5-1-1941

Development of internal fixation of fractures of the neck of the femur : with special emphasis on the action of metals in the body

Nicholas N. Bailey
University of Nebraska Medical Center

THE DEVELOPMENT OF INTERNAL FIXATION
OF
FRACTURES OF THE NECK OF THE FEMUR

with special emphasis on the action of metals in the body.

by

Nicholas E. Bailey

Senior Thesis

Presented to the College of Medicine,

University of Nebraska, Omaha

1941

Introduction

The treatment of fractures of the neck of the femur has always presented a difficult problem. Previous to this century, it was the one fracture in which poor results were consistent and mediocre results accepted gratefully. The treatment of this fracture by internal fixation has been a comparatively recent development. This method is acknowledged not to be perfect and absolute, but it has consistently given better results than previously and has certain definite advantages over the only other recognized method of treatment of this type of fracture - the Whitman method.

Most of the surgeons developing and using this technique have paid more attention to the apparatus and to the methods of application than to the type of metal of which the appliance is made. They even explain their failures upon these details without considering the reaction of the metals used in the body fluids. When discussing their apparatus many of them state that their particular pin, nail or screw is made of stainless steel. This is a loose term which covers a number of alloys of varied composition.

It is my opinion that attention must be given to the metals introduced into the body. It is the purpose of this paper to prove that internal fixation has quite definite advantages in certain circumstances and that if attention is paid to the action of the body fluids on the object introduced as well as on the type of fixation device and its method of introduction, many of the poor results of the method may be eliminated.

THE DEVELOPMENT OF INTERNAL FIXATION OF FRACTURES OF THE NECK OF THE FEMUR with special emphasis on the actions of metals in the body.

There are two distinct fractures of the neck of the femur. They occur in patients of quite different age groups, result from different causes, have different mechanics of production, require different treatment, and have a different prognosis.

The more common of the two fractures is that which goes through close to the head. It is well called the sub-capital or intracapsular. Its location may deprive the head of its blood supply from the capsule. The intertrochanteric fracture is less common, occurs well out at the base of the neck near the trochanter and runs into the shaft below the lesser trochanter. In most cases of this type, a small fragment carrying the lesser trochanter is pulled or split off.

The subcapital fracture is found in elderly people and is produced by a fall. The age of greatest incidence of this fracture is between fifty and sixty. The mechanical reasons for the increased number of fractures in the female are that normally the angle of the neck of the shaft is less than in males, there is more of a coxa vara and the neck is smaller and weaker.

Younger and stronger persons are the victims of the intertrochanteric fracture as well as older persons. A fall or a mixup with machinery or a motor car may be responsible.

In the subcapital fracture a direct blow on the great trochanter drives it inward snapping the neck and often driving the cortex of the neck into the cancellous bone of the head, producing impaction. In very old persons where the position is reasonably good, the impaction may be left undisturbed. In the intertrochanteric fracture a smashing blow shatters the upper end of the femur. There is also an associated factor of muscle pull responsible in part for the site of the fracture and for the shortening which occurs. Impaction never occurs, all the fragments are free and loose. The small third fragment carrying the lesser trochanter is important; it lies free in the muscle but is fastened by strong ligaments.

The signs and symptoms of both types are typical; the observer can tell at a glance that a fracture of the neck of the femur has taken place, but cannot tell which of the two types it is. Loss of function is complete, so that the patient lies on the ground. Shortening occurs as a result of the pull of the powerful thigh muscles. Gravity rotates the foot outward so that the foot lies flat on its outward side. Rarely may a patient with a strong impaction stand and walk for a short time with a subcapital fracture of the neck of the femur. X-ray confirms the diagnosis and determines the type of fracture present.

The subcapital fracture is reduced by internal rotation and abduction. The lever of the femur is useless in treating intertrochanteric fractures, and traction is the best means of reduction. Skeletal traction is preferable but skin traction is good. Abduction in this type of fracture accentuates the separation of the fragments.

Policard[57] says that bone is made up of a fibrillar stroma and calcareous protein substance laid down in the stroma. From the point of view of mechanics, the latter substance resists pressure, the fibrillar stroma resists tension.

In fractures that are well immobilized without displacement of the fragments, there is at first a fibrinous deposit between the ends of the fragments formed by blood and exudate from the fractured bone. By the third to fourth day, filaments of fibrin extend from one fragment to the other like a bridge; these filaments become connective tissue fibers which unite the two fragments (the connective tissue callus). On this framework the bone substance is laid down which ultimately forms the true callus and repairs the fracture. The formation of the true callus depends upon the anatomical formation of good connective-tissue callus. In fractures that are poorly reduced with displacement of the fragments, or in which there is considerable loss of substance, the connective tissue cannot easily form a bridge between the two fragments. Under the influence of many local factors these fibers extend in many different directions. If the mass of fibers is parrallel to the axis of the fractured bone, conditions are very favorable for good bony union; if perpendicular, new bone tissue may form, but it does not satisfactorily unite the fragments, and pseudoarthosis develops.

However even if the mechanical requirements of reduction and fixation are fully complied with, there is still a "nigger in the wood pile" so to speak. This has to do with the blood supply of the head of the femur. It has been shown that the blood supply of the head of the femur is in a large measure carried to it by the artery from the internal obturator vessel and finds its way beneath the cotyloid ligament to the ligamentum teres and along it to the bone. But unfortunately, in approximately 20-25% of adults, this blood supply is either lacking or is so minute that it fails to deliver enough blood to be of any use. Recently it has been determined that there is a very good supply of blood to the head coming up from the shaft and trochanteric region. The nearer the line of fracture is to the head, the poorer the blood supply. This explains why sub-capital fractures are more prone to non-union than those through the base of the neck and also explains the atrophic changes with flattening and distortion of the head in a certain percentage of cases following perfect reduction, fixation and even bony union. Such changes develop six months to a year after union and nothing can be done about it because there is no way to determine whether the blood supply through the ligamentum teres is present or not, or how adequte the supply from the shaft and capsule is. While it is true femoral heads without the supply from the ligamentum teres will unite to the neck of the femur when properly reduced and held in place, nevertheless such a faulty blood supply must account for a considerable percentage of non-unions. The prognosis in all fractures of the neck of the femur must therefore be guarded no matter how successful the reduction and fixation. It takes at least a year to determine whether or not atrophy of the head will occur.

