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PENETRATING HEAD INJURIES

The story begins long before the dawn of recorded history, at the time when man learned to use sticks and stones as weapons. We shall trace the injuries caused by weapons, which became increasingly more deadly from the Stone Age, through the ancient civilisations of Egypt and Greece to modern times.

What do we mean by a penetrating wound of the head? There are three kinds of head injury. First, the blunt injury, often caused by a fall on a flat surface, which produces generalised brain damage without an open brain lesion. Secondly, the comminuted depressed fracture of the skull caused by a falling object such as a brick: indriven bone fragments may damage the cerebral cortex but the patient seldom loses consciousness and usually recovers without serious handicap. Thirdly, the penetrating head injury, where a sharp object or missile fractures the skull and enters the brain, driving fragments of bone before it. The spears and arrows of earlier civilisations frequently penetrated the brain. Nowadays most penetrating injuries are sustained in road traffic accidents or in assaults with sharp weapons; but the most severe penetrating wounds are caused by bullets or bomb fragments.

PRE-HISTORY

Our knowledge of the earliest penetrating wounds is derived from archaeological sources. Little trace remains of most ancient operations, but preserved skulls from the Neolithic Age provide clear evidence of surgical treatment of skull fractures. Pieces of comminuted bone were elevated, sometimes by making a hole beside the fracture not unlike the modern surgeon's burr hole.

Admittedly, we don't know the depth of these wounds or the extent of brain damage, but new growth of bone at the edge of the defect shows that some patients survived the operation. The head was bandaged and occasionally the defect was repaired with a piece of shell, or even a sheet of gold.

A greater number of pre-historic skulls have defects from the operation known as trepanning or



Image courtesy of the Office of Archives, R.V.H., Belfast

trephining. The deliberate fashioning of a hole in the normal skull was carried out in many parts of the world. In Neolithic times a flint or obsidian knife was used; in the Bronze Age more sophisticated instruments appeared and the holes in the skull reached several inches in diameter. The finding of new bone growth at the edges proves that the defect was not the result of disease or post mortem damage. We don't know how or why trepanning of the skull developed; perhaps the early doctors believed insanity or epilepsy might be helped by the operation. It did not die out in the Bronze Age and indeed was recorded in the early twentieth century in Albania and Bolivia. No trace of this apparently ritualistic practice has been found in Egypt and Mesopotamia, the countries in which civilisation first appeared.

THE EARLY CIVILISATIONS

Several times in his history, man has made a rapid, inexplicable leap forwards. The first great leap was about 3000 BC in Mesopotamia and Egypt, another was the fifth century BC in Greece, another a few

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Fig 1. A trepanned skull. (From *A history of neurological surgery*, ed. A Earl Walker. New York: Hafner, 1951).

hundred years later in Rome. The Renaissance period, and the scientific revolution of the nineteenth and twentieth centuries are further examples. What has this to do with head injuries? I would suggest that in most of these periods of change we can trace an advance in medicine in general and sometimes in the treatment of head injuries in particular.

The first documentary record of surgical practice comes from Egypt, the Edwin Smith papyrus named after the explorer and archaeologist who discovered it in the nineteenth century. Imhotep, physician to the Pharaoh Yoser about 3000 BC probably wrote the document, which is almost entirely devoted to neurosurgery and reveals the firm grasp the Egyptians had of neuroanatomy, the scope of head injuries and the significance of their complications. It illustrates the management of 48 patients who had head or spinal injuries. A laceration of the scalp with an underlying simple fracture was to have an application of fresh meat to the wound on the first day and thereafter dressings with honey and lint till it recovered. The Egyptians appreciated the importance of the dura mater: a depressed fracture with an intact dura mater was to be treated. However, a patient with a wound which penetrated the dura leading to a discharging laceration of the brain was regarded as hopeless—'Thou should say of him, an ailment not to be treated'. In spite of their considerable knowledge and experience, operative neurosurgery does not seem to have been widely practised by the Egyptian doctors. Indeed, in the Edwin Smith papyrus we find no mention of the trepan.

