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ON THE HEALING OF ASEPTIC BONE CAVITIES BY IMPLANTATION OF ANTISEPTIC DECALCIFIED BONE.

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The antiseptic treatment of wounds as now almost universally practised constitutes the greatest triumph of modern surgery. Since this treatment has become developed to its present state of perfection primary union is no longer the exception, but the rule. The failure to obtain healing by first intention of an intentional wound made by the knife of the surgeon through aseptic tissues, or of a recent accidental wound, in which parts of the same anatomical structure can be approximated and coaptation uninterruptedly maintained, must be looked upon as an evidence of a faulty technique or want of proper care on the part of the surgeon or his assistants in carrying out the principles of antiseptic surgery. Primary union in the sense in which this expression should be now used means the restoration of injured or lost parts without suppuration. It is a purely reparative process in which all the newly formed tissues are utilized in permanently cementing together divided parts or in restoring tissues lost by injury or disease. If a definitive union or repair is accomplished without suppuration, it must be called primary union whether this result has been obtained with or without visible granulation tissue.

An ideal primary union is one where the surface and deep parts can be brought together and held in perfect approximation until in a few days, by interposition of new living tissue between the divided structures,

the interrupted anatomical continuities have become permanently restored and the suspended physiological functions established. Practically such a result is not often obtainable. Even the most improved methods of approximation and coaptation frequently fail in securing such accurate apposition of similar tissues as to enable organic union to take place in such a short space of time and accomplished by such a small amount of reparative material. Under most circumstances spaces are left here and there between the surfaces of the wound which are first occupied by blood or serum and later by granulation tissue, which in the course of time is transformed into cicatricial tissue and by its contraction unites or brings in closer contact the divided tissues.

The time required for the definitive healing of a wound, other things being equal, will therefore depend largely upon the accuracy with which coaptation can be effected and maintained. In wounds with considerable loss of tissue, and in the healing of cavities with rigid, unyielding walls where coaptation of surfaces which it is the intention to unite, for physical reasons is rendered impossible, we have to rely upon the process of granulation in effecting repair and in restoring interrupted continuities. Under the old treatment the healing of wounds by secondary intention was often prolonged for an indefinite period of time because under the influence of pus microbes or their ptomaines the embryonal cells of which the granulation tissue is composed were transformed into pus corpuscles, and thus the reparative process was delayed until the infective process had exhausted itself, as it were, or until the granulation tissue was in a condition to resist successfully the deleterious effect of pus microbes or their products.

The most signal success of the antiseptic treatment has been obtained in the repair of parts where healing has to be accomplished by the formation of an extensive mass of granulation tissue. If an aseptic condition is maintained throughout, all of the granulations are transformed into tissue of a higher type and extensive defects are healed in a few weeks under a single dressing. Primary healing of an empty large cavity with unyielding walls, even without suppuration, requires often weeks and months, and not infrequently is but incompletely accomplished, as the granulations find no temporary support, and from the absence of such support the process comes to a standstill, while epidermization takes place on its surface *pari passu* with the disappearance of the temporary bloodvessels in the deeper parts which are undergoing cicatrization. When the healing process is finally completed it is at the expense of a considerable loss of substance. Such difficulties are almost invariably met with in the treatment of bone cavities.

I purpose to describe a new method of treatment which I have found exceedingly useful in overcoming the obstacles to favorable and rapid healing by granulation in such cases. Before giving a description of

this method I will call attention to a number of attempts made in the same direction during the past.

A few years ago Dr. Neuber, then assistant to Professor von Esmarch, of Kiel, introduced a method which was intended to secure a speedy definitive healing of the wound without aiming at reproduction of the tissues destroyed by the disease or removed by the operation. It consisted in fully exposing a tuberculous depot in bone or an osteomyelitic deposit, after thorough removal of the products of inflammation with spoon, gouge, or chisel, and chiselling away the margins of the cavity sufficiently to permit the soft parts to be turned inward, thus covering the entire surface of the denuded bone. The cavity was thoroughly disinfected before the flaps were implanted. The flaps were fastened with bone nails. In case the cavity was limited, and, as is so often the case near a joint, the skin flap was made in such a manner that the base was directed toward the joint. In diffuse osteomyelitis of the long bones a gutter was chiselled out and the flaps on each side turned inward in such a manner that their margins came in contact in the bottom of the gutter. Two great objections can be raised against this method:

1. It requires the removal of an unnecessary amount of healthy bone in order to enable implantation of the skin flaps.

2. As the result of tension from fixation of flaps, pressure on the part of the dressings, and more particularly on account of a serious diminution of the vascular supply of tissues predisposed by antecedent disease, gangrene of the flaps has frequently occurred.

I gave this method a fair trial in a number of cases, but I never obtained an ideal result—that is, primary union between flaps and between flaps and the subjacent bone. In a number of cases gangrene of some portion of the margins of the flaps occurred, leaving defects which required a long time to become repaired by a slow process of granulation, cicatrization, and epidermization. This method has a legitimate sphere of usefulness and application in cases of superficial osteomyelitis followed by necrosis, but should never be employed if the disease is centrally located, requiring in its operative treatment the formation of a deep gutter. The next idea that presented itself was to utilize a blood-clot for the purpose of expediting the definitive healing of bone cavities. Years ago Lister observed that under the antiseptic dressings in aseptic wounds coagula between the surfaces of the wound did not undergo putrefactive or degenerative changes, but as he believed, and asserted, became supplied with bloodvessels and were organized. A few weeks after the operation or accident which inflicted the wound he saw that the blood-clot had undergone vascularization and presented other evidences of organization.

In 1876 Lesser visited Lister's wards and made a special study of the organization of blood-clots in aseptic wounds, and reported the results of

his observations in the *Deutsche Zeitschrift f. Chirurgie*, vol. iii. Neuber, as early as 1879, after operations for necrosis, allowed the cavity to fill with blood with the expectation that the same favorable conditions could be secured for the blood-clot by thorough antisepsis as in recent wounds, but the results in these cases were so unsatisfactory that he soon abandoned the idea.

In the admirable paper of Professor von Volkmann, read at the London meeting of the International Medical Congress, special attention was called to the part taken in the healing process of the blood-clot between the fragments in compound fractures. At the end of six weeks he found at the site previously occupied by the coagulum living vascular tissue. Watson Cheyne gives a full description of the organization of blood-clots in recent wounds in his work on *Antiseptic Surgery*.

T. B. Hamilton (*Journal of Anatomy and Physiology*, vol. xiii., 1879; *Edinburgh Medical Journal*, November, 1881, p. 385) substituted for the blood-clot aseptic sponge, as he found that this substance was promptly removed by absorption in aseptic granulating wounds. Sponge-grafting was for a time quite extensively resorted to in hastening the process of repair of hollow wounds in soft parts, but, to my knowledge, was seldom practised after operations on bone.

In a paper read at the meeting of the German Congress of Surgeons in 1886 ("Ueber Heilung von Wunden unter dem feuchten Blutschorf") Schede described what he deemed a new method of treating wounds where accurate coaptation of the parts could not be secured. Schede's method consists in a careful conservation of the blood-coagulum combined with the completion of the healing process under a moist blood-crust. For instance, in operating on a long bone for necrosis, osteomyelitis, or any other lesion centrally located requiring in the removal of the pathological product the formation of a cavity, he renders the part bloodless by applying an Esmarch's constrictor on the proximal side, and, after having removed the dead bone or diseased tissue, he disinfects the cavity thoroughly and then sutures the soft parts in such a manner that a space is left open at a point corresponding to the summit of the cavity. This insures complete filling of the cavity with blood after the removal of Esmarch's bandage. No drainage-tube is introduced. The wound is covered with a strip of protective silk, over which is applied a copious absorbent antiseptic compress. The bandage for retaining this dressing is not firmly applied, in order that a sufficient amount of bleeding may take place to fill the cavity. The protective silk prevents the drying up of the exposed portion of the clot and secures at the surface of the wound the formation of the moist blood-crust, upon the presence of which so much stress is laid by the author for the subsequent favorable and rapid healing in the depth of the wound.