The treatment of fractures of the neck of the femur has been divided into three eras by Ryan and Wheeler.[59] The first antedates the introduction of Whitmans method, the second is the era of Whitman and the third is the era of the Smith-Peterson nail.

Because fractures of the neck of the femur are most often found in elderly patients, the shock is unusually severe and subsequent recumbency favors the development of pulmonary congestion or hypostatic pneumonia. The prognosis is therefore not good and this is further complicated by the occasional break-down of mental faculties. We thus frequently have a patient who has obtained solid union but in the mean-time has become senile and helpless. In view of the foregoing, this fracture carries a high mortality, estimated by Henderson[30] to be as high as fifteen percent.

During the first era most of these fractures were treated by recumbency and traction. Not more than ten to fifteen percent of the cases obtained firm union without disability. Two titles of papers of this period illustrate the situation at that time. Gray[26] presented "a case proving the possibility of walking after fracture of the neck of the femur." Hunt[33] presented a case of fracture of the neck of the femur "completely within the capsule in a young man, apparently from a direct blow." He commented further on the patients "curious ability to walk after the injury." This was not an impacted fracture. Death occurred after some time from pelvic abscesses. In most cases first consideration had to be given to the prevention of complications such as pneumonia and decubitus. Nursing care was exacting and difficult and long periods of treatment were necessary.

Whitmans method was introduced in 1905. The fracture is reduced under anesthesia by traction, internal rotation and abduction to the limit, bringing the fractured surfaces into firm contact. In this position a spica cast is applied extending from the ribs down to the toes on the affected side and down to the knee on the opposite side. The cast is changed when necessary. Three months in plaster was was considered to be the minimum time by Whitman, and the greater number of these patients wore their spicas for six months or longer.

Moore[54] listed the disadvantages of conservative closed treatment of this fracture as follows:

A. Some type of anesthesia is required.

B. Statistics show a higher mortality.

C. A certain number will have a permanent disability.

D. A certain number will be miserable and uncomfortable in the immobilizing cast or apparatus.

E. Pressure sores may develop.

F. Prolonged immobilization or recumbency predisposes to atrophy of soft tissue and of bone with the possibility of absorption of the femoral neck and head, non-union or fibrous union, and various degrees of ankylosis of the joints of the lower extremity. A troublesome stiffness of the knee often follows removal of the cast which requires several weeks or months of physiotherapy to relieve.

G. Weight-bearing cannot be allowed for at least six months, is usually nine months or a year.

H. Prolonged hospital care with increased cost to the patient.

In spite of these disadvantages, the Whitman method definitely improved the treatment of these fractures, increased the percentage of unions as high as sixty percent. Colonna[14] believes the Whitman method should be used more extensively, particularly in general practice and in cases where hospital facilities for nailing are not present.

The principle of internal fixation had previously been used in the treatment of non-union and occasionally of fresh fractures.

Langenbeck[46] in 1855 was the first to use this method, and used it several times over a period of years. He used pegs of ivory or of silver. His results were better than those expected when using recumbency and traction, but this was before the period of antiseptic as well as the later aseptic period of surgery and he had a high percentage of infection and sequestration. Trendelenburg, Langenbeck's assistant and pupil ascribed his master's results to the lack of asepsis when writing in 1878, aseptic surgery then being introduced.

Trendelenburg[73] described in detail his modification of Langenbeck's operation. He made a small incision over the greater trochanter, abducted and rotated the leg so as to place the fragments in apposition and drilled a hole in the upper end of the femur and into the head of the femur. Into this hole he drove a peg of ivory or of silver. If the peg was loose or did not hold, the fragments together, he placed threads upon the peg and screwed it into the drill hole. He made it a practice to remove the peg at the end of fourteen days after healing had progressed well. He remarked that he usually had only a little infection and an occasional small sequestrum. He recommended its use in young adults but said it was also applicable to the elderly. He cited the example of a man, age 51, on whom he performed this operation. He did not say how long it had been since the operation but said that the patient was in the best of health.

Dyas and Aries[20] state that in this country Dr. Charles Davison operated upon fractures of the neck of the femur in 1894, using an ivory peg to hold the fragments together. He later used autogenous fibular transplants with success.

Ivory screws, pegs, nails, metallic screws, square pegs in round holes and every other conceivable non-absorbable material has been tried. According to Dyas and Aries[20] two or more foreign bodies were required to prevent rotation, and this placed a lot of material in the small capital fragment which was already suffering from a lack of sufficient blood.

The present era began when Smith-Peterson[64] published his first article on internal fixation of fractures of the neck of the femur using the three-flanged nail.

The reintroduction of the method by Smith-Peterson[64] was aided by the development of aseptic technique in orthopedic surgery and the development of relatively non-corrosive metals. The aseptic technique had been quite well established for a number of years, but the automotive industry was the principal incentive for the development of stainless steels and non-corrosive alloys.

Smith-Peterson's[64] paper wherein he advocated nailing the fragments with a triple flanged nail was not published until he had a sufficient number of proved good results to show that internal fixation was feasible.

Smith-Peterson's first nail was of stainless steel, was solid with three flanges. When the method was first introduced, the Smith-Peterson technique involved a large incision, opening of the hip joint and introduction of the nail under direct vision. This meant an extensive dissection which required at least one and a half hours even in the best of hands, but necessary in inserting a nail unless some means of determining the line of insertion was available. Various instruments and gadgets have been devised for this purpose, but a practical and accurate method is the threading and insertion of a cannulated nail or lag screw on a guide wire, the position of which has been previously determined by A-P and lateral X-ray films.

Wescott[80] of Virginia advocated closed reduction, followed by nailing through a subtrochanteric incision using protractors and A-P films to guide the insertion of the nail. Johansson[35] of Sweden introduced a centrally-cannulated nail which was threaded over a Kirschner wire introduced under X-ray control by means of a complex precision instrument. King[38] of Australia, independent of Johansson proposed the use of a centrally-cannulated nail, two wire guides being introduced under the fluoroscope.