Perhaps surgical practice in Egypt was regulated

by law, as in Babylon where the *lex talionis* (the principle of retaliation) became encapsulated in the code of Hammurabi, sixth King of Babylon, over 2000 years BC. In this we are given some insight into the life of the surgeons. 'A physician who makes a wound and saves a freeman shall receive ten pieces of silver, five pieces of silver for a plebeian and for a slave two pieces of silver. However, if a doctor treat a patient with a metal knife for a severe wound and has caused the man to die his hand shall be cut off. Perhaps that explains our lack of knowledge about surgical techniques in Babylon or Egypt. With the threat of retaliation hanging over them the doctors were probably afraid to operate.

If the physicians on the banks of the Nile, the Tigris and the Euphrates were conservative in their treatment of head injuries, the Greeks some 2000 years later adopted a much more aggressive approach. 'War,' said Hippocrates, 'is the only real school for the surgeon'. In the fifth century BC, Greece emerged from the Bronze Age. The development of steel made possible new instruments such as saws and a trephine of a design used in Europe until the seventeenth century AD. In the school of Cos, dominated by the Hippocratic corpus, we find the basis of operative neurosurgery. The Greeks perfected the technique of trephining the skull. Their incisions and methods of elevating skull fracture were in use 2000 years later. Earlier civilisations had practised elevation of depressed fractures but the Greeks advocated operation on linear fractures as well. The reasons are not quite clear. Perhaps they hoped to anticipate the development of an extradural haematoma. However, they accorded the linear fracture a status shared today only by the plaintiff's legal advisers in a High Court action. Although their operative skills improved immensely, the outlook for patients with penetrating wounds remained appalling, and if brain tissue exuded from the wound death was to be expected.

Celsus (25 BC-37 AD) kept alive the practical neurosurgical skills developed in Greece; his chief contribution was his extensive writings which, together with those of Hippocrates formed the standard surgical textbooks until the seventeenth century. Galen, the last medical writer of note in the ancient world, developed new instruments for head injury operations. However, even before the fall of the Roman Empire in the West, scientific medicine had gone to sleep, not to awaken for 1000 years when Europe would emerge from the Dark Ages. The Greek and Roman manuscripts went east to Byzantium where Arabs preserved medical knowledge for a time. Later the manuscripts came west again, first to the

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monasteries and later to the great mediaeval universities of Paris, Oxford, Padua, Bologna and Montpellier.

THE SIXTEENTH CENTURY

By this time the Mongols had brought gunpowder to Europe from China and a new era of penetrating head injuries dawned. A ball from a Spanish musket could now penetrate the thickest armour. At first the devastating effect of bullet wounds on the brain was attributed to poisoning from the saltpetre in gunpowder. Surgeons hoped that boiling oil poured into the wound would counteract the poison. By the mid-sixteenth century Ambroise Pare discarded cautery realising that the bullet caused mechanical disruption of the brain. He encouraged the patient to strain against a closed nose and mouth to force out 'sanious matter and filth'. Paré was probably treating brain abscesses when he used the trephine to evacuate 'sanies or matter poured forth upon the membranes'. We now know that retained bone fragments promote infection. The mortality remained high.

THE SEVENTEENTH CENTURY

Even at this time the treatment of missile wounds followed the teaching of the Greeks and the Romans. Surgeon Wiseman, an army surgeon on the side of the Roundheads at the battle of Worcester (1651) dressed wounds using powders concocted by Galen or sometimes used red meat followed by red wine. Wiseman's incisions were those devised by Hippocrates 2100 years earlier. By now the crown saw and circular bit had been invented and Wiseman followed the Greek practice of operating on all fractures, linear and depressed alike. The instrument was to be lubricated with milk and the surgeon was 'to proceed warily not listening to the prattling of Standers by'. Wiseman reports that rapier wounds of the head were easy to treat but wounds caused by 'a poleaxe, or halberd or other obtuse weapons were

more difficult'. Fractures made by musket wounds 'for the most part beat pieces of the skull inside the brain and so may be considered mortal, but be the hurt what it will, if it penetrate not further than the dura mater it is curable if it be timely laid open and dressed'. Here in the seventeenth century was a clear recognition of the importance of the dura mater, a point that the Egyptians had stressed 4500 years earlier. Wiseman was the first surgeon of his time to insist, perhaps for the wrong reasons, that fragments must be removed from the brain 'but if they will not come easily away, leave it to nature, lest the patient die under your hands, and you be thought to hasten his death'.

