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History of internal fixation (part 1): early developments with wires and plates before World War II

Philippe Hernigou [1] · **Jacques Pariat** [1]

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Abstract Though the date at which an orthopaedic implant was first used cannot be ascertained with any certainty, the fixation of bone fracture using an iron wire was reported for the first time in a French manuscript in 1775. The first techniques of operative fracture treatment were developed at the end of the 18th and in the beginning of the 19th centuries. The use of cerclage wires to fix fractures was the most frequent fixation at this time. The French Berenger-Feraud (1832–1900) had written the first book on internal fixation. However internal fixation of fractures could not become a practical method before Lister had ensured the safety of open reduction and internal fixation in the treatment of fractures. Lister is not only the father of asepsis; he also used metal wires to fix even closed fractures. The first internal fixation by means of a plate and screws was described by Carl Hansmann in 1858 in Hamburg. Nevertheless, Arbuthnot Lane (1892) and Albin Lambotte (1905) are considered to be the founders of this method, which was further developed by Sherman in the first part of the 20th century.

Keywords History of internal fixation · Berenger-Feraud · Hansmann · Lane · Lambotte · Sherman · Naval surgery

The ascertained beginnings of internal fixation

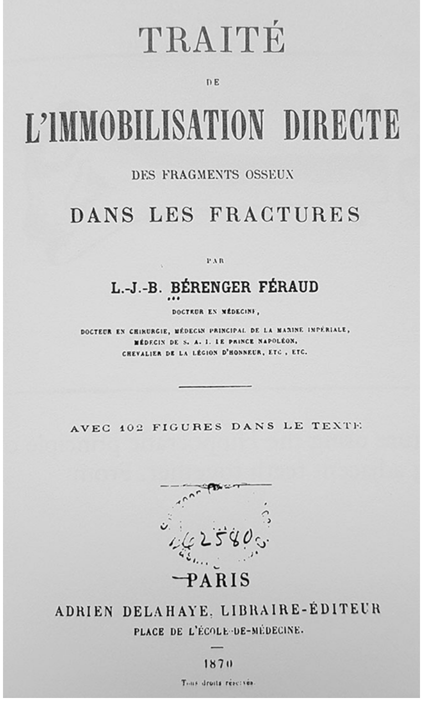
We know that the Etruscans and Greeks wired teeth for fractured jaws. We have no details, but anthropologists have reported that for a very long time the South African tribes sutured fractures with catgut-like material obtained from the dorsal spinal ligament of camels. In the 17th century, a Neapolitan surgeon [1], Marcus Aurelius Severino (1580–1656), was perhaps the first to counsel suture for fracture of the patella (Fig. 1). Moreover, Jacques Croissant de Garengeot (1668–1759), in his "*Traité des Instruments les plus utiles*" (most useful tools in surgery) in 1723 [2], refers to the 'ancient classification of operations into *synthesis, diaeresis, exeresis* and *prosthesis.* In 1775, the *Journal Francais de Chirurgie* contained a report by Icart of two Toulouse surgeons, Lapoyde and Sicre, on the use of brass wire for fracture suture, which excited opposition [3], although we are not certain that surgery was really performed.

We may assume with virtual certainty that these attempts, before anaesthesia, antisepsis, asepsis and antibiotics, were uniformly disastrous. It meant creating an open fracture; and right up to the second half of the 19th century an open fracture spelled death or amputation for the majority of patients. For as late as 1883, Beauregard [4], reviewing 49 cases of patellar fracture wired with silver, steel or platinum or sutured with silk in various European countries, did not find it especially remarkable that these treatments resulted in one amputation and four deaths due to infection. In earlier days, then, the deliberate opening of a simple fracture was to tempt Fate, an act of surgical *hubris* which rarely went unpunished. The surgeon's quandary was well exemplified by Malgaigne, in France. He wanted to fix unstable fractures but believed that metal implants caused hospital gangrene, so in 1837 he designed the first external fixator, an apparatus of clamps with screws attached to percutaneous hooks into the bone that permitted compression. This was successful in six tibial fractures in 1840 and four successes with patellar fractures were published in 1847 [5]. He was surprised at his own success by the absence of deaths among patients.

✉ Philippe Hernigou
philippe.hernigou@wanadoo.fr

[1] Orthopaedic Surgery, University Paris East (UPEC), Hôpital Henri Mondor, 94010 Creteil, France

Fig. 1 Portrait of Marcus Aurelius Severino, the first to counsel suture for fracture of the patella



TRAITÉ

DE

L'IMMOBILISATION DIRECTE

DES FRAGMENTS OSSEUX

DANS LES FRACTURES

PAR

L.-J.-B. BÉRENGER FÉRAUD

DOCTEUR EN MÉDECINE,

DOCTEUR EN CHIRURGIE, MÉDECIN PRINCIPAL DE LA MARINE IMPÉRIALE,
MÉDECIN DE S. A. I. LE PRINCE NAPOLÉON,
CHEVALIER DE LA LÉGION D'HONNEUR, ETC, ETC.

AVEC 102 FIGURES DANS LE TEXTE

PARIS
ADRIEN DELAHAYE, LIBRAIRE-ÉDITEUR
PLACE DE L'ÉCOLE-DE-MÉDECINE.

1870

Tous droits réservés.

Fig. 2 Berenger-Feraud's book published in 1870

Pioneers of internal fixation

Laurent Berenger-Feraud (1832–1900) and the first book on internal fixation

As frequently happens, the beginning of a new period in technology is marked by a work that recapitulates past experience and forecasts future development. Such a work was the "*Traité de l'immobilisation directe des fragments osseux dans les fractures*" (a book on direct immobilisation of bone fragments of fractures) published in Paris in 1870 [6] by Laurent Jean Baptiste Berenger-Feraud (1832–1900). Berenger-Feraud's book was the first work devoted to the treatment of fractures by internal fixation (Fig. 2) .