Smith-Peterson[63] was interested in the fact that all three of these men, Wescott[80], Johansson[35], and King[38] depended upon X-ray control. He felt that they were all influenced by Leonard and George[47] who introduced the curved cassette for the purpose of taking lateral X-rays of the hip. He felt that even though the curved cassette has been shown to be unnecessary, that credit goes to them for calling attention to the value of lateral X-rays of the hip in treatment of these fractures. Lateral X-rays have demonstrated that certain of the so-called impacted fractures are not impacted but distinctly in malposition and are even overlapped.

Smith-Peterson[63] states that the nail still seems the ideal means of fixation; that it displaces a minimum of bone and effectively prevents motion in all planes. However, many substitutes have appeared in the form of wires, pins, screws and bolts. They apparently immobilized the fracture and good results were obtained and introduction was said to be more simple. Smith-Peterson[65] modified his nail by placing threads on the head to facilitate placing and particularly in removing the nail. The present Smith-Peterson nail is better than its predecessors in that it provides a large contact surface for gripping bone with small bulk so that very little damage and necrosis of bone trabeculae result. It holds fragments rigidly so that the percentage of cases in which union occurs has been increased.

The technical difficulties are such as to place it beyond the scope of those who see only occasional cases and who may not have at hand the necessary facilities for its application. Any good cabinet-maker, according to Couch[16] should be able to place a dowel where he wants it. There are, however, a certain number of cases where the nail must be removed because it has missed its mark, because reduction is imperfect or because it has slipped.

There is very little use, according to Couch[16], in using the Smith-Peterson nail in intertrochanteric fractures. Reduction by traction is perfect, the patient is able to move in bed quite freely with the traction apparatus and the cortex along the outer face of the trochanter is thin and does not hold the nail well.

Moore[54] reported 96% successful end results in a series of 25 cases treated by this method of three pins over a period of two and a half years. He used three pins threaded on the end; nuts were placed on the threads and used to control the depth to which the pins were driven. The points were directed toward the point the inguinal ligament and the femoral artery cross. A stainless steel wire was placed around the nuts on the ends of the pins. As the pins formed a pyramid, the locking of the base with the wire acted to keep the pins from being extruded.

Plummer[56] used all three main types of internal fixation, Kirschner wires, Moore pins and the Smith-Peterson nail. He concluded that the wires are inadequate mechanically, dangerously prone to wander, often penetrating some viscus and should be abandoned. Plummer used Moore pins and concluded that they produced good results, but that they fail to fill the mechanical requirements. He states that only one of the nails can be located in the cortex, neck and head so as to resist effectively the shearing force of muscle pull and weight-bearing. While the combined surface areas of the three pins is approximately 20% less than the usual Smith-Peterson nail, the area is so divided as to be much less efficient in all three mechanical factors, namely resistance to shearing force, strain, rotary movement of one fragment on the other, and of less importance, any possible draft effect which the fastening might have. Gröndahl[27] states that the Smith-Peterson nail is superior to other apparatus and is without the danger of migration which is found with the use of multiple Kirschner wires. The chief disadvantage of the Smith-Peterson nail, according to Ryan and Wheeler[59] lies in the mechanical difficulty of proper introduction. Smith-Peterson[65] does not believe any procedure is simple, but he believes that the mechanical principle of the nail is sound, more sound than that of any of the substitutes.

Kulowski and Luck[42] examined pathologically the upper end of the femur which had been treated with a Smith-Peterson nail two weeks previously, the patient having died of other causes. They commented on the rapid progress of the healing process, the minimal evidence of trauma from the nail, the minimal evidence of reaction of the tissue to the nail, and the absence of significant osteoporosis as well as the presence of new bone on the trabecular surfaces.

Kulowski and Luck[42] conclude that any method of internal fixation which meets the mechanical requirements; good reduction, elimination of shearing stress and the fracture site, and adequate fixation of fragments which are and remain in a good state of nutrition will result in bony union.

The use of metals in the repair and reconstruction of various tissues has engaged the interest of surgeons for hundreds of years. The earliest record found is the report of Petronius in 1565 of his use of gold plates to fill the gap in cleft palates. Langenbeck[46] in 1855 was the first to report a technique for the nailing of fractures of the neck of the femur. His method fell into disrepute with other surgeons because of the little-understood, but generally disreputable behavior of metals in tissues, as well as because of the infections encountered. Lane[44] in 1896 began to use steel plates and screws and German silver plates for the internal fixation of fractures. Before long, however, it was found that in a couple of weeks these plates were rejected by the bone with the accompaniment of much local swelling, pain, tenderness and discolored sterile pus.

The long and unhappy history of metals in surgery has been a consistent record of necrosis of bone and soft tissues, interference with bone growth and repair, and delayed union, mal-union and non-union.

Silver, gold, lead, tin, aluminum, copper, iron, steel nickel, bronze, German silver, and many other metals have been used with the same unsatisfactory and often disastrous results. Only in the last few years with the development of fairly non-irritating alloys has the internal fixation of fractures returned to favor.

Doisy[85] in 1894 experimented with the then new metal, aluminum, and found that it produced irritation of the bone like any other foreign body. He concluded, however, that its salts were of weak toxicity and therefore the metal was safe to use.

Algave[84] in 1911 used silver wire in his experiments and stated that he was able to recover a chloride of silver which was harmful to the repair of the bone.

Hey-Groves[87] in 1913 claimed that nickel-plated steel did not produce any irritating effects on the tissues and that magnesium produced destruction of bone if it was in contact with the cortex alone instead of in the medullary cavity. These experiments were quite rudimentary and were not checked by microscopic examination.

LeFort[88] in 1918 observed that the body tissues reacted differently to bullets of different metals in spite of the absence of infection or other extraneous causes. He felt that the variations could possibly be explained by the action of the different metals used in alloys.

LeRiche and Policard[89] in 1918 made elaborate studies of the physiology of bone and constant necrosis under the Lane plates used to immobilize fractures. After excluding injury, pressure, and infection as possible causes, they still found evidence of destruction which they assumed was due to the chemical nature of the fluids about the metals.

