangrene but did not eradicate infections completely. The mortality from wounds complicated by gas gangrene went from 10% to 12% during World War I to 0.16% in the Vietnam War.²⁴ In general, it was accepted that antibiotics were effective in reducing early infection in open fractures of the limbs. Wound and bone infections were common complications following open fractures. The use of antibiotics is now part of the standard protocol for the management of open fractures.

In the 1950s Gavril Abramovich Ilizarov was based in Siberia and was left to look after large numbers of wounded soldiers from World War II with little equipment at his disposal. He was presented with crippling conditions of unhealed, infected and malaligned fractures. With remarkable ingenuity and the help of a local bicycle shop, he developed a ring external fixator tensioned like bicycle spokes. He managed to achieve results as good, in terms of healing, limb realignment and lengthening, as any other form of treatment.²⁵ Ilizarov frames are now widely used in the treatment of complex open fractures and limb reconstruction.

The Korean War (1950–1953) introduced Mobile Army Surgical Hospitals (MASH) and the rapid evacuation of casualties from the battlefield using helicopters. Forward surgical care in combination with rapid evacuation enabled patients to be in an operating theatre between two and four hours after injury. Standard treatment in Korea before evacuation to Tokyo consisted of surgical debridement, administration of penicillin with streptomycin and delayed closure.

The Vietnam War (1959–1975) saw continued advancement in the management of combat casualties. Increased use of helicopters reduced times from injury to surgical care to between one and two hours. Well-trained surgeons were available in modern, clean facilities near the battlefield. McNeur²⁶ showed good results in the Vietnam War with rigid fixation of tibial fractures by plating. Modifications in external fixation allowed its increased use in Vietnam but it was rarely used for femoral fractures.

That open ballistic fractures of the femur can, however, be satisfactorily treated by skeletal traction has recently been further described by Clasper and Rowley²⁷ in patients from the civil war in Sudan. Dougherty²⁸ reported that the incidence of amputation was 8.5% in extremity trauma during the American Civil War with a mortality of 35%. This had dropped to an incidence of 1% to 2% during the Vietnam War with a mortality of 3% to 4%.²⁸

During the United States 'Operation Just Cause' in Panama (1989-1990) there were 37 open fractures, nine of which became infected. Only 12 of the initial 37 injuries underwent debridement in Panama; the others were transported to the United States for debridement. Of the nine type III fractures debrided in Panama two became infected compared to six of the nine that were first debrided in the United States.²⁹ This difference is likely to have been a result of surgical delay because of evacuation policies.

Open fractures continued to cause significant problems in the second Gulf War (2003). The rates of traumatic amputation were 14% from ballistic limb fractures with a further 14% having a primary or late amputation. There was a 30% infection rate with 11.5% of wounds requiring surgical drainage. One study showed that other wounds were being primarily closed with an infection rate of 80%.³⁰

The current practice for the management of open fractures by the British Military in Afghanistan is early adequate debridement by an experienced surgeon, amputation of unviable limbs, external fixation for temporary stabilisation of fractures with dressing of the wounds and avoidance of primary closure. Once patients are stabilised they are evacuated by air to the Royal Centre of Defence Medicine in Birmingham. A second examination is undertaken between 48 and 72 hours after wounding. During the second examination further debridement is undertaken as required. At this point following further planning patients will go back to theatre to have definitive internal fixation, reconstruction and formation of amputation stumps as required. Weekly conference meetings between Afghanistan, Birmingham and the Headley Court Rehabilitation Unit allow complexities in the chain of treatment to be identified and addressed with minimal delay. There is a military Joint Trauma Theatre Register that is used for the appraisal and continued audit of patient management. The Combat Casualty Care group at Porton Down undertakes rigorous research that is incorporated with minimal delay to continually improve patient care.

There are complex decisions to be made by the military or civilian surgeon when treating open fractures. The first is that of limb salvage or primary amputation and the criteria on which to base these decisions. The same problem was posed by Jones in 1775 and remains unanswered.³¹ The second is how to reconstruct these limbs. Adequate early surgical debridement and excision of devitalised tissue appears paramount. New techniques and treatments are continually being developed. Advances under evaluation include better prostheses, osseo-cutaneous implants, the use of bone morphogenetic proteins and stem cells for regeneration of musculoskeletal tissue. The evolution of improved practice continues to be driven by the needs of our patients and the surgeons who care for them.