Laurent Jean Baptiste Berenger-Feraud (Fig. 3), the son of a naval surgeon, was born in the south of France. His father was stationed in Algeria, where he received his early education, returning to Toulon in 1850 to begin his medical education. During his studies, he observed two patients with open fractures of the tibia treated by doctor Long, the chief surgeon of L' Hotel-Dieu Saint Esprit, who used wire sutures to stabilize the fragments. His thesis for the degree of medicine in Paris dealt with the treatment of comminuted fractures of the tibia. He then became a medical officer in the French navy and served on tropical stations in equatorial Africa, where he became interested in tropical diseases [7]. In 1870 he was recalled to serve with the French army during the Franco-Prussian War. He was present at the surrender at Sedan and later served with distinction as a surgeon at the military hospital, Val-de-Grace, during the siege of Paris. His book on fractures was published at this time, although he had published a short synopsis of his ideas six years previously [8, 9]. After 1870, he concentrated on pursuing his naval career and the study of tropical medicine. At the time of his retirement, Berenger-Feraud had reached the rank of surgeon general of the Navy.

Fig. 3 Portrait of Berenger-Feraud

He summarized in his book more than 400 cases of operated fractures from literature. At that time, the problem of anaesthesia had already been solved and the first steps were taken in the prevention of intra-operative infection. Berenger-Feraud described six different methods (Fig. 4) for the direct fixation of fracture fragments: (1) the stabilization of fractures of the mandible by wiring or tying adjacent teeth together, as described by Hippocrates, (2) Malgaigne's point, (3) Malgaigne's clamp, (4) enclavement or impaction of a spike of one fragment into the marrow cavity of the other, (5) suture of the fragments, and (6) ligature or cerclage of the fragments. Of these methods, he believed cerclage to be the most efficient. Berenger-Feraud claimed no credit for devising any of these methods, and he provided extensive documentation of their use by others.

Many of the methods had been used in the treatment of ununited fractures or pseudarthrosis. Berenger-Feraud advised their application only in such cases, and in fresh open fractures where the risk of infection was already present. Following the operation, he gave the surgeon the choice of dressing the wound, which was left open, with dressings soaked with cold water, a mixture of alcohol and water, alcohol, wine, solutions of potassium permanganate, phenol, or creosote. He summarized the advantages of the direct fixation of fracture fragments as follows: The direct immobilization of the fragments simplifies the pathology of the wound about the open fracture because the healing of the soft tissue is not impaired by motion of the bone fragments. The bones are less exposed to change caused by pyogenic or very dangerous putrid elements during the period when they are not protected by granulation tissue.

Joseph Lister (1827–1912) and the antiseptic system

Internal fixation of fractures could not become a practical method of treatment until the introduction of antiseptic and aseptic techniques dispelled the spectre of infection. Although there had been anecdotal reports of the use of wire suture, cerclage, or ivory pegs in patients with open or ununited fractures before Lister, no real progress was possible until the safety of such surgical interventions could be assured. It was the antiseptic system of wound treatment developed by Lister that ensured the safety of open reduction and internal fixation in the treatment of fractures and permitted these methods to develop.

Joseph Lister was born on the 5th of April in 1827 at Upton House, Essex. His father had considerable success in business and research in optics, which led to the perfection of the microscope and his election to the Fellowship of the Royal Society. Joseph Lister qualified in medicine (London) and was appointed house physician and later house surgeon. In 1852 he went to Edinburgh with an introduction to Syme. Lister became his house surgeon, was an enthusiastic pupil, and married his eldest daughter Agnes. After a period assisting Syme in hospital and private practice, Lister was elected, on October 1856, to the post of assistant surgeon to the Edinburgh Royal Infirmary. He held this post for four years, during which time he lectured on surgery.

In 1865, he had knowledge of the writings of Pasteur, and learned that putrefaction was a fermentation due to the growth of microscopical organisms, which could also be found on all material objects. Lister (Fig. 5) realized that putrefaction's explanation of Pasteur was applicable to the decomposition of wounds. He started by casting about for a suitable antiseptic and on learning of the success of carbolic acid as a disinfectant, he decided to give this chemical a trial on wound treatment. After investigation with the pure acid, he finally adopted a 1 in 20 watery solution, and this strength of carbolic acid became a permanent feature of his technique. With this solution he cleansed his hands, his instruments, the patient's skin, and the wound itself. In 1865, Lister began demonstrating that wounds in patients with open fractures could heal

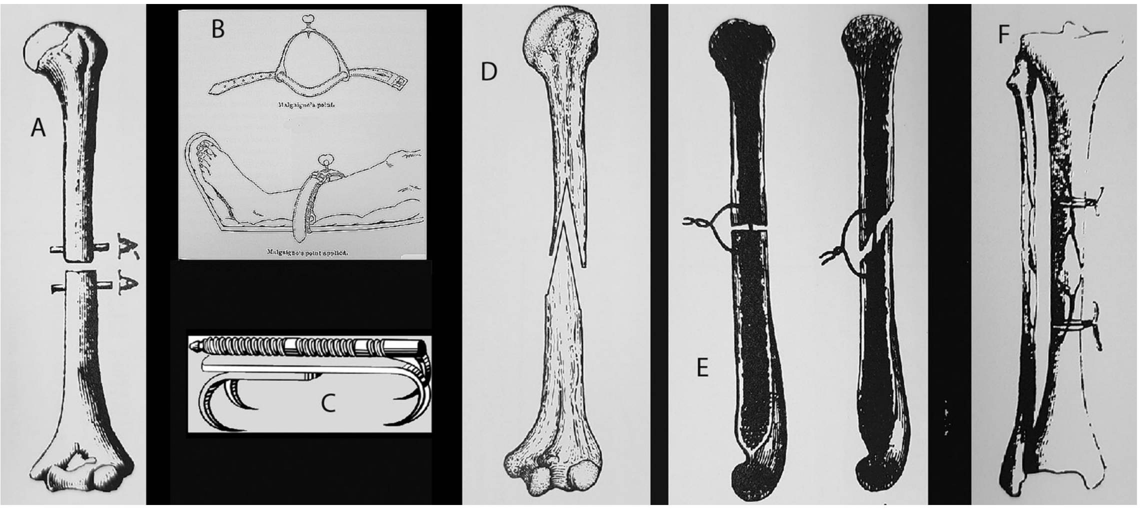


Fig. 4 If we examine carefully the six methods for the direct immobilization of fracture fragments described by Berenger-Feraud, we can see in embryo concepts that contributed to the development and use of pins and nails, external skeletal fixation, intramedullary nailing, and cerclage