Zierold[82] in 1924 reported an intensive study of the reaction of bone to a number of pure metals and of alloys. He used 63 dogs and placed metallic implants in ribs, tibias and femurs. The tissues about the pieces of copper showed much discoloration and marked overgrowth of bone. About the gold, silver and aluminum there was an excessive subperiosteal growth, but gold, aluminum and stellite were readily tolerated by bone and became encapsulated early. Lead caused an indifferent reaction. Silver and lead, which are more easily corroded caused more connective tissue reaction. Zinc was corroded easily and interfered markedly with bone regeneration. Zierold[82] concluded that steel and iron definitely inhibit bone regeneration and that stellite caused the least reaction of the metals he used. Stellite is an alloy containing 58 per cent bobalt, 35 percent chromium, 4 percent tungsten and small amount of iron and carbon.

Jones and Lieberman[36] in 1936 have shown that the varying bone reactions to metals results from the use of impure metals or from alloys of unknown composition. They experimented with small tacks of various types of stainless steels, which were placed in holes in the femurs of dogs. As the tacks were removed they were weighed to compare their weights before and after introduction into the body. Tacks of the same metals were soaked in Ringers solution and kept at body temperature for thirty days to serve as controls. It was noted that there was much soft tissue reaction about all the screws which were used. This reaction seemed to them to be related to corrosion. They decided that chrome-nickel stainless steel was the best metal to use in bone because corrosion of this metal was minimal.

Verbrugge[79] in 1937 contradicted the work of Hey-Groves[87] who had said magnesium was not a suitable metal as he found gas formation, periosteal reaction and even abscess formation. In his work Verbrugge[79] drove pieces of magnesium through the tibia of dogs and killed them periodically. His conclusions were that magnesium is entirely resorbable in the tissues, that it preserves its rigidity long enough to allow abundant callus formation, that the resorption is complete in less than a year, that there is no excessive periosteal reaction, and that the tolerance of the adjacent soft tissue for the metal was excellent.

Because of the wide difference of opinion resulting from former experiments and because of certain unpredictable clinical reactions following the use of metals in the body, Venable, Stuck and Beach[77] assumed that there was another variable factor not yet considered. Their experiments were made with the view of determining whether electrolysis was that variable. In a large series of dogs each radius of each dog was used, the right was fractured and the fracture repaired with two screws of dissimilar metals. In the other radius, two screws were placed without fracturing it. They were sutured, fixed in plaster and sacrificed at intervals. In several cases they found evidence of a migration of ions from one metal to the other, in one animal the transference of ions had involved two separate processes: a deposit of the copper ions from a brass screw onto the chromium of the chromium-plated screw and a deposit of chromium ions from this latter screw onto the zinc of the brass screw, all in accord with the order of electromotive force of metals.

Venable, Stuck and Beach[77] concluded that their experiments show that the various chemical, tissue and bone reactions are changes due to electrolysis when two metals are used in couples in the same bone and explain why there has been so much tissue disturbance locally and such variable results clinically.

They explain that in clinical orthopedic work, electric couples are created by the use of plates, bands wires, washers, lock nuts, etc. in conjunction with screws or other appliances so that two different pieces of metal are used in the same bone. This makes Ohm's law effective, i.e. that an electric current is directly proportionate to resistance. They give an example of the usual Lane plate obtained from surgical supply houses which is nickel-plated or chromium-plated steel in which the iron is exposed at the holes into which screws of plain steel, chromium-plated steel, stainless steel or galvanized steel are placed. Immediately an electrolytic action is set up at the point of contact of each screw with the metal plate and the current is carried by the plate to each other screw. This calls forth a progressive proliferative reaction in the tissues that is protective against the current. A necrosis and destruction of bone cells also takes place and an accumulation of discolored exudate, which contains elements of the metals in solution, forms about the metals and enters the circulation. In two weeks these screws, which were placed in the bone with force, may be picked out with the fingers.

Bothe, Beaton and Davenport[83] used multiple metallic implants in the same bone with the idea of accentuating electrolytic action. They concluded that the implants still showed differences in electrical potential after seven months, that the potentials in themselves were not closely related to bone reaction except that the more soluble metals were more strongly positive in the electromotive series. They also studied two metals not previously studied, manganese and titanium. Manganese was highly reactive and promoted heavy callus formation. Titanium was fully as well tolerated as vitallium and stainless steel with the advantage that bone tends to grow in contact with it. They expressed the idea that the reaction of bone to metals was based on chemical and not electrical phenomena. It was established however that the corrosion of the metal itself is on an electrolytic basis.

Lippman[48] used low tempered tool steel in the form of corkscrew bolts in the internal fixation of fractures of the neck of the femur and stated that it proved entirely satisfactory. However he acknowledged that after the bolt had been in place for a while a small area of rarefaction appeared. He stated that X-rays showed that the screws did not change position in the hip and that healing was always solid before rarefaction was observed.

The disappointing results were, and still are due to the electro-chemical phenomena known as corrosion of the metal, which introduces soluble and more or less toxic salts into the body fluids, according to Burke.[7]

The corrosion of a metal is an oxidation process; that is a process in which electrons are removed from the atoms of the metal. If corrosion is to occur, an oxidizing agent, a substance eager to remove electrons from the metal, must be present. Such an agent, namely oxygen itself, is circulating in equilibrium with hemoglobin in living tissue.

Oxidizing agents other than oxygen are also present, engaging in the long succession of oxidizing reactions occurring in metabolism, but oxygen itself is probably the most important agent in corrosion processes.

Since metals are conductors of electrons, the two steps involved in corrosion, namely the loss of an electron from an atom of the metal and the acquisition of an electron by the oxidizing agent need not, and in general will not occur at the same point on the surface of the metal. Even if the metal involved consists of a single element, for example pure iron, there will be regions of the surface which differ slightly from one another in structure and their tendency to acquire a positive charge. These regions which show the greatest tendency to become positively charged are called anodic regions; at these regions on the surface, the loss of electrons from atoms of metals occurs most readily. The regions which show the least tendency to become positively charged are called cathodic regions; at these points on the surface the donation of electrons to the oxidizing agent occurs most readily. The corrosion of a piece of pure iron may then be represented by the following scheme:

Anodic reaction: $2Fe$ (metal) $> 2Fe^{++}$(ion) $+$ 4 electrons.
Cathodic reaction: $O_2 + 4H^+$ (ion) $>$ 4 electrons $+ 2H_2O$.