Schede's experience with this method of treatment has been exceedingly favorable. Small cavities in bone he has healed completely in from twelve to fourteen days, while large cavities required from three to six weeks. In some instances this treatment proved a failure even in his hands, and in these cases the unfavorable result could sometimes be traced to an inadequate hemorrhage, the cavity filling only partly with blood. When imperfect filling of the cavity with blood was found the cause of failure of the entire cavity closing under one dressing, the healing was found to have proceeded only as far as the coagulum reached, and the balance of the cavity closed later by the usual tedious process of granulation from the wound surfaces and the upper surface of the granulation mass. In operations for tuberculous affections of bone he found not infrequently a recurrence of the disease in the cicatrix of the wound which had healed by primary union. In severe cases of general tuberculosis the so-called organization of the coagulum did not take place. The author insists that only clean and aseptic wounds are adapted to this form of treatment. In cases where it is impossible to secure asepticity of the bone cavity, or where the primary treatment failed, he waits until suppuration has ceased, and then, by scratching the granulation surfaces, obtains enough blood to fill the cavity and then applies the same dressing as in recent cases. A number of cases are reported to show that this plan has proved successful.

In the discussion which followed the reading of this paper, von Bergmann reiterated his views that he had so strongly expressed on a previous occasion, that in the treatment of all wounds it should be the surgeon's imperative duty to effect complete hæmostasis, as the accumulation of blood in wounds renders antiseptic treatment more difficult and less efficient. Volkmann stated that he did not believe in the transmutation of blood as a tissue, as extravasated blood is removed by absorption and gradual substitution on the part of the granulations. He favors moderate compression of the wound, so as to prevent unnecessary loss of blood, as the escape of blood beyond what is necessary to fill the minute spaces between the wound surfaces is unnecessary and injurious.

At the meeting of the German Congress of Surgeons last year, Lauenstein ("Zur Heilung der Wunden unter dem feuchten Blutschorf") read a paper on Schede's treatment of wounds, wherein he compared the healing under a moist blood-crust to the healing under a dry crust as described by John Hunter. He regards the superficial portion of the coagulum in the light of an occlusive dressing. During two years he resorted to this treatment in seventy-four cases, with the result that in sixty-four it proved successful, and proved a failure only in ten. A cavity in the head of the tibia the size of a walnut, caused by the removal of a tuberculous deposit, he found completely healed under one dressing after three weeks. In four operations for extensive necrosis

the treatment failed. In one case coagulation of the blood in the cavity failed to take place, a circumstance which he attributed to imperfect antisepsis, and yet the final result was favorable.

Schleich has studied this subject experimentally, and, as the result of his observations, he claims that the aseptic coagulum must be considered as a porous organic substance which, by compression, occlusion, and by diminishing wound secretion, places the cavity in which it is located in a more favorable condition for healing.

Landerer asserts that extravasated blood takes no active part in the healing of a wound, and he attributes Schede's success more to faultless antiseptic measures than the presence of the coagulated blood. In the light of modern research, it must be conceded that, when blood escapes from vessels into the tissues or accumulates between the surfaces of a wound, it has lost its physiological functions and has become a foreign substance. If the blood and its surroundings remain in an aseptic condition, it is removed sooner or later by absorption on the part of the granulations which take its place by substitution. The blood-coagulum in Schede's treatment of wounds serves as a temporary nidus for the granulations which permeate it from all directions, thus placing the cavity in a condition capable of becoming filled with a mass of active granulation tissue and a reticulum of bloodvessels, which furnish ample nutrition for the growth and development of the new tissue while the blood is removed by the encroaching granulations. A hollow, empty space, particularly in a bone, where its walls are firm and immovable, presents the most unfavorable conditions for healing by the process of granulation. As the granulations and vessels have no support toward the centre of the cavity, the defect is repaired in a slow and unsatisfactory manner. The deeper portions of the granulation tissue undergo transformation into tissue of a higher type, and, while this change is undergoing perfection, the vascular supply toward the surface is diminished by disappearance of many of the new temporary vessels, and the conditions for the growth and development of the granulations are correspondingly impaired. A coagulum, as long as it remains aseptic and sufficiently firm, furnishes an admirable support for the granulations and delicate new bloodvessels, and constitutes the direct means by which the entire cavity is filled with active and exceedingly vascular granulation tissue in a remarkably short time. Schede's treatment marks a decided advancement in the treatment of bone cavities, but is open to the following objections:

1. It implies an unnecessary loss of blood, which, in some cases at least, must be detrimental to the patient. The loss of from two to eight ounces of blood required to fill a bone cavity in an anæmic child or a marantic adult might result in a collapse which a careful hæmostasis would have prevented.

2. The blood-coagulum is at best but an aseptic substance. Careful hæmostasis is one of the essential requirements of good surgery. Perfect asepsis is not always attainable. Recent experiments have demonstrated the fact that pathogenic microbes are more likely to become the cause of disease when they come in contact with substances that serve the purpose of a culture soil. Coagulated and fluid blood, at the temperature of the body, furnish an admirable culture substance for a number of the most dangerous varieties of pathogenic microbes. In case perfect asepsis is not obtained, the coagulum of necessity must become a source of danger.

3. The bleeding may not be sufficient in quantity to fill the entire cavity. In such cases the prompt and early production of embryonal tissue will be limited to the size of the coagulum, and the balance of the cavity has to close by the ordinary slow process of granulation and cicatrization.

4. The extravasated blood may fail to undergo coagulation, and fluid blood would not form a good medium for the rapid diffusion of the granulations throughout the entire cavity.

It occurred to me that if in the healing of bone cavities an absorbable, firm, antiseptic substance could be substituted for the coagulum, it would present a number of advantages not obtainable by Schede's method. The substance which I selected for my experimental and practical work was thoroughly decalcified bone, rendered not only completely aseptic, but *thoroughly antiseptic* by keeping it immersed for a considerable length of time in sublimate alcohol (1 : 500). Before the removal of Esmarch's bandage, and after thorough disinfection of the cavity, its walls and the bone chips are lightly dusted with iodoform before implantation is made. The wound is completely closed, with the exception of the lower angle, where a capillary drain of a few threads of catgut is introduced. I shall first describe the details and the results of my experimental work. All of the experiments were made under strict antiseptic precautions. The part to be operated on was shaved, thoroughly washed with warm water and potash soap, and disinfected with a 1 : 2000 solution of sublimate. The same solution was used for irrigation during the operation. The bone was exposed by a straight incision, and after reflecting the soft parts the bone defect was made either with a trephine or chisel, the former instrument being used mostly in the operations on the skull and the latter in excavating the long bones. The operations on the extremities were rendered bloodless by using elastic constriction. In all instances the cavity was filled by a piece of well-decalcified antiseptic bone, which was so cut as to fit the cavity as accurately as possible. In some cases the bone plate, after implanting it in a trephine opening, was fastened in its place by driving two or more small aseptic steel nails into the margins of the opening. Before

implantation the cavity and the bone plate were dusted with iodoform. The external wound was completely closed, without making any provision for drainage. Where the fact is mentioned the plates were perforated with numerous small openings, so as to enable the granulations to penetrate it more readily and thus expedite the process of absorption and substitution.