Fig. 5 Portrait of Lister

without infection if they were covered carefully with an occlusive dressing containing phenol (carbolic acid). The next step, electively converting a closed fracture into an open one, was long delayed. Lister had to accumulate experience with the treatment of open fractures and with non-union by operative methods. He also had to learn how to sterilize the instruments and materials that he used so that they did not infect the wounds. The simple decision to cut off sutures at the knot, leaving them buried in the wound, was a crucial one. His first paper [10] in the *Lancet* in 1867, was entitled "On a New Method of Treating Compound Fracture, Abscess, etc., with Observations on the Conditions of Suppuration." During the same year he read a paper in Dublin called "On the Antiseptic Principle in the Practice of Surgery" at a meeting of the British Medical Association. It should be noted that his constant aim was the prevention of sepsis in wounds, with the least irritation to the tissues.

Finally, in October 1877, when he was confident of his technique, a patient with a closed fracture of the patella was admitted to his ward in King's College, London. Lister's decision was strengthened by his knowledge of the success of his former colleague in Glasgow, Hector Cameron, who in March 1877 had repaired an eight-week-old displaced transverse fracture of the patella using a wire suture and antiseptic techniques. After an initial attempt at closed treatment that did not completely reduce the fracture, Lister carried out an open reduction and internally fixed the fracture by means of a heavy silver wire (Fig. 6). The wound healed without infection and the wire was removed after eight weeks. Lister believed that this was the first case of a fresh fracture of the patella treated by "wire suture antiseptically applied." He was unaware that Samuel Cooper in San Francisco had used a silver wire to successfully suture a fresh fracture of the patella in 1861 [11]. Cooper's success was also due to his use of antiseptic techniques that employed 50 and 75 % alcohol. In 1883, Lister was able to report good results in seven patients in whom he had wired fractures of the patella [12]. Fifteen years later, the treatment of displaced closed fractures of the patella by open reduction and wiring was an established procedure described by Lister as follows: "That the operation has a well-fixed place in surgery seems plain. I believe it should be done only by adepts in the surgical art, that it be confined to healthy individuals of suitable age, that its dangers and advantages should always be fully explained to the patient, that it should be reserved for fractures presenting a diastasis of over one-half of an inch or with extensive lateral tears of the capsule, and that it should always be supplemented by early massage and mobilization of the joint. The preferable form of operation is open arthrotomy. The suture of the soft parts should always be carefully made; such suture may be applied to the bone as the operator's judgement may dictate".

The precursors of modern internal fixation with plates

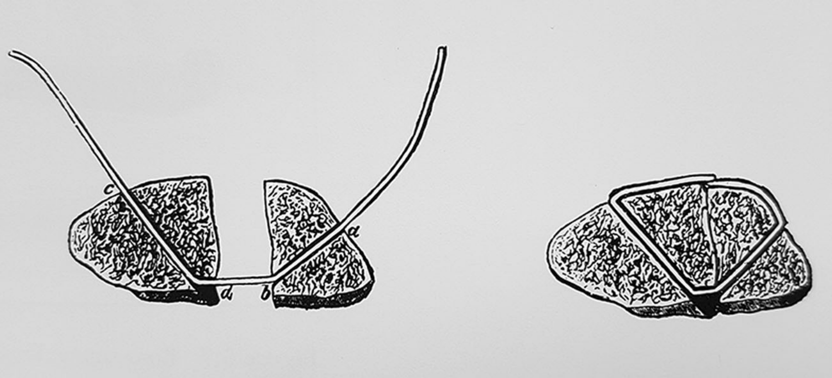
The end of the 19th and the first decade of the 20th century saw the emergence of effective advocates for the internal fixation of fractures, one in Germany, the second in London and the third in Belgium. The first internal fixation by means of a plate and screws was described by Carl Hansmann (1853–1917) in Hamburg. Nevertheless, Arbuthnot Lane (1892) and Albin Lambotte (1905) are considered to be the founders of this method.

Carl Hansmann (1853–1917): the first plate

Fixation by means of a plate and screws designed in such a way that they could be removed after the fracture consolidated without reopening the wound was introduced by Hansmann in 1886 (Figs. 7 and 8). He fixed fractures with strips of unhardened nickel-plated sheet steel and nickel-plated screws, one end of the plate being bent at a right angle to protrude through the skin and facilitate removal after six to eight weeks (Fig. 9). This he reported to the 15th Surgical Congress in Germany, and two visitors were impressed: Halsted took some plates back to Johns Hopkins in the United States and Lambotte, of Belgium, saw this as the ideal future treatment of fractures.

The first to publish his experience with plate osteosynthesis was Carl Hansmann, in 1886, as mentioned above [13]. Hansmann used plates from nickel-coated sheet steel in 20 cases: 15 times in fractures (8 fractures of the tibia, three

Fig. 6 Lister's method of patellar suture using silver wire



fractures of the femur, one fracture of the radius, one olecranon fracture and two fractures of the mandible) and five times in non-unions (humerus, ulna, radius, femur, tibia). As part of the plate and the shanks of the screws that fixed it to the bone protruded from the wound, Hansmann kept the surgical wound strictly aseptic and used washable external rubber splints. The material could be therefore removed percutaneously. He did not mention any complications and removed the plates after four to eight weeks. Neither in Germany nor elsewhere in Europe did Hansmann have a successor for a long time. It was only after a 14-year interval that other publications in this field appeared.