The electrons are transferred from the anodic regions to the cathodic regions by conduction through the metal. The H^{+} ions which engage in the cathodic reactions are supplied by the tissue fluid in which the reaction occurs, the more acid the medium, the more readily the cathodic reaction occurs. If the positive charges formed at the anodic region are confined to the surface of the metal, it becomes increasingly difficult for the oxidizing agent to extract electrons from the metal, since the electrons are attracted by a positive charge. If, however, the positive ions formed at the anodic region diffuse away into the surrounding tissue, corrosion goes on unhindered.

The positive ions liberated into the tissue may react with other substances present in the tissue with more or less harmful results. In the case of iron, the oxidation of the metal is carried to the ferric stage: the ferric ions (Fe^{+++}) produced react with water to precipitate hydrated ferric oxide or common iron rust. The hydrogen ions so produced may then diffuse to the cathodic region to make the deficiency of hydrogen ions caused by the occurrence of the cathodic reaction. The localization of the anodic and cathodic reactions in different regions of the surface accounts for the pitted appearance in a piece of corroded metal.

Some metals produce ions which form no insoluble products by reaction with the tissue fluid. The corrosion of zinc, for instance, will introduce soluble and toxic zinc ions into the tissues.

If the metallic object is an alloy of dissimilar metallic elements or consists of one metal plated on another, the process of corrosion is essentially the same but is more complicated in some details. The metal component which is more active chemically, i.e., which occupies a higher position in the electromotive series will more readily become anodic, since great metallic activity is synonymous with small reluctance to form positive ions. This circumstance may lead an alloy or imperfectly plated metallic object to corrode more readily than a pure metal. The corrosion of a piece of galvanized iron, which consists of iron covered with a thin layer of zinc, will proceed initially just like the corrosion of pure zinc. As soon as any flaws develop in the coating, however the exposed iron, which is less active than the zinc becomes almost exclusively cathodic, and takes upon itself almost the entire labor of supplying electrons to the oxidizing agent. The entire surface of the zinc iable concentration of soluble compounds. Unfortunately even quite inert metals may, in the presence of a reasonable concentration of oxygen, form soluble complex compounds which are sufficiently stable so that in time a toxic concentration of these elements can be built up. The only hope of preventing corrosion lies therefore in using a metal which, although it would be corroded considerably if the metal were to reach equilibrium with its surroundings, corrodes at a negligible rate. It should be borne in mind that the rate at which a reaction proceeds and the extent to which it will proceed if given an infinite time are entirely different factors.

Many metals are able to resist corrosion successfully under mild conditions because of the formation of a thin film of an insoluble compound, usually an oxide, on the surface. If this film is sufficiently compact, continuous and adherent to the surface of the metal, it will inhibit corrosion almost completely. The formation of the film prevents metal ions from migrating from the surface of the metal and also prevents the transfer of electrons from the metal to the oxidizing agent. The formation of such films is believed to be the reason for the ability of stainless steels, aluminum, and the familiar chromium trim on automobiles to resist corrosion under mild corroding conditions. If the film is soluble in the medium in which the metal finds itself, however, corrosion will occur.

Immersion in the living tissue is a very severe test of the ability of a metal to resist corrosion, because of the variety of substances which are continuously circulating about the metal and with which the protecting film may form soluble compounds.

Caution must be used in interpreting corrosion results. The conditions of testing are necessarily accelerated by the use of high temperatures or of concentrated solution so that results would be obtained in a reasonable time. Any extrapolation from these data over to service conditions should be done by those very familiar with the corrosion resistant characteristics of the various stainless steels.

Data regarding corrosion following the placing of the metal in Ringers solution is certainly not an adequate expression of the reaction of the metal within the body fluids.

Electrolysis of metals is accelerated by certain physical forces. Thus if a plain carpenter's nail is bent and placed beside a similar straight nail in saline, the bent nail will corrode more rapidly and in an electrolyte than similar articles of the same alloy which are highly polished.

Raagaard[90] and Harris[86] of Toronto were of the opinion that corrosion of nails and surrounding bone was directly affected by the finish of the nails. They inferred this by pointing out that the more rapid disintegration of metals took place in screw threads or near the ends of nails. Venable and Stuck[78] also observed this but they observed that corrosion will not take at any point in a piece of non-electrolytic alloy. They declared that when an alloy is non-electrolytic there are no anodic or cathodic points where currents are initiated.

Masmonteil[49] has stated that metals suitable for bone surgery must be biologically inert, i.e., free of organisms; mechanically inert, i.e., placed in a proper position on the bone; chemically inert, contain no injurious substances; and physically inert, or free of electrolytic activity.

Alloys of various composition have been recommended as suitable for bone surgery and their proponents have stated that they caused no erosion of bone, but tests for electrolytic activity have seldom been performed according to Venable and Stuck[78]. Stainless steel (Moore), monel metal (Henderson), chrome steel (Carothers), chrome-nickel steel (Plummer)[56], low-tempered tool steel (Lippman)[48] and many other have been utilized in the body with varying success. Venable and Stuck[78] found that many of these alloys were sufficiently electro-active to produce a marked current when connected with a micrammeter.

Venable, Stuck and Beach[77] demonstrated the presence of chromium in the livers of dogs that had only small chromium plated screws in their legs. They stressed the importance of this finding because of the extreme toxicity of chromium. They recognized, in retrospect, patients in which devices plated with chromium had been introduced became much more ill than had been anticipated.

During the last decade rapid strides have been made by the steel industry in the perfection of new alloys for the benefit of those industries demanding materials to withstand excessive heat and corrosion. These requirements have been met generally with the chromium and chromium-nickel stainless steels. The degree of resistance to corrosion depends upon the amount of alloying elements present.

The simplest of these alloys consists of 12% chromium. Various others contain this element in increasing amounts. The most popular and most effective is an alloy of iron with 18% chromium and 8% or more of nickel, this being an austentitic type of metal. Throughout the technical literature this is known as the 18-8 stainless steel.