I. Implantations of Decalcified Bone-disks after Trephining of the Skull.

Exp. 1.—Dog, weight fifteen and a half pounds. Operation Nov. 13, 1887. A disk of bone was removed from each side of the longitudinal sinus with a trephine three-quarters of an inch in diameter at a point corresponding to the junction of the anterior with the middle portion of the cranial vault. From the right opening a profuse hemorrhage occurred, which had to be arrested by plugging it firmly with iodoform gauze, which was left in the wound. A circular piece of decalcified bone, corresponding in size to the trephine opening, rendered strongly antiseptic by several days' submersion in a 1 : 500 solution of sublimate in alcohol and by sprinkling it with iodoform, was implanted. The thickness of the disk corresponded to the diameter of the cranial bones at the site of operation. The piece of bone was driven into the opening with a hammer, so as to secure fixation by pressure. The antiseptic dressing was retained by plaster-of-Paris bandage, which was made to encircle the entire head. Primary healing of wound. No untoward symptoms. Dog killed forty-four days after operation. Brain adherent to dura on left side. Left trephine opening closed by a firm cicatricial mass, corresponding in thickness to the cranial bones. External margins of this opening little, if any, bevelled. Cicatrix not translucent. The opening in the skull considerably diminished in size by new bone deposited upon its margins. Right opening appears somewhat enlarged externally by absorption of margins, giving it a strongly bevelled appearance. The centre of the thin membrane closing the defect in the skull translucent, and at this point slight bulging in outward direction.

Exp. 2.—Old dog, weight fifteen and a half pounds. Operation same as in the first experiment. Right trephine opening plugged with a circular decalcified bone-disk. From the left opening profuse hemorrhage, caused by injury of a large vein contributory to the longitudinal sinus. As the bleeding did not yield to compression, it was finally arrested by irrigation with hot water. Wound healed by primary union. Animal killed at the end of three months. Examination of the skull showed on the right side that the opening in the bone was considerably diminished in size, the balance of the defect being closed by a firm circular membrane seven-sixteenths of an inch in diameter, presenting in the centre and toward the left side a translucent point. Left opening about the same, only that the defect in the bone was somewhat larger, the membrane somewhat thinner, and the surfaces not as smooth as on the opposite side.

Exp. 3.—Young dog, weight seventy and a half pounds. In this case two disks of bone were removed on each side of the middle line, and the two openings transformed into an oblong defect, one and a half by three-quarters of an inch, by the use of a chisel. On the left side free hemorrhage from a small artery in the dura mater, which was arrested by plugging the opening firmly with a plate of decalcified bone corresponding in shape and size to the piece of bone removed. Slight suppuration from the surfaces of the wounds. Killed four weeks after operation. Right opening not diminished in size; closed by a thin translucent membrane; external margins strongly bevelled. Left opening closed by new bone, with the exception of a space one-third of an inch in diameter, which is occupied by a thick, firm membrane.

Exp. 4.—Old dog, weight fifty-nine pounds. On the left side of the median line of the cranial vault a portion of the bone, one and a half

inches in length and three-quarters of an inch in width, was removed with trephine and chisel, and closed with an accurately fitting plate of decalcified bone. Hemorrhage was very profuse from the large veins of the diploë, but was promptly arrested by the bone implantation. Slight suppuration in the superficial portion of the wound. Animal killed seventy-five days after operation. The opening in the skull was found greatly diminished in size by the formation of new bone from the margins. The defect was closed by an oval, thick, and firm membrane one and three-eighths inches in length and three-eighths of an inch in width. Margins of opening in the bone bevelled at the expense of the external table.

Exp. 5.—Old dog, weight forty-four pounds. Three disks of bone were removed with the trephine on the left side and parallel to the sagittal suture. These openings were transformed with the chisel into an oblong space one and one-fifth inches long and three-quarters of an inch wide. The hemorrhage from the bone was very profuse and could only be arrested by the implantation of a closely fitting decalcified plate of bone. The animal was stupid and disinclined to move for four or five days. At the end of the first week the dog appeared as lively as before the operation. The skin at the site of operation was raised, and underneath it a fluctuating swelling could be felt. The sutures were removed, and on opening the posterior angle of the wound about two fluidrachms of a sero-sanguinolent fluid escaped. Two weeks after the operation it was ascertained that the dog had become deaf, otherwise the recovery was complete. The deafness remained at the time the animal was killed, seventy-two days after the operation. The anterior portion of the defect in the skull was closed by a firm membrane, to which the brain was adherent over a surface the size of a split pea. The defect in the bone measured one and one-fifth of an inch in length, posteriorly two-fifths of an inch in width, while anteriorly the bony margins were only distant one-third of an inch. Membrane nearly as thick as the surrounding bone. These appearances indicate that the defect in the skull had been considerably diminished by ossification proceeding from the margins of the opening.

Exp. 6.—Young dog, weight fourteen and one-third pounds. One disk of bone removed with trephine from left side well under the temporal muscle. Opening plugged with a disk of decalcified bone. Primary union of wound. Animal killed seventy-two days after operation. Osseous defect greatly reduced in size, as the circular thick membrane which was present in the centre of the opening measured only seven-sixteenths of an inch in diameter.

Exp. 7.—Old dog, weight fifty pounds. On the left side, some distance from the sagittal suture and parallel with it, three disks of bone were removed with the trephine, and the two anterior openings made into an oblong space with the chisel. In the posterior opening the inner table was left *in situ*, on account of its being directly over the lateral sinus. The hemorrhage, which was quite profuse, was arrested by means of hot-water (120° F.) irrigation. In this instance the decalcified bone-plate was fixed in its place by driving an aseptic steel nail into the margins of the opening at either extremity. Considerable swelling of soft parts at the time the sutures were removed; later, a slight discharge from wound. The animal never showed any signs of cerebral disturbance, and was killed eight weeks after operation. In the centre of the cicatrix the brain was found adherent over a limited surface. Nails not found, and are supposed to have escaped through the wound at the time it was discharging. Posterior third of defect closed by bone which presented a rough appearance externally and was nearly as thick as the surrounding bone. Anterior two-thirds of the opening occupied by a thick membrane, five-eighths of an inch in length, which was traversed by spurs of bone from opposite sides, so that at some points the new bone seems to bridge the defect completely. This specimen presents a beautiful illustration of advanced substitution of the decalcified bone-plate by osteoplastic material from the margins of the opening.

Exp. 8.—Young dog, weight fifteen pounds. In this instance the trephine was applied too near the frontal sinus, and on removing the disk of bone

it was found that this structure had been opened. The opening in the sinus was plugged with a piece of iodoform sponge, and another disk of bone was removed immediately behind the first opening, and the intervening projections of bone removed with the chisel. The plate of decalcified bone was fastened with two small steel nails. Some suppuration from the anterior angle of the incision followed, and the nails undoubtedly escaped through this opening. As suppuration continued, the bone-plate was removed and the wound was thoroughly disinfected, and a new plate introduced two weeks after the operation. After this the wound healed rapidly. Animal killed one hundred and four days after operation. At the anterior angle of the wound a small opening led directly into the frontal sinus. The oval defect in the bone was occupied by a dense, firm membrane one inch long and half an inch wide, presenting two translucent points near its centre.