References

1. **Breasted JH.** *The Edwin Smith papyrus*. New York: New-York Historical Society, 1922. <http://www.touregypt.net/edwinsmithsurgical.htm> (date last accessed 24 August 2010).
2. **Lloyd GER.** *Hippocratic writings*. New York: Penguin, 1978:272-314. <http://catalogue.nla.gov.au/Read/997169> (date last accessed 20 December 2009).
3. **Billroth T.** *Historical studies on the nature and treatment of gunshot wounds from the fifteenth century to the present time*. Berlin 1859. translated by Rhoads CP. *Yale J Biol Med* 1931;4:118-48. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2606360/> (date last accessed 24 August 2010).
4. **Donaldson IML.** *Ambroise Paré's account in the Oeuvres of 1575 of new methods of treating gunshot wounds and burns*. The James Lind Library. http://www.jameslindlibrary.org/trial_records/16th_century/pare/pare_commentary.html (date last accessed 24 August 2010).
5. **Paget S.** Ambroise Paré and his times, 1510-1590. *J Am Med Assoc* 1898;165. <http://jama.ama-assn.org/cgi/reprint/XXX/3/165-a> (date last accessed 25 August 2010).
6. **Jones J.** *Plain concise practical remarks on the treatment of wounds and fractures, to which is added, an appendix, on camp and military hospitals*. Philadelphia: Robert Webb, 1776. <http://books.google.co.uk> (date last accessed 25 August 2010).
7. **Haeger K.** *The illustrated history of surgery*. First edition. New York: Bell Publishing Co, 1988.
8. **Holmes R.** *The Oxford companion to military history*. Oxford: Oxford University Press, 2003.
9. **Saadla R, Schein M.** Débridement of gunshot wounds: semantics and surgery. *World J Surg* 2000;24:1146-9.
10. **Peltier LF.** *Fractures: a history and iconography of their treatment*. San Francisco: Norman Publishing, 1990.
11. **Otis GA.** *The medical and surgical history of the war of the rebellion. Part II, Volume II: Surgical History*. Vol. 2. Washington: Government Printing Office, 1876. <http://www.archive.org/details/MSHWRSurgical2> (date last accessed 25 August 2010).
12. **Otis GA, Huntington DL.** *The medical and surgical history of the war of the rebellion. Part III, Volume II: Surgical History*. Vol. 2. Washington: Government Printing Office, 1883. <http://www.archive.org/details/MSHWRSurgical3> (date last accessed 25 August 2010).
13. **McCallum JE.** *Military medicine: from ancient times to the 21st century*. Santa Barbara: ABC-CLIO, 2008:268.
14. **Helling TS, Daon E.** In Flanders: the Great War, Antoine Depage, and the resurgence of débridement. *Ann Surg* 1998;228:173-81.
15. **Rowe RM.** A note on the Carrel-Dakin-Daufresne treatment. *Br Med J* 1917;2:387. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2349187/pdf/brmedj07119-00116.pdf> (date last accessed 25 August 2010).
16. **Orr H.** The treatment of infected wounds without structures, drainage tubes or antiseptic dressings. *J Bone Joint Surg* 1928;10:605-11.
17. **Baer WS.** The treatment of chronic osteomyelitis with the maggot (larva of the blow fly). *J Bone Joint Surg* 1931;13:438-75.
18. **Trueta J.** The treatment of war fractures by the closed method: (section of surgery). *Proc R Soc Med* 1939;33:65-74.
19. **Hey Groves EW.** On the application of the principle of extension to comminuted fractures of the long bone, with special reference to gunshot injuries. *Br J Surg* 1914;2:429-43.
20. **Kuntscher G.** Die Marknallung von Knochenbrüchen: Langenbecks. *Arch Klin Chir* 1940;200:443-55 (in German).
21. **Gray HMW.** *The early treatment of war wounds*. London: H. Frowde and Hodder and Stoughton, 1919.
22. **Bagby GW.** Compression bone plating: historical considerations. *J Bone Joint Surg [Am]* 1977;59-A:625-31.
23. **Cleveland M.** The management of compound fractures: techniques of fracture management. In: *Surgery in World War II, European theatre*. Washington DC: Department of Army, 1956:109-18.
24. **Pailler JL, Labeeu F.** Gas gangrene: a military disease? *Acta Chir Belg* 1986;86:63-71.
25. **Ilizarov GA.** A new principle of osteosynthesis with the use of crossing pins and rings. In: *Collected scientific works of the Kurgan Regional Medical Society*. Kurgan Regional Medical Society, 1954:145-60.
26. **McNeur JC.** The management of open skeletal trauma with particular reference to internal fixation. *J Bone Joint Surg [Br]* 1970;52-B:54-60.
27. **Clasper JC, Rowley DI.** Outcome, following significant delays in initial surgery, of ballistic femoral fractures managed without internal or external fixation. *J Bone Joint Surg [Br]* 2009;91-B:97-101.
28. **Dougherty PJ.** Wartime amputations. *Mil Med* 1993;158:755-63.
29. **Jacob E, Erpelding JM, Murphy KP.** A retrospective analysis of open fractures sustained by U.S. military personnel during Operation Just Cause. *Mil Med* 1992;157:552-6.
30. **Hinsley DE, Phillips SL, Clasper JS.** Ballistic fractures during the 2003 Gulf conflict: early prognosis and high complication rate. *J R Army Med Corps* 2006;152:96-101.
31. **Brown KV, Ramasamy A, McLeod J, Stapley S, Clasper JC.** Predicting the need for early amputation in ballistic mangled extremity injuries. *J Trauma* 2009;66(4 Suppl):93-7.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.