These stainless steel are highly resistant to acids such as nitric and to many others except sulphuric and hydrochloric. They are resistant to oxidation and scaling at high temperatures. They can be rolled, drawn, formed or worked into almost any desired shape or apparatus.

There is a definite difference between the type of corrosive attack of various chemical solutions. Acid chloride and acid sulphate solutions in this type of stainless steel usually give rise to a general attack. Ferric chloride solutions are macroscopic pitting agents; nitric acid gives rise to a pitting attack on microscopic scale in addition to a general attack.

The reaction of acid chloride solution upon the steel is particularly sensitive to the amount of cold work of the metal. In this type of alloy, uniform, highly polished and buffed surfaces are inherently more corrosion resistant than annealed, heavily cold-rolled or non-uniformly cold worked surfaces.

Uhlig and Wulff[74] conclude that there is no protective oxide coating on stainless steels.[74] They quoted G.P. Thompson as saying that if present at all it is less than seven Angstroms in thickness. They state that the surface of the alloy has the same composition as the interior. The concept of Uhlig and Wulff[74] is that in the pure state, the passive alloys and the transition and pre-transition elements such as chromium and nickel are passive. They are more passive if they are in contact with an oxidizing agent or electron-absorbing agent or an adsorbed layer of axygen atoms, not the oxide. They lose passivity if charged in some way with hydrogen, which tends to dissolve in the metal lattice as protons and electrons. Dissolved hydrogen is considered to fill in electronic energy levels of the lattice normally responsible, when unoccuped, for passivity. By removing hydrogen by exposure to an oxidizing medium, the metal changes from an active to a passive state.

It has been pointed out by Harris[86] and Jones and Lieberman[36] that the terms "rustless steel" and "stainless steel" are used to describe many of these ferrous alloys of widely dissimilar composition. They state further that most surgeons are not qualified to determine the suitability of a proposed alloy for use in the body and are therefore at the mercy of instrument salesmen or must depend upon the recommendations of surgical catalogs.

The metal which has been used most successfully in surgery thus far is vitallium, an alloy of cobalt 65%, chromium 30%, and molybdenum 5%. This alloy, which was introduced into surgical work by Venable, Stuck, and Beach[77] is quite resistant to corrosion in the tissues, is hard, non-malleable and at first not strong enough. Venable and Stuck[78] in May 1940 believed that it had been sufficiently toughened to be comparable in strength to any of the steels. They knew of no case in which a vitallium hip nail had cracked or broken in the hip. They state that a single vitallium nail will support 500 pounds in a power tester without bending.

According to Venable and Stuck[78] it produces no appreciable current on the microammeter; it is not affected by submersion in saline and is electrically passive in body fluids. They state that appliances of vitallium can be used in the body with perfect safety and can remain in the bone indefinitely without fear of the occurrence of late complications. They state that vitallium screws and nails do not loosen in bone; no fluid forms around them, and normal body healing processes are in no way delayed by the presence of the metal.

It has several disadvantages: first, even a small amount of corrosion introduces into the tissues soluble and highly toxic chromium salts whose cumulative action over a period of time may be injurious to the patient. It is for this reason that Dr. Stuck[77] has suggested that an effort be made to develop a similar alloy which would offer the same resistance to corrosion and not be too brittle, possibly using vanadium instead of chromium. Vitallium cannot be machined; every appliance must be cast or ground. For this reason a large supply of various sizes of nails, screws, plates and cups must be kept on hand. Finally it cannot be drawn into wire, and is expensive. Lippman[48] used vitallium but deplored the inability to clip off the excess. He also called attention to the flaws found in cast objects, vitallium of necessity being cast.

Burke[7] has been experimenting with tantulum and is convinced that it is a useful metal for surgical purposes. This little known metal is element 73 of the periodic table. It has the advantage of being a single elementary substance, and is resistant to corrosion, probably because of the formation of an extremely thin, transparent, but strong and tenacious oxide film. The oxide is insoluble in almost all acids but is soluble in concentrated sulphuric and phosphoric acids. The metal is used in the chemical industry where great resistance to corrosion and chemical attack is required. Burke[7] says that tantalum is inert to salts, dry, wet or dissolved, except those which hydrolyze to strong alkalies. It is inert to weak alkalies and dilute solutions of strong alkalies. It is completely unaffected by hydrochloric acid, aqua regia, organic acids, salts, alcohols, ketones, aldehydes, and esters. It is totally inert to wet or dry chlorine, bromine or iodine at temperatures below 150 C. The only acids which will attack tantalum according to Burke, are hydrofluoric, sulphuric and phosphoric, the latter two only in concentrated solution at high temperatures.

The mechanical properties of tantulum are impressive according to Burke.[7] The metal is comparable to steel in its strength, toughness, and workability. The tensile strength of unannealed tantulum is comparable to that of cold rolled steel; annealed tantalum is as strong as annealed steel. Tantalum can be drawn, stamped and formed into complicated shapes. It may be machined with ordinary steel tools if carbon tetrachloride is used as a cutting compound.

The metal can also be hardened by a special process to any degree in the range of 150 to 600 Brinell. (The hardness of aluminum bronze is about 200 Brinell, that of chromium manganese steel about 400 Brinell).

Single tantalum screws and two bone plates were inserted by Burke[7] into the fractured and unfractured tibia and femurs of six dogs and rabbits, and removed at intervals ranging from three weeks to three months. In each case the screws were held so tightly by the bone that considerable force was necessary to unscrew them. There was no macroscopic, microscopic, or X-ray evidence of bone or soft tissue irritation. The normal process of healing was the only reaction noted by Burke and his coworkers.

The main objection to tantalum at present is that it is expensive. At present it costs sixty dollars a pound. If the metal comes into general surgical use, the prices would probably be lower. The wire is comparatively inexpensive.

The advantages of treatment by internal fixation are so dramatic that they only need be enumerated. No cast, splint or traction is required after operation. The patient may sit up in bed or be lifted into a chair the next day, thus immediately reducing the risk of hypostatic pneumonia and decubitus. The patient is encouraged to move the hip joint actively and is allowed to be on crutches as soon as his strength permits. Thus firm apposition of fragments and early function increase the chance of union by preventing atrophy of the head and neck of the femur. The stiffness of the knee does not develop in patients treated by this method. Hospital and nursing costs are greatly reduced since the patient may be allowed to go home as soon as the wound has healed.