Exp. 9.—Old dog, weight thirty-nine and a half pounds. With the chisel a portion of the cranial vault, one and four-fifths inches in length and three-quarters of an inch in width, was removed on the left side of the skull some distance from the sagittal suture. The hemorrhage from the dura mater was profuse, and resisted the ordinary hæmostatic measures, but was finally controlled by an application of the actual cautery. The plate of decalcified bone which was implanted was perforated by numerous small openings, for the purpose of facilitating the penetration of granulation tissue. The plate was fastened in its place by two steel nails. No unfavorable symptoms. Animal killed thirty-two days after operation. The opening in the skull was found closed by a thick, firm cicatrix, corresponding in thickness to the diameter of the cranial bones. Formation of new bone had diminished the opening to a space one and three-tenths of an inch long and three-eighths of an inch wide. Nails encysted, the one in the anterior margin being firmly and immovably fixed in the bone, while the one in the posterior margin had become somewhat loosened.

Exp. 10.—Dog, weight twenty-two pounds. An area of bone, one and three-quarters of an inch in length and eighty-six one-hundredths of an inch in width, was removed with trephine and chisel on the left side of the skull. A dural vessel which bled profusely was ligated with fine silk. A perforated plate of decalcified bone was implanted. The operation was followed by suppuration and suppurative pachymeningitis, which resulted in a subdural abscess and perforation into the longitudinal sinus, in consequence of which the dog died eight days after operation. The specimen is preserved for the purpose of showing the method of implantation after trephining.

These experiments demonstrate the value of implantation of a disk or plate of decalcified bone after operations on the skull where re-implantation of the bone removed cannot be practised. It is applicable in cases where loss of bone has been sustained by injury or after operations for osteomyelitis, tumors, or syphilitic or tuberculous disease of the cranial bones. Implantation of decalcified bone prevents direct union between the pericranium and the brain or its envelopes. The implanted bone is removed by the granulation tissue which forms all around it, and thus a large mass of embryonal tissue is interposed between the soft tissues covering the skull and the underlying coverings of the brain, a condition which is favorable to the formation of new bone at the site of the operation. In all instances where this procedure was resorted to, the defect in the skull had been more perfectly repaired than on the opposite side, where the soft parts were brought in direct contact with the cranial contents. In cases where the trephine disks or the chips of a chisel operation are aseptic and healthy, Macewen's method of re-implantation

should be done; but where this plan cannot be followed, implantation of decalcified bone constitutes the best substitute.

Aside from favoring the process of osteogenesis, the bone-disk answers a most useful purpose in affording protection to the brain, and in arresting hemorrhage from the vessels of the diploë. It is unsafe to rely upon the hæmostatic effect of the implanted bone when the hemorrhage takes place from the surface of the dura mater, as in such a case there is danger arising from compression of the brain from a blood-clot forming between the disk and the dura mater, but when troublesome hemorrhage is encountered from the vessels of the bone, it is promptly arrested by pressure made by the implanted disk. If the implantation is intended to act as a hæmostatic, then the plate of bone should fit the opening closely, so as to exercise direct compression against the orifice of the bleeding vessel. Bone, when thoroughly decalcified, is an elastic substance, and can be readily compressed at the time of implantation. I am strongly impressed with the advantages to be derived from multiple perforations in the disk, as the perforations, in the first place, afford free drainage to the space between the dura mater and the disk; secondly, they increase the elasticity and compressibility of the disk; and, thirdly, they expedite the removal of the disk by absorption and substitution by the granulation tissue. For the purpose of retaining the disk in place after implantation, one of two expedients may be resorted to:

1. The opening in the bone is shaped, at least at some points, in such a manner that the margins are bevelled at the expense of the internal table.

2. Two or more fine bone nails, rendered thoroughly aseptic, can be driven into the margins of the opening.

The bone-plates should correspond in thickness to the margins of the opening. If implantation of decalcified bone after operations on the skull does not entirely prevent the inconveniences incident to defective repair of the cranial defect, it can be relied upon as a measure which is well calculated to favor the reparative process, and to secure for the cranial defect which remains after the process of ossification has ceased, a firm, thick, and unyielding protective cicatrix, far superior to the cicatrix which forms where no re-implantation of bone or implantation of decalcified bone is resorted to.

II. Implantation of Antiseptic Decalcified Bone in the Treatment of Bone Cavities.

The following experiments were made for the purpose of studying the process of healing in antiseptic bone cavities after implantation of decalcified bone. In making the cavities the compact layer was removed with a chisel, and the spongy tissue and medulla with a sharp spoon. With a view to eliminate the function of the periosteum as an osteo-

genetic agent at the site of the operation, this structure was excised over an area corresponding in extent to the circumference of the cavity. The decalcified bone was cut in pieces to fit the cavity, and the wound in the soft parts was closed completely. In suturing the wound, catgut was used for the deep tissues and silk for the skin. The antiseptic dressing was retained in place with a plaster-of-Paris dressing.

Exp. 11.—Old dog; weight twenty-nine and three-quarters pounds. Operation February 23, 1888. A gutter was chiselled in the left tibia over its anterior upper aspect one and one-seventh inches long, one-fourth of an inch wide, its depth including the entire medullary cavity. The cavity was dusted with iodoform, and a piece of decalcified bone implanted in such a manner that the entire cavity was plugged. Primary union of wound. Dog killed thirty-five days after operation. Skin not adherent to subjacent bone. Site of operation marked by a slight depression on the surface of the bone. Centre of cavity filled with a firm cicatricial mass, into which spurs of bone are seen to project from each side and the floor, leaving a central line about one-thirtieth of an inch in width occupied by tissue which has not yet undergone ossification. Examination of this specimen shows that ossification commenced from the osseous walls of the cavity and progressed toward the centre of the implanted bone, and would have eventually resulted in the production of a sufficient quantity of new bone to fill the entire cavity. The process of ossification in this case was slow, probably on account of the advanced age of the animal.

Exp. 12.—Dog; weight twenty-one pounds. Operation the same as in the preceding experiment. Animal killed fifty-seven days after operation. At site of operation the tibia presents a symmetrical spindle-shaped enlargement corresponding in length to the length of the cavity. Margin of cavity somewhat raised by the formation of new bone. Cavity much diminished in size by the formation of new bone from its surfaces, the centre occupied by connective tissue undergoing ossification. Process of repair further advanced in the upper than the lower portion of the cavity.

Exp. 13.—Young dog; weight twenty-nine and three-quarters pounds. Implantation of a decalcified piece of bone two inches long, and one-third of an inch wide into a cavity made in the upper end of the left tibia, parallel to the axis of the bone. Animal killed eighty-two days after operation. Bone at point of operation considerably enlarged in all directions, imparting to it the appearance of a fracture repaired with little or no displacement. Cavity almost completely filled with new bone, leaving only in the centre a few points which had not so far undergone ossification. Surface of new bone somewhat rough and on same level with the margins of the cavity. This specimen furnishes a beautiful illustration of the existence of plastic periostitis and osteomyelitis starting from the seat of trauma and involving the entire thickness of the bone.