Sir William Arbuthnot Lane (1856–1938): no-touch technique and plate osteosynthesis

But it is Sir William Arbuthnot Lane (1856–1938), in London, who must be regarded as the great precursor in internal fixation. He was born on a British army post in Scotland [14]. His father, a regimental surgeon, moved his family with the regiment, and by the time "Willie" was sixteen he had lived in Africa, India, Corfu, Malta, Nova Scotia, and England. His early education was obtained along the way. His father's posting to Woolwich, south of London, gave him the opportunity to go to medical school. In 1872 he was enrolled at Guy's Hospital, where during his rotations he served as a surgical clerk on the service of Thomas Bryant, developer of "Bryant's traction". Beginning as a demonstrator of anatomy at Guy's Hospital, he became an assistant surgeon and finally a surgeon on the staff of the hospital in 1903. A glance at his extensive bibliography reveals him to have been a general surgeon in the broadest sense. His interest in the treatment of fractures was but only a small part of his work. Lane was an innovative surgeon and a brilliant technician. His knowledge of anatomy allowed him to operate boldly.

His strict adherence to a sterile, "no touch" technique in the operating room ensured his procedures a low rate of infection [15]. This technique was made possible by the use of many instruments of his own design. Lane (Fig. 10) realized that a rigorous aseptic technique was essential, including the skin

Fig. 7 Mural painting by Johannes Grützke in the administration building of the Berufsgenossenschaftlische Unfallkrankenhaus, Hamburg, Germany: "Aus der Geschichte der Unfallchirurgie". Carl Hansmann can be found holding his plate in the company of many famous surgeons on this painting. As a game you can try to recognize the other surgeons of the painting; the solution is in the next figure

Fig. 8 *22* fellows; *23* Carl Hansmann, *24* Bernhard von Langenbeck; *25* Otto von Bismark; *26, 27, 28, 29* and *30* fellows

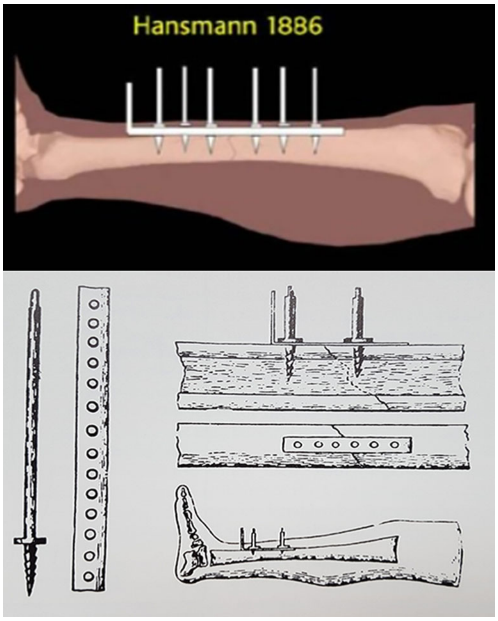


Fig. 9 Hansmann's method. Note that the screws and the plate could be removed after the fracture had healed without reopening the wound. From Hansmann, "Eine neue Methode der Fixierung der Fragmente bei complicirten Fracturen," *Dtsch Ges Chir* 15(1886):134–37

preparation several hours before the operation, and in the operating room skin disinfection with a solution of iodine. The operation area was surrounded sterile mackintoshes clipped to the skin. All instruments were kept dry after sterilization. The first knife used for incising the skin was discarded and a second fresh knife employed in the wound. Towels covering the skin were dressed over the edges of the wound because the exposed subcutaneous edge was considered a greater danger than the prepared skin. The theatre nurse held an instrument with forceps when handing it to the operator and she threaded needles with the aid of two pairs of forceps. To facilitate reduction of the fracture, Lane used bone forceps with long handles, which kept the hands well away from the wound. No part of an instrument that entered the wound was allowed to touch the surgeon's hand. All ligaturing and sewing were done with the aid of needle holder and forceps. This scrupulous no-touch technique had a transforming effect on operative orthopaedic surgery.

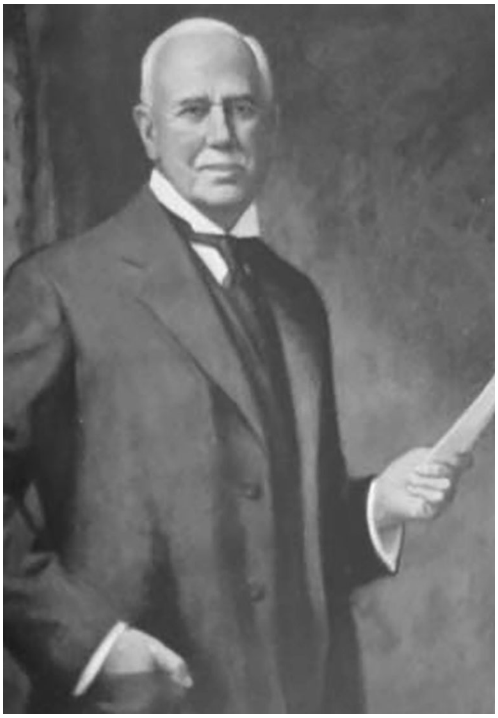


Fig. 10 Portrait of Lane

After an early trial of silver wire, he began early in the 1890s to fix oblique tibial fractures with ordinary steel screws [16, 17], on the grounds that this secured better alignment of ankle joint fractures and promoted rehabilitation. Lane's attitude toward the treatment of fractures stemmed from his anatomical dissections, where he had observed the effects of mechanical stress on the skeleton and the traumatic arthritis associated with malunited fractures. His book *The Operative Treatment of Fractures* published in 1905 [18], was illustrated with drawings, photographs, and X-rays demonstrating the use of wires, screws, and staples. In 1905, he proceeded to the use of plates and though not the originator of the method he was the first to apply it safely and systematically. These screws and plates were made of plain high-carbon steel and were intended to bring together and maintain the opposing surfaces of the bone into the most accurate and forcible apposition, an aim that must have resounded in the compression enthusiasts of the 20th century. The "Lane plate" made its appearance in 1907, and in the second edition of his book, published in 1914, was the preferred method of fixation [19]. However, Lane's methods were opposed by many of his colleagues as too risky and prone to failure. This was with his new 'no touch' technique, and since, in his hands, infection was rare, it became possible to distinguish the failures due to corrosion (Fig. 11).