The procedure has been simplified since it was first introduced but it still cannot be considered an office procedure. It is necessary that the surgeon has had experience in the technique and that the operation be done in a hospital adequately equipped as far as instruments and personnel is concerned.

The present consensus of opinion is that the Smith-Peterson nail as modified by Johansson and King is the most effective in fixing the fragments and allowing the patient to be up and about early and with the utmost safety.

Those using the method must be acquainted with the properties of the various metals available and be governed accordingly when choosing the material of which the nail is fashioned. At the present time, it would seem that if the nail were to remain only two or three months in a younger individual, a stainless steel nail of the 18-8 alloy would be acceptable. If a longer period of fixation is anticipated the vitallium nail would be acceptable. It appears as if tantalum would be the metal to be used if adaptability and indefinite fixation time are considered. The presence of other metals bathed in the body fluids must be avoided; two dissimilar metals should not be in the body at the same time even though at some distance apart. Theoretically the universal use of one single element which is markedly corrosion resistant would prevent the action between separate fixation devices. As presented by Burke,[7] tantalum seems to fill all the requirements for a suitable metal to be used in the body, and increased demand for it would tend to stimulate cheaper methods of production.

B I B L I O G R A P H Y .

1. ALBEE, H. Treatment of fractures of the neck of the femur. Am. J. Orth. Surg. 16:493 1918.

2. ARNOLD, I.A. The different methods of internal fixation of fractures of the neck of the femur. South. Med. J. 25:971 1932

3. BECK, CARL Textbook of fractures. Pages 27, 69, 70. Philadelphia W.B.Saunders & Co. 1900.

4. BELL, W.L. The use of metallic fixation. Ann. Surg. 70:754 1919.

5. BILLET, H. Perfect toleramce of osseous tissues of metals. Bull. Soc. Belge D'Orth. Quoted by Burke (7).

6. BREWSTER, R. Internal fixation of fractures of the neck of the femur. Am. J. Surg. 30:420 1935.

7. BURKE, G.L. Corrosion of metals in tissue. Can. Med. Ass. J. 43:125 1940.

8. CAMPBELL, W. Fractures in and about the neck of the femur. Minn. Med. J. 15:654 1932.

9. CAMPBELL, W. Internal fixation of fractures of the neck of the femur. Ann. Surg. 105:939 1937.

10. CAMPBELL, W., ORR, H., & OSGOOD, R. Report of commission. J. Bone & Joint Surg. 12:966 1930.

11. CARRELL, W.B. End results of 100 fractures treated by internal fixation. J. Bone & Joint Surg. 18:408 1936.

12. CLEARY, E.W. & MORRISON, G.M. Lockbolt fixation of fractures. J. Bone & Joint Surg. 22:125 1940.

13. COLE, W. Internal fixation. Proc. Minn. Acad. Med. October 12, 1938.

14. COLONNA, P.C. Treatment of ununited fracture of the neck of the femur. South. Med. J. 32:65 1939.

15. CONN, H.R. Internal fixation of fractures. J. Bone & Joint Surg. 29:261 1931.

16. COUCH, J.H. The two fractures of the neck of the femur. Can. Med. Ass. J. 43:31 1940.

17. DELBERT, P. Screw treatment of fracture of neck of femur. Bull. Acad. de Med. Paris 87:533 1921.

18. DICKSON, R. Treatment of ununited fractures of femur. Surg. Clin. N. Am. 39:1235 1939.

19. DOEGE, K. Metallic bone plates. Wis. Med. J. 17:10 1918.

20. DYAS, F., & ARIES, L. Treatment of fracture of the neck of the femur. Surg. Gyn. & O.B. 63: 499 1936.

21. EDINGTON, J. Temporary plating of fractures. Brit. Med. J. 2:1214 1922.

22. FRIEND, H. Causes of suppuration around metallic foreign body. J.A.M.A. 87:1599 1926.

23. GAENSLEN, R. Fractures of the neck of the femur. J.A.M.A. 107:105 1936.

24. GILLETTE, A.J. Mechanical and surgical treatment of fractures of the neck of the femur. Northwest Lancet St. Paul. 18:307 1898.

25. GODOY-MOREIRA, S. A special stud bolt screw. J. Bone & Joint Surg. 22:683 1940.

26. GRAY, R. Case report. Med. Times. & Gaz. London. Given in Surg. Gen. Index. 2:220 1861.

27. GRÖNDAHL, N.B. Fracture of the neck of the femur. Surg. Gyn. & O.B. 64:1073 1937.

28. HENDERSON, M.F. Editorial. Surg. Gyn. & O.B. 64: Nov. 1937.

29. HENDERSON, M.F. Internal fixation of fractures of the neck of the femur. Ann. Surg. 106:107 1938.

30. HENDERSON, M.F. Internal fixation. Arch. Surg. 35:419 1937.

31. HENDERSON, M.F. Fractures of the neck of the femur. Papers of Mayo Clinic 1842 1936.

32. HOTZ, H. Screws for subcapital fractures of neck of femur. Schweiz. med. Woch. 55:490 1925.

33. HUNT, W. Case report. Phila. Med. Times 1872. Given in Surg. Gen. Index.

34. JONAS, A.K. Indications for and results with metal bone plates. Nebr. Med. J. 3:329. 1918.

35. JOHANSSON, S. Operative treatment and result in fracture of the neck of the femur. Brit. Med. J. 2:361 1937.

36. JONES, L. & LIEBERMAN, B.A. Interaction of bone and various metals. Arch. Surg. 32:990 1936.

37. KIDNER, J. Wiring fractures. J. Orth. Surg. 1:549 1919.

38. KING, T. Closed operation on fractured femur. Brit. J. Surg. 26:721 1939.

39. KING, T. Recent intracapsular fractures of the femur. Med. J. Australia 1:5 1934.

40. KNICKERBOCKER, H.J. Removable lag bolts. N.Y.State J. Med. 31:1438 1931.

41. KNOWLES, R. Fractures of the neck of the femur. Wis. Med. J. 35:106 1936.

42. KULOWSKI, J. & LUCK, J.V. Microscopic changes after internal fixation of transcervical fracture of neck of femur. J. Bone & Joint Surg. 23:17 1941.