Exp. 14.—Young dog; weight seventeen and one-half pounds. Operation the same, only that by accident the knee-joint was opened. Animal killed seventy-two days after operation. Bone at site of operation not enlarged, only that the margins of the cavity present a ridge of dense bone. The entire cavity filled with compact bone, which on its surface is rough and firmly adherent to the soft tissues. A longitudinal section of the bone through the centre of the cavity shows that the new bone is exceedingly dense, and that partial restoration of the medullary cavity has taken place. The injury of the knee-joint resulted in bony anchylosis between the articular surfaces of the tibia and femur. These experiments demonstrate that it requires a long time to fill with new bone a cavity two inches long and five-sixteenths of an inch wide, the average time being approximately from seventy-five to ninety days. The length of time is greatly modified by the age of the animal, as ossification of the granulation tissue progresses much more rapidly in young than in old animals. Ossification takes place first

in the oldest granulations starting from the bone surfaces and advances toward the centre of the cavity in the shape of spurs or projections, so that in a cavity where ossification has not been completed after removal of the soft tissues, the new bone presents a rough and uneven surface. In the specimen from the last experiment the compact tissue in the medullary cavity has become osteoporotic and medullary tissue has become deposited in spaces over an area indicating the extent of the new medullary canal.

III. Clinical Observations on Implantation of Antiseptic Decalcified Bone.

Case I. *Circumscribed central osteomyelitis of head of tibia.*—A man, thirty-five years of age, German, by profession a teacher, was admitted into the Milwaukee Hospital, October 26, 1887. No history of syphilis. Received a glancing gunshot injury of the tibia during the Turko-Servian war. The bone was not fractured, and the wound healed in the course of a few weeks. Since then he has been in excellent health, and the injured leg caused him no inconvenience until six weeks before his entrance into the hospital. At that time, without any apparent cause, he was attacked with a deep-seated pain at the site of the previous injury. The pain became so excruciating that the patient, finding no relief from the usual treatment, repeatedly threatened to commit suicide. Examination revealed a scar at the junction of the epiphysis with the shaft of the tibia over the anterior surface. No swelling of soft parts and no enlargement of the bone, but a circumscribed spot exceedingly tender to pressure indicated the seat of pain. The diagnosis of circumscribed deep-seated suppurative inflammation was made.

The leg was shaved and thoroughly disinfected and the operation performed without an anæsthetic, as the patient refused to take either ether or chloroform. Esmarch's constrictor was applied to the thigh and the bone exposed by a straight incision. The periosteum at this point was found slightly thickened and abnormally vascular. The tibia was opened with a small round chisel and an abscess cavity the size of a hazelnut disclosed near its centre. The cancellated tissue around the abscess was osteoporotic and infiltrated with pus, which required the removal of more bone with the chisel and sharp spoon, until the cavity in the bone measured one-fourth of an inch in length and one-sixth of an inch in width, when healthy tissue was reached. The cavity was thoroughly irrigated with a strong solution of sublimate, well dried and dusted with iodoform, when it was firmly packed with iodoformized decalcified bone chips. A catgut drain was introduced into the lower angle of the wound, the periosteum sutured with catgut and the skin with silk. A copious antiseptic, absorbent dressing, composed of iodoformized gauze and a cushion of sublimated moss applied and the elastic constrictor removed. The limb was placed upon a posterior splint and was kept in an elevated position. The pain was promptly relieved.

First dressing at the end of a week, when the wound was found completely healed with the exception of a few granulations at the point of drainage. The patient left the hospital four weeks later, when, by an examination of the bone, it would have been difficult to locate the site of operation. The cicatrix was movable and not adherent to the subjacent bone. There has been no return of any symptoms since the operation.

It is hardly probable that in this case the osteomyelitis was caused by pus microbes which might have remained in the tissues since he sustained the injury. As the injury to the bone was superficial and the abscess was centrally located, it is more reasonable to assume that the injury created a *locus minoris resistentiæ*, and that the tissues thus predisposed became infected by floating microbes from the circulating blood. The customary treatment for such a lesion consists in operative measures, which are intended simply to secure an outlet for the products of inflammation, while the successful treatment of the cavity with decalcified bone depends on securing perfect asepticity of the cavity, which in this instance required the removal of a considerable area of infected tissue beyond the limits of the abscess.

CASE II. *Recurring suppurative osteomyelitis of head of tibia.*—Female, aged twenty-seven years; nurse in Milwaukee Hospital. Twelve years ago suffered from an attack of acute osteomyelitis about the junction of the upper with the middle portion of the tibia. A number of pieces of bone escaped at different times during a period of two years, when, finally, without operative interference, an apparent cure followed. Since then she has enjoyed good health until a few weeks ago, when she experienced a severe pain in the knee on the side of the previous attack of osteomyelitis. The knee-joint became swollen and tender. The temperature was always above normal toward evening. Rest in bed and applications of ice were of no avail in removing the swelling or mitigating the pain. Suspecting the existence of a central osteomyelitic focus in the head of the tibia, I regarded the gonitis as a secondary affection, and made a careful search for evidences of a primary affection of the bone. A circumscribed tender point to the inner side of the tubercle of the tibia was found. This place was taken as a guide, and, under strict antiseptic precautions, an opening was made toward the centre of the head of the tibia, and an abscess cavity about the size of a hickory-nut was found, centrally located, at a point between the epiphyseal line and the articular cartilage. The spongy tissue around this abscess was infiltrated, and almost the entire interior of the head of the bone had to be removed with the sharp spoon and chisel. A very thin layer of bone and the articular cartilage separated the joint from the cavity. The cavity was fully as large as a medium-sized orange. After thorough disinfection and iodoformization, this enormous space was packed with decalcified bone chips, each layer being freely dusted with iodoform. Deep and superficial sutures and capillary drainage with strings of catgut.

Primary healing of wound. The pain and swelling of knee-joint subsided completely after the operation. The patient left the hospital a few weeks after the operation. A slight superficial suppuration followed a partial reopening of the wound. The progress of repair in the interior of the bone progressed uninterruptedly, and in about three months' time definitive healing had taken place. The contour of the upper portion of the tibia has been completely preserved, and the bone at the site of operation presents a smooth and even surface. The skin is not adherent to the new bone. The functions of the knee-joint are unimpaired, and the patient has since then performed the arduous duties of a nurse without suffering the slightest pain or inconvenience.

In this case the secondary osteomyelitis was a manifestation of continuation of the primary cause, some of the pus microbes having remained in a latent condition on the proximal side of the primary seat of infection, and had again become pathogenic upon the accession of an exciting local cause or causes. As no retraction of the skin at the point of operation has taken place more than a year after the operation, it must be assumed that the entire cavity has become filled with new bone.

CASE III. *Plastic osteomyelitis of the lower end of the tibia following fracture of the fibula.*—A man, twenty-eight years old, was admitted into the Milwaukee Hospital, April 18, 1888. General health good. No hereditary predisposition. Five years ago he sustained a fracture of the fibula with severe sprain of ankle-joint. After a slow recovery from this injury he was able to walk about until two years later, when a fixed pain appeared in the lower end of the tibia, which gradually increased in severity for several months, followed by swelling and marked tenderness just above the internal malleolus. When examined the lower portion of the tibia was found uniformly enlarged, and a localized point of tenderness was detected over the inner surface of the bone just above the epiphyseal line. At this point an opening was made into the tibia, after carefully reflecting the periosteum, one-third of an inch in length and one-fourth of an inch in width, and extending its depth beyond the centre of the bone. The bone was harder than in a state of health, consequently I explored the surrounding tissue with a drill from the cavity, but failed in detecting evidences of suppuration. The cavity was filled with one large piece of decalcified bone. Wound closed by buried and superficial sutures. The pain ceased immediately after the operation and has never returned since. The wound was completely healed in two weeks. The limb was kept at rest for a number of weeks for the purpose of favoring the process of repair in the interior of the bone. The cavity has become filled with new bone, and the surface of the tibia at the site of operation presents a smooth and even surface. The osteomyelitis in this case was of the plastic variety, and hence the operation was done entirely in aseptic tissue, and it was not deemed necessary to resort to disinfection of the cavity or to iodoformization of the bone chips. The pain was evidently due entirely to tension, and was promptly relieved by the operation.