THE EIGHTEENTH CENTURY

Our information on penetrating head injuries at this time is derived from army surgeons. Their views depended largely on whether they worked at the front line or in a base hospital. In 1761 John Hunter, then surgeon to the British troops at Belle Isle, well away from the front line, felt that 'injuries in consequence of a musquet-ball' were very little different from other head injuries and should 'require no peculiar mode of treatment'. He didn't appreciate that he was seeing the less severe cases, the slow journey to hospital having 'selected out' good survivors. Hunter wrote 'it was hardly necessary for a man to be a surgeon to practise in the army'—not much progress was made at that time.

On the other hand, Napoleon's doctor, Baron Larrey, was recognised, even by the British, as the foremost of army surgeons. He appreciated the need for swift action at the front line and invented what he called the 'ambulance volante'—the flying ambulance. It was a well-sprung, two-wheeled cart fitted with litters. Each division had 12 of these ambulances and 130 mounted medical staff, providing an evacuation service, vital to patients with head injury, and probably unequalled till the 1939-45 War. At Waterloo the British surgeon had no ambulance and operated

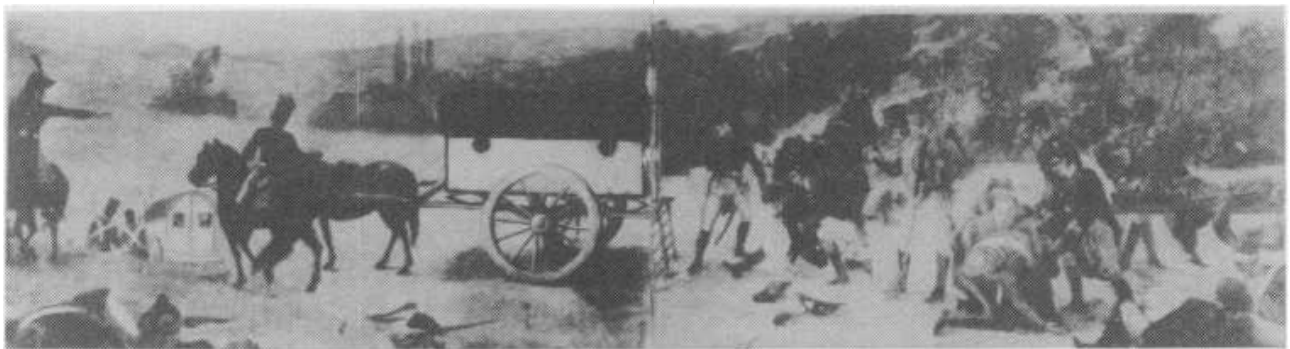


Fig 2. Baron Larrey's flying ambulance. (From *A near run thing*, by D Howarth. London: The Literary Guild, 1968).

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near the battle. He brought his own equipment including a canteen of good wine and spirits; for, as a medical handbook said, 'many men sink beyond recovery for want of a timely cordial before, during and after operations'.

Towards the end of the late eighteenth century the policy of operating on all skull fractures was being challenged. A rational approach came from Sylvester O'Halloran, surgeon to the Limerick County Hospital, and descendant from one of the oldest families in Connaught. His training had been in Paris, Vienna and London. He must have cut a conspicuous figure in Limerick. Sir William Wilde, father of Oscar Wilde, describes him as 'a tall thin doctor in his quaint French dress, with his gold-headed cane, beautiful Parisian wig and cocked hat, turning out every day to visit his patients'. Pride in his ancestry led him to revive the old family motto 'I destroy and I kill', not a very suitable motto for an eminent surgeon. He was elegant, well known all over the continent and, according to Sir Lucius O'Brien, Bt, President of the Antiquarian Society, 'he was never more at home than when abroad' an aphorism that could be applied to many of his academic successors.

Although he was an Honorary Fellow of the Royal College of Surgeons in Ireland, O'Halloran appreciated that, as a surgeon practising in Limerick, a city which had neither a philosophical nor a medical society, he must establish his qualification to write with authority. In 1793 he prefaced one of his books on head injuries 'that I may not be deemed presumptuous in thus assuming the style of a master and, by way of engaging the favourable opinion of the public, I beg leave to submit to the candid and critical reader my pretensions to this character. Without doubt there is not part of the habitable globe as for half a century past has afforded such an ample field for observations on the injuries of the head as Ireland in general and this province of Munster, in particular. A slight offence is frequently followed by serious consequences and sticks, stones and every other species of offence are dealt out with great liberality. To this add the frequent abuse of spirited liquors, particularly whiskey, which has unhappily for the morals and constitutions of the people found its way to every part of the kingdom. Many of our fares, patrons and hurling matches terminate in bloody conflict. From this it appears what superior advantages Irish surgeons have long possessed in this department of their profession over those of the neighbouring nations. I have had no less than four fractured skulls to trepan on a May morning and frequently one or two other injuries resulting from the activities of the Whiteboys. The infirmary



Fig 3. Sylvester O'Halloran, MRIA.

becomes as necessary as the gaol of which it seems but the outer porch'.