43. KURLANDER, H. Rustless steel wire. J. Bone & Joint Surg. 28:191 1930.

44. LANE, SIR W.A. Operative treatment of fractures. 2nd. Ed. London 1914.

45. LANGENBECK, R. von Verhandl. Deutsch. Gesell. f. Chir. Berlin 7:40 1878.

46. LANGENBECK, R. von Schiefgehilte fractur. Deutsche Klinik. Berlin 7:315 1855.

47. LEONARD, R.O. & GEORGE, A.W. Lateral Films of the hip. Am. J. Roentg. 32:402 1932.

48. LIPPMAN, R. Corkscrew bolt in treatment of fracture of the neck of the femur. J. Bone & Joint Surg. 37:735 1939.

49. MASMONTEIL, F. Metals for bone surgery. Presse Med. 61:234 1935.

50. MATCHETT, F. The conception, past and present, of the use of foreign materials as an aid in bone repair. Senior thesis Univ. of Nebr. Coll. Med. 1932.

51. MATHEWSON, C. Misuse of skeletal traction. Am. J. Surg. 47:408 1940.

52. MERELLO, M. & ALLENDE, C.I. Screw fixation of fractures of the neck of the femur. Rev. Asoc. Med. Argent. 34:839 abstracted in J.A.M.A. 78:549 1922.

53. MORRISON, E.E. Use of bone plates and nails. J. Kansas Med. Soc. 23:57 1923.

54. MOORE, A. Treatment of fracture of neck of femur. Surg. Gyn. & O.B. 64:420 1937.

55. NICOLAYSEN, J. Lidt om diagnosen og Behandlungen af frac. colli femoris. Nord. Med. Ark. Stockholm 8:1 1897.

56. PLUMMER, W.W. Internal fixation in fresh fractures of the neck of the femur. J. Bone and Joint Surg. 36:97 1938.

57. POLICARD, A. Histological processes taking part in bone repair. Presse med. Paris 48:409 1940.

58. POLLACK, G.A. Pathologic and related changes in head of femur following ununited fracture. Proc. Mayo Clinic 683 1939.

59. RYAN, G & WHEELER, D. Treatment of fractures of the neck of the femur. Can. Med. Ass. J. 43:231 1940.

60. SCHAUFFLER, R. Complications following internal fixation. Surg. Clin. N. Am. 3:1631 1923.

61. SELIG, S. Objections to the use of Kirschner wire. J. Bone & Joint Surg. 21: 182 1939.

62. SHERMAN, W.O. Vanadium steel bone plates and screws. Surg. Gyn. and O.B. 14:629 1912.

63. SMITH-PETERSON, M.N. Treatment of fracture of neck of femur. Surg. Gyn. and O.B. 64: 287 1937

64. SMITH-PETERSON, M.N. Intra capsular fractures of the femur. Arch. Surg. 23:715 1931

65. SMITH-PETERSON, M.N. Arthoplasty. J. Bone and Joint Surg. 2:269 1939

66. SMITH, J. and ODAR, R. Stainless steels Iron Age 143;43 1939

67 STUCK, W.C. Electrolytic destruction of bone caused by metal fixation devices. J. Bone and Joint Surg. 19:107 1937

68. SWETT, P.P. Nailing in ununited fracture of neck of femur. Am. J. Orth. Surg. 15: 521 1917

69. TELSON, D.R. and RANSOHOFF, N.S. Treatment of fracture of neck of femur by axial fixation with steel wires. J. Bone and Joint Surg. 17:727 1935

70. THORNTON, R. and SANDISON, N. Recognition of modern treatment of fracture of neck of femur. South. Med. J. 29:456 1936

71. THOMAS, T. Fixation by a wood screw. Am. J. Surg. 35:292 1936

72. TOMBAUGH, R. Lanes plates J. Iowa Med. Soc. 6:251 1916

73. TRENDELENBURG, K. Eine seltene Fractur des Femur mit Pseudo-arthrose. Verhand. der deutsch. Gesell. fur Chir. 7:91 1878 Berlin.

74. UHLIG, H.H. and WULF, J. Stainless steels. Iron Age. 143:43 1939

75. United States Dept. Commerce, Bureau of Standards. Commercial Standard CS 37-31

76. VENABLE, C.H. Osteosynthesis in presence of metals. South. Med. J. 31:501 1938

77. VENABLE, C.H., STUCK, W.G., and BEACH, A. Electrolysis in metal bone pegs. Ann. Surg. 105;917 1937

78. VENABLE, C.H. & STUCK, W.G. Vitallium nails used in fractures of the hip. Surg. Gyn., and O.B. 70:964 1940

79. VERBRUGGE, J. Magnesium and bone repair. Presse Med. 63:813 1937

80. WESCOTT, H.H. Method of internal fixation of fracture of neck of femur. J. Bone and Joint Surg. 16:372 1934

81. WHITMER, V.W. Stainless steel welding. J. Am. Welding Soc. Sept. 37

82. ZIEROLD, A.A. Reaction of bone to various metals. Arch. Surg. 9:365 1924

83. BOTHE. R., BEATON. L., & DAVENPORT. H. Reaction of bone to multiple metallic implants. Surg. Gyn. and O.B. 7:598 1940

84. ALGAVE Reported at the 24th congres de chir. 1911. quoted by Venable et al 77.

85. DOIZY. H. De la prothese interne au moyen d'attelles d'aluminum dans le traitment des pseudoarthroses. Paris 1894 Quoted by Venable et al 77.

86. HARRIS, R.I. Experiences with internal fixation of fresh fractures of the neck of the femur. Jour. Bone & Joint Surg. 20:114 1938

87. HEY-GROVES Brit. Journal Surg. 1:438 1918.

88. LEFORT Bull. Soc. de Chir. 44:733 1918 Quoted by Venable et al 77.

89, LERICHE & POLICARD. Bull. Soc. de Chir. 44: 1145 1918 Quoted by Venable et al ~~88~~ (77)

90. RAAGARD O. Some comments on complications occasioned by rustless surgical nails. Acta chir. Scandinav. 82:1939