CASE IV. *Secondary central suppurative osteomyelitis of head of tibia.*—A female, thirty years old, was admitted into the Milwaukee Hospital June 5, 1888. Eight years ago I made an extensive operation for necrosis of the central and lower portion of the tibia which had followed an attack of osteomyelitis when she was a child. A number of sequestra were removed and suppurating cavities laid open. After a number of months the wound finally closed, leaving quite a defect in the bone at the site of operation with the cicatrix firmly adherent to the bone. She remained well until two months ago, when, without any apparent cause, she was attacked with a severe pain in the upper portion of the same bone. The suffering increased in intensity from day to day until the pain became so severe that opiates failed to procure relief. No swelling of the bone or soft parts could be detected, but over the anterior surface of the head of the tibia in close proximity to the knee-joint a well-defined circumscribed area of tenderness could be mapped out. The

entire limb was thoroughly disinfected and while the limb was elevated Esmarch's constrictor was applied around the thigh.

A straight incision was made parallel to the limb through the centre of the tender surface down to the bone. The periosteum was found slightly thickened and could be easily separated from the underlying bone. The bone itself was exceedingly vascular and not as dense as in a condition of health. With an ordinary drill the bone was explored in a central direction. At the depth of about one-fifth of an inch resistance ceased, and upon withdrawal of the instrument a few drops of pus escaped. The bone was now chiselled in the direction of the perforation, and near the centre of the head of the tibia on a level with the epiphyseal line an abscess cavity the size of a small walnut was disclosed. The abscess was surrounded by a zone of osteoporotic bone the meshes of which contained granulation tissue and pus. All of the tissues which presented macroscopical evidences of disease were removed with the chisel and sharp spoon. After this was done the cavity was as large as a hen's egg and in very close proximity to the knee-joint. A number of punctures were made with the sharp point of Paquelin's cautery in different directions from the cavity, for the double purpose of destroying pus microbes which might have remained and to initiate a plastic osteomyelitis. The cavity was thoroughly irrigated with a 1 : 2000 solution of sublimate, and after drying it it was freely dusted with iodoform. It was then packed with decalcified bone chips cut the size of a thumb-nail and thickness of blotting-paper. In making the implantation layer after layer was covered with a thin film of iodoform. The periosteum was sutured with catgut and the skin with silk, leaving only a small opening in the lower angle of the wound for capillary drainage, which was made with a catgut string tied in a bundle. The operation had the effect of relieving the pain at once.

The limb was kept as usual for the first few weeks in a slightly elevated position upon a posterior splint. At the end of the first week the dressing was removed and the wound was found in an aseptic condition. At the end of the second week superficial sutures removed, wound completely healed, except a small granulating surface where the catgut drain had been inserted. At the end of six weeks patient could walk and the head of the tibia presented a normal contour, its anterior surface being perfectly smooth and skin not adherent to bone. A minute linear cicatrix was the only thing which remained as a visible reminder of the recent extensive operation.

This case is one of many of secondary osteomyelitis of the head of the tibia that I have seen following years after a primary attack of acute suppurative inflammation of the shaft and lower extremity of the bone. The etiological relation between the primary and the secondary attack appears to be a direct one, the cause of the first attack, the pus microbes, remaining in the tissues in a latent condition in the direction of the venous and lymphatic circulation, until at a later date by some accidental cause or causes, a *locus minoris resistentiæ* is created. My own experience has taught me that the secondary attacks, as a rule, are not as intense as the first, the lesion appearing in a more circumscribed form and attended by less febrile disturbance.

CASE V. *Secondary chronic osteomyelitis of upper epiphysis and shaft of tibia.*—Male, aged thirty, admitted into the Milwaukee Hospital June 19, 1888. Family history good. Twenty-seven years ago suffered from an acute attack of osteomyelitis of tibia. Seven years ago I removed, by quite an extensive operation, a number of sequestra from the lower third of this bone. The middle third at that time was much enlarged, but as the patient experienced no pain and no sinuses were present nothing was done to this part of the bone. After many months the wound healed by granulation, leaving quite a depression over the lower anterior surface of the bone. He remained well until a year ago, when the pain recurred in the upper and middle portion of the bone, which was soon followed by the formation of several fistulous openings. On examination now, the whole shaft of the tibia and the upper epiphysis were found enormously enlarged and through the fistulous openings a probe could be introduced into the interior of the bone without detecting necrotic bone. I decided to perform Neuber's implantation of skin flaps. The operation was rendered bloodless by Esmarch's constrictor. About one-third of the entire thickness of the shaft of the tibia had to be chiselled away before it was found possible to cover the bone with the sutured skin flaps. The outer portion of the bone was as hard as ivory, while the interior of it was traversed by numerous sinuses lined with granulation tissue and containing here and there small fragments of dead bone. The head of the tibia had to be excavated almost completely before healthy tissue was reached. It contained an abscess cavity the size of a pigeon's egg. As it was found impossible to line this large cavity with a skin flap, it was packed with chips of decalcified bone.

The whole operation was performed under strict antiseptic precautions, and the extensive wound was dressed with iodoform gauze and sublimated moss, and limb confined upon a posterior splint was kept in an elevated position. On the third day the dressing was removed, as it had become saturated with bloody serum. The margins of the skin flaps had become gangrenous and suppuration had commenced. The cavity in the head of the bone also suppurated and the bone chips had to be removed. It required several months before the wound was completely healed, the longest time being required to line the cavity in the head of the bone with a healthy cicatrix.

In this case the implantation of decalcified bone chips failed because the cavity was not rendered completely aseptic by the operation. The elastic constriction produced a very disagreeable effect, inasmuch as it caused complete paralysis of sensation and it required several weeks before sensation returned.

CASE VI. *Acute osteomyelitis of lower end of the femur.*—Boy, seven years of age, was admitted into the Milwaukee Hospital June 5, 1888. Three years ago, when the child was in good health, osteomyelitis developed after a contusion of the thigh. An abscess formed and was opened by incision over the outer and middle aspect of the thigh. A few weeks later another opening had to be made over the internal condyle of the femur. The upper incision healed while the lower has continued to discharge pus. The lower posterior aspect of the femur was exposed by an incision in the line of the fistulous opening. An opening at the point of bifurcation of the linea aspera was found in the bone which led into

a cavity lined with granulations and containing a small sequestrum. The cavity was freely laid open with the chisel and the granulations were thoroughly removed with Volkmann's spoon. After thorough disinfection the cavity was iodoformized and packed with decalcified bone chips. The granulations lining the tract in the soft parts were also removed, and the deep tissues united with catgut sutures and the skin with silk. Capillary drainage with several strands of catgut. Wound and limb dressed in the usual manner. Wound healed under two dressings. Later a connective tissue abscess retarded the progress of the case, but did not interfere with the process of repair in the cavity. In the course of two months recovery was complete with perfect restoration of the bone defect.