O'Halloran's first achievement in the management of head injuries was to lay to rest the notion that all patients with fractures of the skull automatically require an operation. His work was soon recognised in Paris and in London and the practice of speculative trephining of the skull in patients with linear fractures had ceased by the early nineteenth century, bringing to an end the Hippocratic tradition of 2400 years. His next achievement was to improve the treatment of penetrating head wounds. He quotes the case of Patrick Casey, aged 18, who sustained a penetrating head injury when he fell from a horse. Another doctor had performed a delayed and inadequate operation leaving bone fragments in the brain, O'Halloran pointed out that the patient was 'free from pain and fever at the beginning'. Delay led to deterioration and 'the substance of the brain poured forth and he expired the next

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morning'. That patient almost certainly died from a brain abscess. Although the relevance of pus was not appreciated in those days, O'Halloran, working at the same time as Baron Larrey, appreciated from his own experience that early and meticulous wound debridement was important. O'Halloran in Limerick and Dease in Dublin were having some success with their improved surgical technique. We find the first note of optimism in the management of these open brain injuries from a contemporary, Abraham Colies, in his lecture notes from Trinity College, Dublin, published posthumously in 1844: 'Suppose you are called in immediately after a man has received a severe injury of the head, and you find a part of his brain in his hat, or that it comes away in his night cap after he is laid in bed—does it make any difference in the case? None whatever, many such cases have done very well'. That was the Irish contribution from the civilian field at the turn of the eighteenth century, but few of these patients had gunshot wounds.

THE NINETEENTH CENTURY

The writings on war surgery throughout the nineteenth century convey unrelieved gloom. In the Crimean War of 1856, the mortality from penetrating head injuries in soldiers who were evacuated from the front line was over 90 %. In the American Civil War (1861-65) 80% died. In the Franco-Prussian War of 1871, few operations were performed, presumably because of the remote chance of success. Slow evacuation and inadequate surgery no doubt contributed to the bad results. There was still no knowledge of bacteriology: infection was attributed to miasma. One new benefit to the injured appeared just before the American Civil War—the introduction of general anaesthesia by Morton.

Lister's introduction of the antiseptic method in 1867 coupled with new techniques developed by British surgeons of the Royal Army Medical Corps in the Anglo-Boer War (1899-1902) opened the modern era of the surgery of penetrating head wounds. With these advances one might have expected an improved chance of survival. However, the South African war also saw the introduction of high velocity, small calibre bullets fired from modern rifles. At first it was thought that these small missiles might cause less brain damage than the larger Martini - Henry low velocity bullet. It soon became clear that survival from a penetrating high velocity bullet was rare unless the bullet was fired at long range. The South African war was the only modern military conflict in which bullet wounds were more common than wounds caused by metallic fragments from shells or mortars, and bullet wounds carry a much higher mortality. Transport of



Fig 4. Firing on the ambulance : a scene during the battle of Lombard's Kop at Ladysmith, 1899. (From *Frontline artists*, by Peter Johnson. London: Cassell, 1978).

the wounded to hospital was, as usual, difficult. A front line artist has left an impression of the ambulances which conveyed the British wounded during the battle of Lombard's Kop at Ladysmith. We see a cumbersome unsprung oxen cart, comparing very unfavourably with Baron Larrey's 'ambulance volante'. The cart has been struck by a shell; we see the felled oxen and wounded men staggering in bewilderment and agony around the wreckage.

Comparison of results between one conflict and another is difficult because the results depend on the interval between wounding and treatment and on the severity of the wound. Nevertheless, surgical progress seems to have been made: of the patients who reached hospital in South Africa the mortality was only 33%. The essential improvement in technique lay in gaining wide access to the track of the wound by large incisions, identifying and removing indriven bone fragments and blood clots, suturing the dura mater and closing the wound without drainage. Not enough credit has been given to the Boer War surgeons, notably Makins, Bowlby and Wallace.