Albin Lambotte (1866–1956): discovery of problems of alloy and tissue reaction

Much credit is due to the brothers Lambotte, in Belgium. Albin Lambotte (1866–1956) was born in Brussels, where

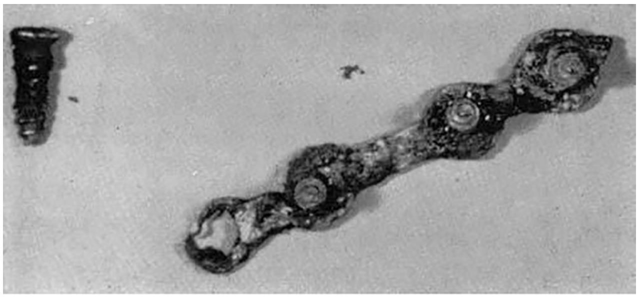


Fig. 11 Lane's plate abandoned because of corrosion (1895)

his father was a professor of anatomy, biology, and chemistry at the university. His older brother, Elie, was a surgeon and became the greatest influence on his life. Elie Lambotte had used wires and screws for oblique tibial fractures in the 1890s with good results but was discouraged by criticism. There, Elie Lambotte enjoyed the reputation of a daring pioneer in abdominal surgery. His premature death was a great personal loss to his brother.

After his medical education, Albin Lambotte became a house officer on his brother's service at the hospital of Schaerbeck in suburban Brussels. Albin Lambotte obtained an appointment at the hospital of Stuyvenberg in Antwerp in 1890 and spent the rest of his professional life there. At Stuyvenberg he was a general surgeon who operated on patients with all sorts of diseases and injuries. However, the treatment of fractures remained his major interest. Albin used plates and screws, transfixion pins, external fixators, curved or Y-shaped plates for condylar fractures at the lower ends of the humerus or femur and thin guided pins for the scaphoid.

Lambotte published his accumulated experience on the treatment of fractures by surgical methods in 1907, his subtitle introducing and coining the term *osteosynthesis* [20]. He reported on 187 patients with only two deaths due to infection. He believed that open reduction and internal fixation were indicated in cases of displaced, comminuted, and "puncture-compound" fractures as well as fractures complicated by arterial and nerve injuries. To fix the fractures, Lambotte used wire sutures and cerclage, screws, staples, plates (Fig. 12), and external skeletal fixation. In patients with diaphyseal fractures, those that were transverse were fixed with a plate and screws or external skeletal fixation; those that were oblique, by cerclage or cerclage in combination with external skeletal fixation. Metaphyseal fractures were fixed with staples, screws, and plates.

His 1909 paper had dealt with the fate in the bone of alloys such as brass and also of aluminium, silver, copper and magnesium, all of which proved malleable and corrodible, so that he settled on soft steel plated with gold or nickel. It is interesting to note that some contemporary work (1909) by von Baeyer, on cellular reactions to implants, anticipating much later work on piezoelectricity, noted that if copper and zinc were implanted close together the connective tissue cells aligned themselves axially along the path of the corrosion current [21]. An integral part of Lambotte's treatment was the institution of early active, assisted motion. A second, expanded edition [22] of his book appeared in 1913.

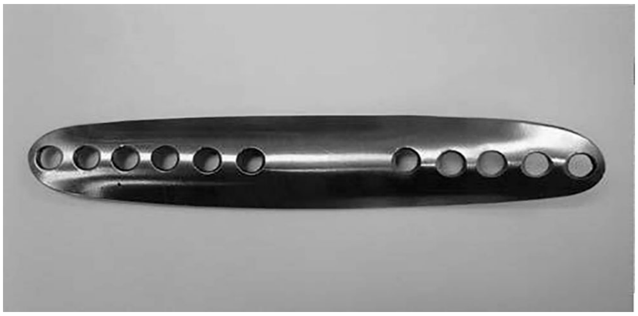


Fig. 12 Lambotte's plate (1909) is thin, round, and tapered at both ends

Evolution of internal plate fixation during the first half of the 20th century

It is not surprising that closed methods of treating fractures would come under close scrutiny as a result of the triple impact of the introduction of the X-ray, improvement of surgical techniques for open reduction and material for internal fixation, and the tissue reaction to the metals.

X-rays in orthopaedic surgery and discussion of osteosynthesis before World War I

Until the end of the century, open reduction, with or without internal fixation, was generally only used when conservative treatment had long failed; and the use of plates and screws was rare until the advent of X-rays in 1895 when, as Delbet wrote, "we know more of what we have to do, of what we are doing, and of what has been done".

It is not surprising that closed methods of treating fractures would come under close scrutiny as a result of the double impact of the introduction of the X-ray and surgical techniques for open reduction and internal fixation. At the annual meeting of the British Medical Association in 1910, and at the meeting of the American Surgical Association in 1912, a committee was appointed and charged to report on the ultimate results obtained in the treatment of simple fractures with or without operation. More than 2,900 cases were reviewed, only 208 of which had been treated by surgical methods. The committee consulted with experts advocating a wide variety of approaches to the treatment of fractures including Lane, Lambotte, Fritz Steinmann, Bernhard Bardenheur, and Lucas-Championniere. Its report, published in 1912 [23], contained some very interesting conclusions: "*Although the functional result may be good with an indifferent anatomical result the most certain way to obtain a good functional result is to secure a good anatomical result. No method whether non-operative or operative which does not definitely promise a good anatomical result should be accepted as the method of choice. Operative treatment should not be regarded as a method to be employed in consequence of the failure of non-operative measures as the results of secondary operations compare very unfavorably with those of immediate operations. In order to secure the most satisfactory results from operative treatment it should be resorted to as soon as after the accident as practicable. It is necessary to insist that the operative treatment of fractures requires special skill and* *experience and such facilities and surroundings as will ensure asepsis. It is therefore not a method to be undertaken except by those who have constant practice and experience in such surgical procedures". Each has its indications and should be employed when required. Generally speaking the age period under fifteen years is the period in which non-operative methods are especially effectual. The open method when adopted should be employed early. It may be used at any age period except in senile cases whenever a radiogram (X-ray) shows a deformity or a position of the fragments which obviously cannot be reduced or when proper efforts at reduction and retention have proved unavailing.*

The reports of these two important committees clearly show that the operative treatment of fractures had become an established method of treatment. Why then was the further development of these methods delayed for so many years? The reports themselves acknowledged that the operative treatment required specially trained surgeons, operating under optimal conditions, with an expensive and complicated armamentarium. The battlefields of World War I could provide none of these. Instead, inadequate numbers of poorly trained surgeons provided care for enormous numbers of patients with fractures under less than optimal, even appalling, conditions. Only the simplest methods could be used safely. The disruption caused by World War I and the economic depression that followed arrested the momentum that was necessary for continued progress [24].

