lished in 1937, two more were added in 1939, and other centres will no doubt be considered. Obvious advantages are smaller attendance allowing for more careful work and more frequent service to the local doctor and the community. The field for monthly clinics is, however, limited in Manitoba because for adequate attendance these centres need to be in the larger towns surrounded by a fairly dense rural population. For the less populated districts it seems the annual clinic offers the best answer to our own problem at an unusually low cost.

In conclusion, we look upon travelling clinics in Manitoba as an important phase in our anti-tuberculosis campaign. Besides the activities already outlined, travelling clinics are a powerful factor in keeping the public and medical profession tuberculosis-conscious. From the public standpoint a large clinic outfit becomes somewhat of a personality within the province, and, like a circus, is always news when it comes to town. The local doctor occupies a key position in our program. We appreciate the rôle he plays and attempt to maintain it by encouraging his attendance at clinics, emphasizing that we come as consultants to examine his patients, and by sending reports to him and not to those examined. We need his co-operation and support to make our clinics a success, and in return we bring to him a necessary service which has also a definite educational value.

THE CORROSION OF METALS IN TISSUES; AND AN INTRODUCTION TO TANTALUM

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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 I have found, in a none too diligent search, is the report of Petronius in 1565 of his use of gold plates to fill the gap in cleft palates. Langenbeck in 1850 was the first to report a technique for the nailing of fractures of the femoral neck. His method fell into disrepute because of the little understood but generally disreputable behaviour of metals in tissues. Lane, in about 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 discoloured 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 favour.

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.

THE THEORY OF CORROSION

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 hæmoglobin in living tissue. Oxidizing agents other than oxygen are also present, engaging the long succession of oxidation reactions occurring in metabolism, but the following discussion will be presented as if oxygen were the only oxidizing agent involved, since it is probably the most important one 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 in their tendency to acquire a positive charge. Those regions which show the greatest tendency to become positively charged are called anodic regions; at these points on the surface the loss of electrons from atoms of the metal occurs most readily. The regions which show the least tendency to become positively charged are called cathodic regions; at these points of 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 —> $2\ H_2O$.

The electrons are transferred from the anodic regions to the cathodic regions by conduction through the metal. The hydrogen 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 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 (common iron rust), thus:

$$Fe^{+++} + 3H_2O \longrightarrow \underline{Fe(OH)_3} + 3H^+.$$

The hydrogen ions so produced may then diffuse to the cathodic region to make up 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 tissue.

If the metallic object is an alloy of dissimilar metallic elements, or consists of one metal plated with 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 rapidly 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 labour of supplying electrons to the oxidizing agent. The entire surface of the remaining zinc is now anodic, and the corrosion of the zinc proceeds much more rapidly than would be the case if the zinc were alone. Until most of the zinc is gone, however, the iron corrodes to only a negligible extent. The cathodic reaction is of course the same as before; the anodic reaction may be represented as:

$$Zn \longrightarrow Zn^{++} \text{ (ion)} + 2 \text{ electrons.}$$

The corrosion of zinc in this case is accelerated not only because the whole area of the zinc is anodic but also because the difference between the electrochemical properties of iron and zinc is much greater than that between two regions on the surface of a single metal. This effect exists also in alloys but is less important than in plated objects or in objects made up of pieces of different metals in contact with one another, since the constituents of an alloy are so closely mixed that the development of large areas which are exclusively anodic is unlikely.

THE PROBLEM IN SURGERY

The difficulty confronting the surgeon is that of finding a metal which will not corrode in the tissue, since corrosion may cause necrosis of the tissue not only by liberating toxic metallic ions but also by secondary effects such as the building up of local deviations from the normal hydrogen-ion concentration. The solution of the problem would be the use of a metal so inert that no oxidizing agent available in the tissues could cause the liberation of any appreciable 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 dependent on entirely different factors.

Many metals are able to resist corrosion successfully under mild corroding 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 closely 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.

The metal which has been most successfully used in surgery thus far is vitallium, an alloy of chromium, cobalt and nickel. This alloy, which was introduced into surgical work by Venable, Stuck and Beach, is quite resistant to corrosion in the tissues. It has, however, 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 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 by using vanadium instead of chromium. Vitallium moreover cannot be machined; every appliance must be cast or ground. For this reason a large supply of various sizes of nails, screws, plates, cups, etc., must be kept on hand. Finally, it cannot be drawn into wire and is expensive.