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THE TWENTIETH CENTURY

The history of war surgery is that the lessons of earlier conflicts are forgotten. The 1914-18 War was no exception. The lessons from South Africa were 'rediscovered' in 1916, but only after two years of disastrous experience. In 1916 Cushing, who had had the benefit of meeting Sir George Makins, Sir Anthony Bowlby and Sir Cuthbert Wallace, redefined the essential operative techniques which soon reduced the mortality from penetrating wounds from over 60% to about 40%. Even so definitive neurosurgical treatment was often delayed for 48 hours.

In the 1939-45 War, history was again repeated. In 1942 Ascroft found that 27 % of penetrating head wounds in the Middle East developed brain abscesses.¹³ Neurosurgeons were by then available but many patients were operated on first by general surgeons and evacuation was slow. The lessons from 1914-18 had been forgotten; Cairns sent to the United States for Cushing's papers to guide him in establishing the neurosurgical forward units which ultimately proved so successful. More rapid evacuation, better neurosurgical debridement and the introduction of penicillin, after Ian Fraser's field trials of the drug, brought the infection rate down to only 3 % by 1945. Surgical techniques for the most difficult cases were further refined by Cecil Calvert and Hugh Cairns. Many patients with missile wounds, especially those injured by metallic fragments rather than bullets, made an excellent recovery. Since these techniques were developed, the risk of serious infection from penetrating injuries sustained in road traffic accidents has been almost eliminated provided the patient reaches neurosurgical care early.

Helicopter evacuation was used in Cyprus and in Korea where the patient reached neurosurgical care within eight hours of injury. The time interval came down to 1-1½ hours in Vietnam, where the incidence of serious wound infection fell to only 1 - 2 %. Of the 49 British soldiers with penetrating head injuries who received definitive neurosurgical care in Korea, there were no brain abscesses, but three patients developed meningitis.

NORTHERN IRELAND

The Northern Ireland experience with missile wounds is in some respects unique. It differs from military conflicts in that patients arrive at hospital much sooner after injury, their wounds are more severe and better facilities are available for resuscitation and treatment. Most patients, especially those injured in Belfast, reached hospital within 30 minutes of injury. Almost immediate resuscitation, which was seldom possible in military conflicts, now became possible.

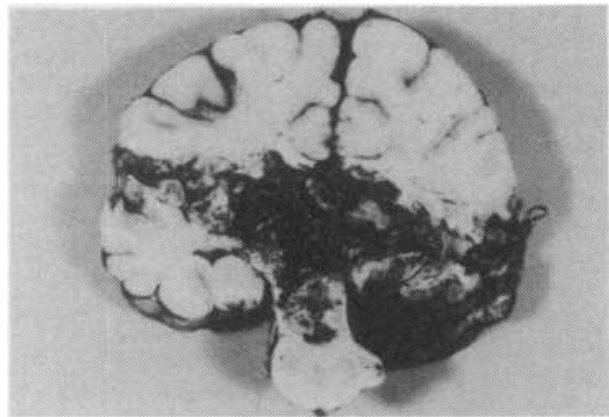


Fig 5. High velocity bullet wound of the brain.

On the other hand the rapid ambulance service led to many moribund patients reaching hospital only to die shortly after admission. Forty-two per cent of hospital deaths took place within six hours of injury.

In twentieth century warfare over 80% of head wounds are caused by metallic fragments from explosions, These injuries are usually less severe than bullet wounds. In 1947, Russell had reported that 43% of patients with penetrating head wounds in the 1939-45 War did not even lose consciousness. In Vietnam, 86% of metallic fragment wounds were operable as compared with 56% of bullet wounds. In Northern Ireland the pattern of injuries has been different: over 80% of penetrating head wounds have been caused by bullets; because of the severity of these wounds and the rapid transport to hospital, the hospital mortality is high, at 56%.