William O'Neill Sherman (1880–1979) and the improvement of surgical techniques for open reduction and material for internal fixation

William O'Neill Sherman (1880–1979) did the most to popularize internal fixation in the United States (Fig. 13). In 1912, Sherman reported the treatment of 55 femoral shaft fractures with Lane's plates, three of which broke at this junction. He considered that the plate should be sufficiently ductile and elastic to bend rather than break, introduced a high-carbon steel containing vanadium, and redesigned the plate to reduce the 'necking' between holes. Sherman's plates served in good stead and were recommended by the US Bureau of Standards and the Committee on Fractures of the American College of Surgeons in 1932 and again in 1947 and are probably still to be found in some parts of the world. Still, even in the 1920s, Sherman's plates, though usually mechanically sound, often loosened or caused local iron staining, and it is fair to say that up to 1920, despite experiments with many materials, some rather dubious, nothing totally reliable had been found and implants were generally removed once union was achieved. Such modifications as the rectangular Venable plate were an improvement. It is interesting that a contemporary of Sherman's, F J Cotton, in 1912, thought that, no matter how good a rigid plate is, it necessarily exposes the patient to the danger of pulling out screws.

Fig. 13 Portrait of Sherman

He favoured the use of steel plates and screws because of their ease of application and the anatomical reduction that could be obtained. Sherman was unhappy with the quality of the bone plates available because he had experienced breakage during the immediate post-operative period. As the surgeon for the Carnegie Steel Company of Pittsburgh, he was in an ideal position to experiment with better metal alloys and to use them in the manufacture of appliances whose design was based on engineering principles. He was able to devise plates made from a vanadium steel alloy [24, 25] and introduced self-tapping screws of the same material designed to fit into the holes of the plates [26] (Fig. 14). His search for improved metal alloys and his application of engineering principles in the design of the implants were major contributions [27].

At the same time, Peterson [28] was reviewing the status of internal fixation with plates and screws on behalf of the Office of the Surgeon General. He concluded that the deficiencies in the plates were due to improper design, variations in the hardness of the metal, improper manufacture, and poor quality control. The screws did not always fit the plates; the design of the heads was unsatisfactory, and the threads were cut poorly. The drill points were too brittle, and sizing was not consistent. He urged that the plates, screws, and drill points all be made of the same metal alloy. He promoted a more precise technique using a drill guide to centre the hole, a power drill, and screws whose heads accurately fit the holes. He used a tap to cut threads in the bone for the screws, but abandoned this technique as too time-consuming. He also used interfragmentary compression and double onlay plates for femoral shaft fractures. Increased precision in technique was promoted by the introduction of a simple device for determining the length of the screws required [29] (Fig. 15).

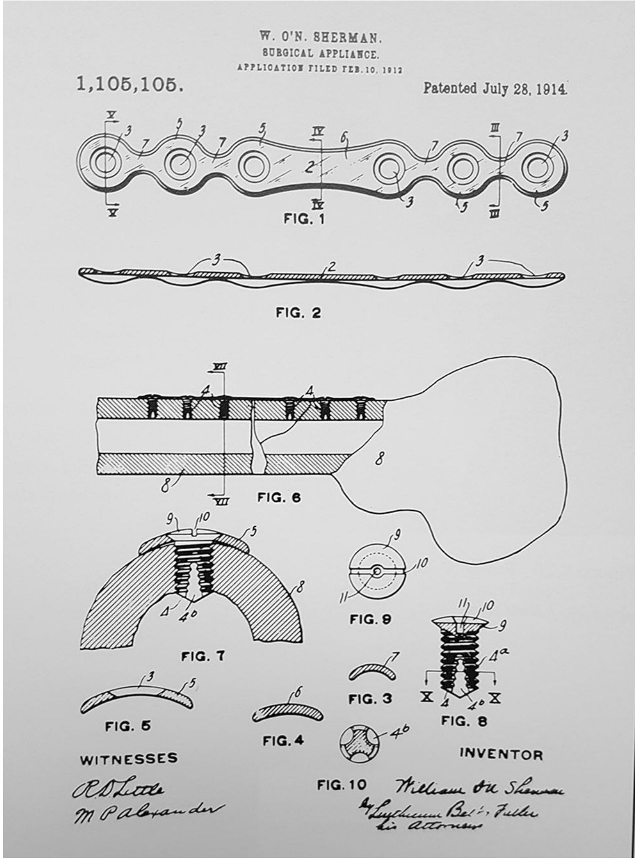


Fig. 14 Patent of the Sherman plate

The results of open reduction and internal fixation were not always favourable. In 1928, Roscoe N. Gray, a medical referee for Aetna Insurance Company, after a review of 34,753 compensation files from northern California, concluded [30] that ”*it is questionable if open bone surgery should ever be done except by highly trained men with highly trained assistants in highly trained hospitals; otherwise disaster is likely to result.*"

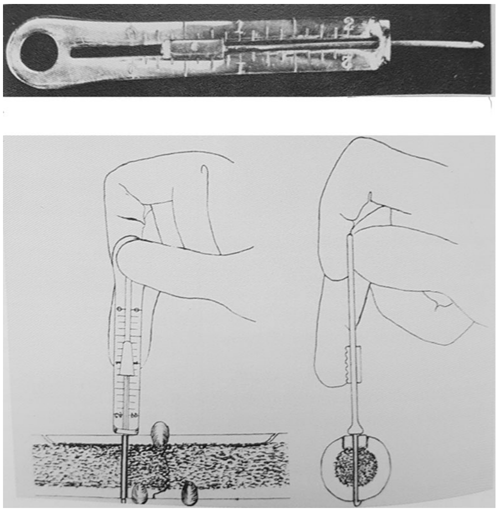


Fig. 15 Instrument for accurate measurement of bone screw

Cytotoxicity of metals, tissue reaction to the metals, corrosion and evolution of materials for plates and screws

At any given period, the status of orthopaedic implants has to be considered in the light of the contemporary technology and of the status of orthopaedics itself. Metallurgy reached its peak in the latter half of the 19th century when it transformed the western world, but orthopaedics did not become a separate discipline until the turn of the 20th century or even later; and even then, as was pointed out at the first congress of the German Association for Orthopaedic Surgery, the wish to associate was tempered by the fear that separation from general surgery would reduce them once more to the status of mere “bandagists”. Even in the first decades of the 20th century, when implants were very much in vogue, and later still with the expansion in plastics at the mid-century, tissue reactions to materials were still not fully understood and there was still no adequate science of biomechanics.