TANTALUM IN SURGERY

We have been experimenting with tantalum for the past year and a half, and have become convinced that it should be a useful metal for surgical purposes. This little known metal is the 73rd element of the periodic table. It has the advantage of being a single elementary substance and is very 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 chemical industry where great resistance to corrosion and chemical attack is required. Tantalum is inert to salts, dry, wet, or dissolved, except those which hydrolyse 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 are hydrofluoric, sulphuric and phosphoric, the latter two only in concentrated solution at high temperatures. The following table shows its life-expectancy when exposed to the action of the last two acids.

The mechanical properties of tantalum are also impressive. The metal is comparable to steel in its strength, toughness and workability.

Substance	*Time*	*Temperature Deg. C.*	*Percentage loss in weight per month*	*Depth of corrosion cm. per month x 10^{-5}*	*Estimated life based on 50% corrosion loss*
Phosphoric Acid H_3PO_4 Conc.	3 mos.	145	0.014	0.099	870 yrs.
Sulphuric Acid H_2SO_4 Conc.	3 mos.	147	0.013	0.09	955 yrs.

The tensile strength of unannealed tantalum is comparable to that of cold rolled steel; annealed tantalum is as strong as annealed steel. Fine tantalum wire is similar in strength to steel wire of the same gauge. Annealed "dead soft" it can readily be tied in minute strong knots.

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 150 to 600 Brinell. (The hardness of aluminum bronze is about 200 Brinell, that of chromium-manganese steel about 450).

To summarize its virtues: it is uniquely resistant to corrosion, is as strong as steel, and can be stamped, machined and drawn into wire.

From the foregoing brief and somewhat simplified discussion of corrosion, and from the consideration of the properties of the metal, one would judge that in a nearly neutral system such as the human body there should be no foreign body reaction to tantalum. It should be absolutely inert. This judgment has been borne out in our experience.

Pieces of the metal were kept in Ringer's solution at body temperature for a period of three months. In these elementary tests of corrosion resistance there was no change in the weight or appearance of the metal or in the appearance of the solution. Single tantalum screws and two bone plates were inserted into the fractured and unfractured tibiæ and femora of six dogs and rabbits and removed at periods ranging from three weeks to three months. In each case the screws were held so tightly by the bone that considerable effort was necessary to unscrew them. There was no macroscopic, microscopic, or x-ray evidence of bone or soft tissue irritation. The normal progress of healing was the only reaction detected.

To date, tantalum wire has been used as a skin suture in 34 patients. It has been left *in situ* in several cases for as long as six weeks, and one length of tantalum wire has been used in 5 successive patients. It has proved to be an incomparable skin suture. A few weeks after removal of the suture it is difficult and often impossible to detect where it passed through the skin. These closures are in striking contrast with the customary blobs of scar tissue that line the edges of a wound.

In 11 of these cases tantalum has been used as a subcutaneous suture; in 3 cases as a Bunnell tendon suture; in one case each a fractured patella and a fractured medial condyle of the humerus was wired; and two plates have been used in the internal fixation of fractures. The last two we intend to leave *in situ* for two years before removal. So far we have been unable to unearth the slightest sign of objection on the part of any tissue to the presence of tantalum.

We wish this, however, to be regarded as a preliminary report. We have projects under way on the use of tantalum as arthroplasty cups, as nails for femoral neck and intertrochanteric fractures, as screws to be placed in the jaw and capped by teeth to replace individual missing teeth, and for other dental appliances.

The interest and co-operation of a number of large orthopædic clinics has been secured in the further evaluation of this metal and the detailed consideration of a considerable number and variety of cases will form the basis of a later report.

We should add that tantalum is expensive. At present it costs $60.00 a pound. Appliances supplied to us cost for example: a 3/4" screw $1.50; a 3½" bone plate $5.00; a 1½" bone plate $2.75. These of course had to be made to order, one at a time, by hand. If the metal comes into general surgical use the prices would probably be lower. The wire is comparatively inexpensive.

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