CASE VII. *Suppurative osteomyelitis after compound fracture of tibia.*—The patient, a female, aged sixty-five years, was admitted into the Milwaukee Hospital, September 26, 1888. She was anæmic and considerably emaciated. Eighteen months ago she sustained a compound fracture of the left leg. The fracture of the tibia was about four inches above the ankle-joint, and the upper fragment had perforated the skin. The wound suppurated, but the fracture united after the usual time. A fistulous opening communicating with the interior of the bone has remained. The patient is unable to use the limb, as she suffers from pain in the lower end of the tibia, which is greatly aggravated by attempts to walk. Some œdema about the ankle and foot. Lower end of tibia slightly enlarged and painful on pressure. The bone was exposed by a straight incision, and after reflecting the periosteum with the attached soft parts the bone was found very vascular and softened. Taking the fistulous opening as a guide, the compact layer was removed over the entire length of the cavity with the chisel. The cancellated tissue in the interior of the bone was found infiltrated with pus and permeated by granulation tissue. After removal of all diseased tissue with a sharp spoon, the cavity in the bone measured one inch in length and one-fifth of an inch in width. After thorough cleansing and disinfection with a 1 : 2000 solution of sublimate, it was dried and dusted with iodoform, after which it was packed with bone chips. Over this gutter the periosteum was stitched with catgut sutures and the external wound with silk, leaving only a small space for the insertion of a catgut drain. Pain ceased after operation. No rise in temperature. External wound healed by primary union. Six weeks after operation the patient left the hospital with the entire cavity apparently filled with bone.

The purulent infection of the bone in this case did not lead to sequestration, but to osteoporosis and the formation of an abundance of granulation tissue. The infection extended from the seat of fracture downward to the lower epiphyseal line. The walls of the cavity were composed of a thin shell of compact tissue.

CASE VIII. *Acute suppurative osteomyelitis and necrosis of upper portion of tibia.*—Male, twenty-three years of age, was admitted into the Milwaukee Hospital, January 7, 1889. Had an acute attack of osteomyelitis of the upper portion of the tibia three years ago, which led to the formation of an abscess which was opened on the tenth day. This opening never closed. A number of small pieces of dead bone have

escaped. General health good. The upper portion of the tibia is very much enlarged, and a fistulous opening situated on the inner surface of the tibia about one-fifth of an inch below the tubercle leads into the interior of the bone. After chiselling away the compact layer anteriorly in the line of the opening, it was found that the disease had taken its starting-point at the epiphyseal line and had extended upward to near the articular cartilage and downward obliquely from the inner to the outer side of the bone to a distance of one and one-fifth inches. The upper terminus of the inflammatory process was an infiltration of the cancellated tissue with pus, necessitating an excavation of a cavity the size of a walnut. The exposure of the sinus in the bone made it necessary to chisel a gutter in an oblique direction from within outward and downward one-third of an inch in width and one and one-fifth inches in length. A number of small sequestra were removed and the granulations scraped out with a sharp spoon. Disinfection and packing of the cavity with decalcified bone chips in the usual manner. Catgut drain and deep and superficial sutures. As the dressings were saturated the next day they were removed. Suppuration followed the third dressing, with the result that four weeks after the operation some of the bone chips, showing the corroding action of the granulations, escaped. At this time some of the bone chips could be seen in the cavity embedded in granulation tissue.

The subsequent course demonstrated that the chips which were in close contact with the walls of the cavity were retained while the central portion of the packing was eliminated. When suppuration ceased the cavity had nearly closed, and the gutter was filled two-thirds of its depth with vigorous granulations; after another thorough disinfection the remaining cavity was again implanted with bone chips, and in the course of another four weeks the entire surface has healed, leaving only a very slight depression on the surface of the bone.

The clinical history of this case shows that the cavity was aseptic from the beginning, and that the reparative process had progressed in a satisfactory manner for two weeks, when accidental infection occurred at the time the third dressing was made, which for a time arrested the healing process and resulted in the elimination of the central portion of the bone packing. As soon as suppuration had ceased and an aseptic condition of the granulating surfaces could be secured, secondary implantation was done and was followed by complete success.

CASE IX. *Resection of knee-joint; large tuberculous cavity in head of tibia.*—Female, aged twenty years, was treated at the Milwaukee Hospital for tuberculous arthritis of knee-joint during the year 1888. The disease had existed for several years, and, in spite of the usual treatment, continued to grow worse. The knee-joint was greatly distended by what appeared to be masses of granulation tissue. As the head of the tibia presented two well-marked points of tenderness, it was surmised that the disease had taken its starting-point in this bone, and that the knee-joint had become involved secondarily. Typical resection of knee-joint. The section made through the tibia revealed three small tuberculous cavities. Condyles of femur healthy. A careful inspection of the sawed surface of the tibia revealed at one place osteoporotic bone, and exploration at this point disclosed another deep-seated tuberculous focus,

the removal of which resulted in the formation of a cavity the size of a walnut. This cavity was packed with bone chips before the resected surfaces were brought in apposition. Complete healing under two dressings. Firm bony union in the course of two months. Good use of limb and no relapse to date. That the filling of the cavity with decalcified bone chips expedited bony consolidation, there can be no doubt, as with the removal of the implanted chips the osteoporotic material invaded the cavity and approached the resected surface of the femur, furnishing a considerable portion of the intermediary callus.

CASE X. *Chronic circumscribed suppurative epiphyseal osteomyelitis of tibia.*—Male, aged eighteen years, was admitted into the Milwaukee Hospital March 13, 1887. For the last three years the patient has suffered at times from a severe pain just above the ankle-joint. At different times he has been treated for sprain of the ankle or rheumatism. During the last few weeks the pain has become so severe that he was unable to walk, and had to take opiates to procure sleep. No history of tuberculosis or syphilis. At a point corresponding to the lower epiphyseal line of the tibia some swelling and increased local temperature. About the centre of the swelling great tenderness on pressure. On making an incision down to the bone through the centre of the swollen part the periosteum was found very much thickened. On removing the compact tissue with the chisel an abscess cavity the size of a hazelnut was found in the centre of the bone, immediately above the epiphyseal line. As the bone around the cavity showed evidences of disease it was scraped out with a sharp spoon until the cavity was as large as a walnut. Disinfection and iodoformization of cavity followed by implantation with decalcified bone chips. Double row of sutures and capillary drainage with catgut. External wound healed under first dressing. Later some suppuration in connective tissue about the wound, which, however, did not affect the healing process in the cavity, which was completed at the end of six weeks.

IV. GENERAL DIRECTIONS FOR TREATMENT OF BONE DEFECTS BY IMPLANTATION OF ANTISEPTIC DECALCIFIED BONE.

1. *Decalcification and disinfection of bone.* A fresh tibia of an ox is the best material for decalcification. The bone is cut in sections two inches in length, and, after carefully removing the medullary tissue, is kept in dilute muriatic acid, the fluid being changed every few days until the process of decalcification has been completed. After this has been accomplished the bone can be readily cut into pieces about one millimetre in thickness, making the sections parallel to the long axis of the bone. The acid is then removed by washing and by keeping the bone immersed in a weak solution of caustic potash. The bone is then rendered antiseptic by keeping it until it is needed in a solution of sublimate in alcohol 1 : 500 in a wide-mouthed bottle, which is kept hermetically sealed by a glass stopper to prevent evaporation of the solution. When the bone is needed, it is taken from the bottle and placed in a five per cent. solution of carbolic acid, or a weak solution of sublimate. In making the plates or disks for filling a cranial

defect the bone is cut so as to correspond in thickness to the bone removed, and accurately to fit into the opening. A number of small perforations in the disk or plate should always be made, as through these openings the space underneath the bone is kept drained; at the same time the early entrance of granulation tissue into these openings effects fixation of the bone *in situ* and favors the early removal of the implanted substance by substitution with permanent living tissue. Before implantation both sides of the plate should be dusted with iodoform. For packing bone cavities the decalcified bone should be cut in thin slices or chips, which should be laid upon a compress of aseptic gauze, so as to remove the surface moisture, when they are dusted with iodoform before they are implanted into the cavity. Aseptic decalcified bone drains, in the absence of more suitable material, can be used in packing bone cavities.