In the Anglo - Boer War the difference between wounds caused by high velocity bullets and low velocity missiles of all kinds became obvious. The effect of a bullet passing through the body depends largely on its kinetic energy rather than on its size, shape or flight characteristics. As the kinetic energy of a bullet is a function of its mass and the square of its velocity ($E = \frac{1}{2} mv^2$), it follows that a small high velocity bullet from a rifle carries more energy than a larger low velocity bullet from a hand gun. High speed photography of bullets fired into gelatine blocks or animal tissues demonstrates the effect of the radial forces generated by a high velocity bullet. The pictures reveal a large, almost spherical, temporary cavity which exists for only microseconds before giving way to the smaller, more fusiform permanent cavity. A low velocity bullet leaves a track of a diameter not much greater than that of the bullet itself.

The first hour of treatment

A patient with a cranial missile injury is in a highly labile state. He may be conscious on admission, only

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to deteriorate rapidly and die within an hour. Clinical deterioration is often associated with hypoxia due to epileptic fits, bouts of coughing or inhalation of vomitus or blood. Hypovolaemic shock from other injuries, or due to bleeding from cerebral vessels, can also cause cerebral ischaemia which may prove fatal in a patient with a severely injured brain. Prevention of secondary brain damage from hypoxia and hypotension is the chief aim of early management. This was the chief challenge facing us in Belfast in the early 1970s. We soon realised that practically every patient with a cerebral missile wound, conscious or unconscious, needed immediate tracheal intubation and mechanical ventilation. The blood O₂ and CO₂ levels could be controlled and excessive rises of intracranial pressure prevented.

Adequate resuscitation demands the presence of appropriate medical staff. A team of three doctors is ideal: one to examine and record and to assess priorities of treatment; the second, preferably an anaesthetist, to take care of the airway, and the third to replace fluid loss, which may be substantial, by intravenous infusion. Patients with cerebral missile wounds who remain in deep coma after cardio-pulmonary resuscitation do not survive. The fact that 72% of patients with a mean blood pressure under 90mmHg on admission died, gives an indication of the importance of early and adequate transfusion. One of the advances in the management of these injuries in Northern Ireland has been the involvement of anaesthetists in resuscitation, in subsequent intensive therapy and, outstandingly, in transporting patients from other hospitals using mechanical ventilation in the ambulance. Clinical deterioration in the ambulance, which can be a problem with any kind of head injury, has been almost eliminated in Northern Ireland.

Surgery

The aim of surgery is to arrest haemorrhage, to prevent infection by removing bone and any accessible metal fragments and to repair the dura mater and scalp in a way that facilitates cranioplasty at a later date. No patient treated in the neurosurgical department has developed a brain abscess.

Extensive debridement of a missile wound often leaves a very large skull defect which has to be repaired to protect the brain and to improve the patient's appearance. None of the conventional cranioplasty techniques—bone grafting or insertion of acrylic or metal plates—proved satisfactory.

A high pressure moulding technique developed in the Royal Victoria Hospital School of Dentistry has proved ideal for producing accurately contoured

titanium plates. Titanium was chosen because of its low density, radiolucency, malleability and, most important of all, its lack of reactivity with the tissues. Titanium cranioplasty has now been adopted in many centres as the method of choice.

The challenge of the missile injury is increasing in western society. To meet this challenge, the emergency services must be organised to provide immediate resuscitation and intensive therapy and, when necessary, expert care during transportation to the neurosurgeon. Many patients with severe head injuries from any cause die from primary brain damage. Our experience in the past 18 years indicates that emphasis must be placed on preventing secondary brain damage brought about by hypoxia and hypotension. Immediate action can save lives and prevent some of the after-effects of brain injury.

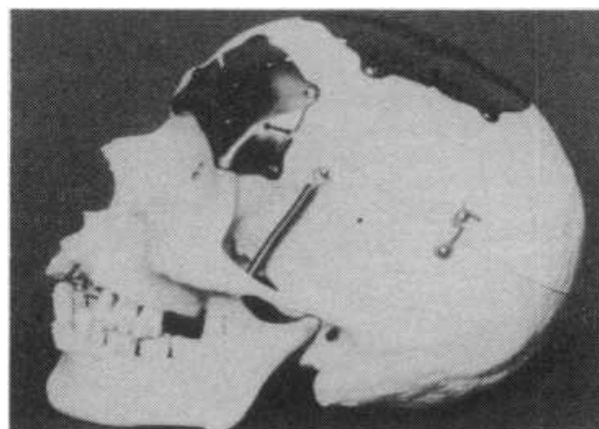


Fig 6. Titanium cranioplasty: a demonstration specimen which is now in the Science Museum, London.