Along with the development of suitable designs for implants to be used for the internal fixation of fractures was a continuing search for the best materials from which to fabricate them. Surgeons tended to use materials easily at hand. Those of biologic origin, e.g. bone, ivory, horn, etc., were used in the hope that they might be absorbed or be incorporated into the healing bone with a minimal reaction [30, 31]. Metal screws and plates initially were of the quality that could be found in any hardware store. Sometimes devices made of one metal were plated with another, and it was common to use plates made of one metal with screws made of a second. Rene Leriche and A. Policard [33] concluded that the plates used by Lambotte inhibited fracture healing and new bone formation because of the deposition of iron salts in the local tissues. They stressed the advantage of using plates made of more nonreactive metals such as gold, silver, magnesium, and aluminum.

On tissue tolerance Ernest William Hey-Groves (1872–1944) noted that magnesium rapidly disintegrated and dissolved but that nickel-plated steel was inert, and also that continued minor movement between metal and bone led to irritation of bone. In 1924, Zierold [34] studied metal corrosion extensively in dogs, noting that iron and high and low carbon steels rapidly dissolved, their erosion affecting the bone. Inserts of copper, nickel, zinc and aluminium alloy all discoloured bone, but there was no reaction to gold, silver, lead (though this was systemically toxic), or pure aluminium—materials too soft for plates though useful for wires or plating other metals. Stellite, a cobalt alloy, was very well tolerated but, strangely, not further studied at this time. 1926 saw the introduction of ‘stainless’ steel, though it did not gain early acceptance when first patented.

In 1929, a nonferrous alloy of cobalt with chromium and molybdenum, similar to Zierold’s stellite and labelled vitallium, began to be used in dentistry and its complete inertness and suitability for orthopaedic implants were noted by

Venable and Stuck in 1936 [35]. Similar inertness to tantalum was noted at this time, but its poor mechanical properties made it fitter for neurosurgeons and plastic surgeons. Titanium [36] and its alloys appeared around 1947 and trial implants of the pure metal proved it very inert and corrosion-resistant. Specifications for the various metals and alloys were laid down by the American Committee on Fractures in 1947, and after 1950 there were few new developments.

The extensive literature on the reaction of tissues, especially bone, to the implantation of metals that accumulated during the 19th century has been reviewed by Georges Menegaux and Donatien Odiette [37] and by Venable and Stuck. Gazziotti [38], in 1923, and Arthur Adalbert Zierold, in 1924, reported animal experiments describing the reaction of bone to the implantation of a wide variety of metals. They concluded that while different metals produced varying degrees of reaction, none were inert. In 1932, Menegaux and Odiette of the Institute du Cancer in Paris began [36] their study of the cytotoxicity of metals. The results of their experiments were collected in an important monograph, *L'osteosynthese au point de vue biologique,* published in 1936 [36]. A major portion of their work was done with tissue cultures of fibroblasts from chicken embryos and human osteoblasts. Into these cultures they placed individual discs (1.5-mm in diameter) of 12 pure metals, eight alloys of aluminium, two alloys of magnesium, and 21 different types of steel. The discs of copper, magnesium, the alloys of magnesium, aluminium-bronze, and two of the steels gave evidence of a high degree of toxicity. Only the discs of gold, aluminium, lead, and three of the steels (V^2 A Extra, nickel, and Platinostainless) showed no toxicity. In other experiments, two discs of different metals were placed in tissue cultures together. In these cultures, the toxicity of a metal was neither enhanced nor inhibited by the presence of another, although they noted the presence of local electrolytic couples.

Menegaux and Odiette also studied the formation of salts of calcium and phosphorus in tissue culture and found that this was inhibited by all pure metals, alumnium alloys, and most steels except V^2 A, Inchal, and Platinostainless. It is interesting that there was no correlation between cytotoxicity and salt inhibition. In other experiments, metal discs were implanted subperiosteally and within the bones of rats, rabbits, and dogs.

On the basis of this work they reached the following conclusions: "1) *The tissue reaction to the metal is a general nonspecific one.* 2) *The use of metal implants in patients involves important problems of cytotoxicity. 3) It is the nature of the implants themselves that is responsible for* l'osteiten rarefiante *or* maladie metallique du Call *complications that accompany osteosynthesis.* 4) *Only gold, aluminium, lead, and the steels (V^2 A Extra, Nickel, and Platinostainles) showed no toxicity."*

Electrolytic activity of metallic implants and corrosion was another problem. That metals were not physiologically inactive in the body had been known since Galvani's discovery in 1779, but the physical basis of corrosion as an electrochemical process was first elucidated by Sir Humphrey Davy in the 1820s, followed by Michael Faraday, and the theory was refined by many other later works. In 1804, Bell of New York was using steel-tipped silver pins for wound closure and noted the galvanic corrosion that occurred, and in 1829 another American, Levert, experimented with gold, silver, lead and platinum implants in dogs and found platinum the least irritant of buried wire sutures. While Menegaux and Odiette published their monograph on the cytotoxicity of metals, Venable and Stuck [34] were beginning their experiments on the electrolytic activity of metallic implants. They implanted screws made from various metals into the tibiae of dogs and made the following observations: "1) *after a period of weeks, metallic ions could be found in the soft tissue around the screws.* 2) *There was evidence of migration of metallic ions of one metal to the region of a screw of another metal.* 3) *These migrations were related to the electromotive forces between the metals.* 4) *Metals that corroded rapidly produced the most damage to bone.* 5) *The application of a micro-ammeter to the screws demonstrated the presence of small electric currents."*

In vitro experiments followed in which "batteries" were constructed by immersing implants of different metals in Ringer's solution and measuring the current generated between them. As a result of their experiments, they believed that they had conclusively proved "that the cause of failure of previous metal appliances in bone surgery was due to electrolytic reactions about the appliances in the presence of blood serum." In their experiments, Stuck and Venable identified an alloy of cobalt (65 %), chromium (30 %), and molybdenum (5 %), later called Vitallium, as being totally inert and possessing some of the other properties desirable for the fabrication of devices for internal fixation. The work of Menegaux and Odiette on cytotoxicity and of Stuck and Venable on electrolytic reactions provided some understanding of certain types of implant failure and established some criteria for the choice of metals for implants [39, 40].

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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References

1. Severino MA (1653) Therapeuta neapolitanus, Naples (with a commentary by Thomas Bartholin)
2. de Garengeot J C (1723) Nouveau Traité des instruments de chirurgie les plus utiles, et de plusieurs nouvelles machines propres pour les maladies des os. Paris, Bienvenu
3. Evans PE (1983) Cerclage fixation of a fractured humerus in 1775: fact or fiction. Clin Orthop 174:138–142

4. Beauregard (1883) De la suture osseuse dans les fractures transversales de la rotule avec ecartement. Bull Mem Soc Chir Paris 9:804
5. Malgaigne JF (1847) Traité des fractures et des luxations. Paris
6. Berenger-Feraud LJB (1870) Traité de l'immobilisation directe des fragments osseux dans les fractures. Adrien Delahaye, Paris
7. Gourniou E, Berenger-Peraud LJB (1938) Medecine générale du service de santé de la marine. Arch Med Pharm Nav 128:297–312
8. Berenger-Feraud (1864) Des fractures en V au point de vue de leur gravite et de leur traitement. Henneuyer et Fils, Paris
9. Berenger-Feraud LJB (1864–65) De l'immobilisation directe des fragments dans les fractures compliquées. Bull Acad Med Paris 30: 83–87
10. Lister J (1867) On a new method of treating compound fracture, abscess, etc. Lancet 90(2291):91–120
11. Cooper S (1861) Treatment of fractured Patella by Malgaigne's Hooks. San Fran Med Press, pp 13–16
12. Lister J (1883) An address on the treatment of fracture of the Patella. Brit Med J 855
13. Hansmann (1886) Eine neue Methode der Fixierung der Fragmente bei cornplicirten Fracturen. Dtsch Ges Chir 15134–37
14. Tanner WE (1946) Sir W. Arbuthnot Lane: His life and work. Williams and Wilkins, Baltimore
15. Lane WA (1894) Some clinical observations on the principles involved in the surgery of fractures. Clin J 5:392–400
16. Lane WA (1893) On the advantage of the steel screws in the treatment of un united fractures. Lancet 2:1500–1501
17. Lane WA (1893–94) A method of treating simple oblique fractures of the 'tibia and fibula more efficient than those in common use. Trans Clin Soc London 27:167–75
18. Lane WA (1905) The operative treatment of fractures. Medical Publishing Co., London, 32–33
19. Lane WA (1907) Clinical remarks on the operative treatment of fractures. Brit Med J 110:37–38
20. Lambotte A (1907) L'intervention opératoire dans les fractures récentes et anciennes envisagée particulièrement au point de vue de l'osteo-synthèse. Lamertin, Brussels
21. von Baeyer H (1909) Cellular reactions to implants. Munchen med Wsch 56:2416
22. Lambotte A (1913) Chirurgie operatoire des fractures. Masson, Paris
23. Jones R (1912) Presidential address on the present position of treatment of fractures. Brit Med J2:1589–1594
24. Binnie JF et al (1922) Treatment of fractures: reports of the committee on fractures of the American Surgical Association for 1913, 1914, 1915, 1916, 1917, 1918, 1921. American Surgical Association
25. Sherman WO (1912) Vanadium steel bone plates and screws. SGO 14:629–3440
26. Sherman WO, Tait D (1914) Fractures near joints and fractures into joints. SGO 19:131–14l
27. Hazlett TL, Hummel WW (1957) Industrial medicine in Western Pennsylvania, 1850–1950. University of Pittsburgh Press, Pittsburgh
28. Peterson LT, Reeder OS (1950) Dual slotted plates in fixation of fractures of the femoral shaft. J Bone Joint Surg 32A:532–541
29. Flanagan JJ (1945) Instrument for accurate measurement of bone screws. J Bone Joint Surg 27:723
30. Gray RN (1928) Disability and cost of industrial fractures. J Bone Joint Surg 10:27–38
31. Brougham EJ, Eeke AC (1914) A preliminary report of treatment of fractures by fixation with animal bone plates and bone screws. SGO 18:637–640
32. Henderson MS (1920) The use of beef-bone screws in fractures and bone transplantation. JAMA 74:715–717
33. Leriche R, Policard A (1918) Recherches biologiques sur l'ostéosynthèse à la plaque de Lambotte. Bll Mem Soc Chir Paris 44:1145–1148
34. Zierold AA (1924) Reaction of bone to various metals. AMA Arch Surg 9:365–412
35. Venable CS, Stuck WG (1947) The internal fixation of fractures. Charles C Thomas, Springfield
36. Leventhal GS (1951) Titanium: a metal for surgery. J Bone Joint Surg 33A:473–474
37. Menegaux G, Odiette D (1936) L'ostéosynthèse au point de vue biologique. Masson, Paris, pp 164–65
38. Gazzotti LG (1923) La osteogenesi in rapporto all azione chimica cli alcuni metalli. Chir Org Mov 7:311–328
39. Jones L, Lieberman BA (1936) Interaction of bone and various metals. A Arch Surg 32:990–1006
40. Brettle J (1970) A survey of the literature on metallic surgical implants. Injury 2:26–39