2. *Asepsis at the seat of implantation.* The most essential condition for success in the treatment of bone defects by implantation of decalcified bone is a perfectly aseptic condition of the tissues to be brought in contact with the implanted bone. This condition is easily procured in operations on bones for lesions other than those caused by infection with pus microbes, such as tumors, parasites, and tuberculous and syphilitic affections uncomplicated by suppuration. In the surgical treatment of these affections after the removal of the diseased tissue the seat of operation must be aseptic if the ordinary precautions in the prevention of infection from without have been observed. In such cases speedy healing of the external wound and the early partial or complete reproduction of the lost bone are assured.

The next most favorable cases for this procedure are circumscribed osteomyelitic processes in the epiphyseal extremities of the long bones as we observe them in cases of primary circumscribed epiphyseal osteomyelitis, or in the form of a recurring attack in the same place, perhaps years after a diffuse osteomyelitis of the entire shaft. Under such circumstances the inflammatory focus can be located externally by the presence of a circumscribed area of tenderness, and the tender spot constitutes the guide in the search for the abscess. The seat of inflammation is freely exposed with a chisel and the walls of the abscess cavity are scraped out with a sharp spoon until healthy tissue is reached all around. The precaution should be taken to wash out the cavity with an antiseptic solution before attacking the abscess wall so as to prevent the contamination of the healthy tissue with the products of the infection by the mechanical diffusion of the pus microbes. For the final disinfection of such a cavity a strong solution of sublimate is used, and after thoroughly drying its walls it is dusted with iodoform. Iodoformization of the cavity and the implantation of antiseptic bone chips are measures which are well calculated to resist the pathogenic action of

pus microbes which might still remain, and in the majority of cases will secure an aseptic healing of the wound.

This method of treating bone cavities is also applicable after operations for necrosis resulting from a previous attack of acute suppurative osteomyelitis. With a view to obtain an aseptic condition of the cavity it is necessary that the line of demarcation between dead and living tissue should have formed, the involucrum must be well developed and the soft parts in a healthy condition. The operation which precedes the implantation must accomplish more than the simple extraction of the necrosed bone, it implies the removal of all infected tissue lining the interior of the involucrum and the fistulous tracts in the soft tissues. The involucrum must be laid open with the chisel sufficiently to expose to sight and direct treatment its entire interior for the purpose of removing with the sharp spoon all of the infected granulations, at the same time the fistulous tracts in the soft tissues must be made accessible to the same treatment. After the thorough mechanical removal of all infected tissues the wound surfaces must be irrigated freely with a hot solution of sublimate, and for final disinfection a twelve per cent. solution of chloride of zinc may be applied with a brush, after which the cavity is flushed again, dried, and iodoformized. In operations for acute diffuse osteomyelitis all known surgical resources are inadequate in rendering the field of operation aseptic, and hence contraindicate the subsequent treatment by implantation with decalcified bone.

3. *Necessity of performing the operation by bloodless method.* I have previously made the statement that in the implantation of a disk or plate of bone into a defect in the skull the hemorrhage from the brain and its coverings should be carefully arrested before the implantation is made, as otherwise compression of the brain might arise from accumulation of blood underneath the implanted bone. The disk or plate may be relied upon in arresting hemorrhage from the vessels in the bone which by other measures it is sometimes found difficult to control. In the treatment of bone cavities in regions where it is possible to render the operation bloodless by elastic constriction, this should always be resorted to, as it prevents unnecessary loss of blood during the operation and enables the surgeon to resort to means and measures for procuring an aseptic condition, which otherwise it would be impossible to apply with the same degree of thoroughness and efficiency. Unless special indications present themselves the elastic constriction is continued until after the dressing has been applied.

4. *Implantation.* In the treatment of a bone cavity by implantation with decalcified bone, the chips are poured into the cavity and are packed quite firmly until the surface of the cavity is reached. The bone chips act as an antiseptic tampon which arrests the free oozing from the surface of the bone which always takes place after the removal

of the constrictor. Some blood escapes between the bone chips and coagulates at once, thus forming a desirable and useful cement substance, which permeates the entire packing and temporarily glues, as it were, the chips together and the entire mass to the surrounding tissues.

5. *Treatment of external wound.* The periosteum should be carefully preserved in exposing the bone and, after the implantation, is sutured over the surface of the bone chips with catgut sutures. If the bone is deeply located, it may become necessary to apply another row of buried sutures in bringing into accurate apposition other soft parts. The skin is finally sutured with silk. It is of great importance to secure accurate apposition of the divided soft parts in order to preserve for the subjacent bone all of its natural coverings.

6. *Drainage.* In some instances it would be undoubtedly superfluous to secure any form of drainage, as when the cavity is perfectly aseptic and hemorrhage is not in excess of requirements, healing of the entire wound would be accomplished under one dressing. Experience, however, has taught me that tension arising from extravasation of blood often exerts an injurious influence upon the process of healing and should be carefully avoided. As it is desirable to heal as much of the wound as possible without interfering with drainage I have invariably introduced an absorbable capillary drain in the lower angle of the wound. A string of catgut twisted into a small cord answers an admirable purpose.

7. *Dressing of wound.* The wound is covered with a strip of aseptic silk over which a few layers of iodoform gauze are applied. Over this a cushion of sublimated moss is placed with a thick layer of salicylated cotton along its margins for the purpose of guarding more securely against the entrance of unfiltered air; the whole of it is retained by a circular bandage of gauze evenly and smoothly applied. For the purpose of securing absolute rest for the limb it is placed upon a posterior splint and kept in a slightly elevated position. If no indications arise, the first dressing is not removed for two weeks, when the entire wound will usually be found healed, except a few granulations at the place where the catgut drain was inserted. A smaller antiseptic compress is applied and the limb dressed in a similar manner. It is advisable to enforce rest not only till the external wound has healed, but until the whole process of repair has been completed, which embraces a period varying from four weeks to three months, according to the size of the cavity and the age of the patient.

8. *Secondary implantation.* If an operation is followed by suppuration the result of imperfect antisepsis tubular drainage must be established and the same treatment pursued as in suppurating wounds. If suppuration takes place soon after the operation and is profuse, it is probable that all of the bone chips will be lost. If it develops after

granulation tissue has had time to form and the purulent discharge is moderate in quantity, the prospects are that the bone will remain and serve its purpose as a nidus for the granulation tissue. In such cases an antiseptic irrigation should be made every three or four days until suppuration has ceased. If the bone chips are lost by suppuration or have to be removed for the purpose of a more thorough disinfection of the cavity, no attempt should be made at re-implantation until suppuration has been arrested, or, in other words, until the cavity has become lined with granulations, and is in a comparatively aseptic condition, when the time for secondary implantation has arrived. After the cavity has been irrigated with a strong antiseptic solution it is dusted with iodoform and the granulations are scarified in a number of places for the purpose of obtaining a sufficient amount of blood to fill the spaces between the bone chips, which are implanted in the same manner as in the treatment of a recent cavity. Complete closure of the external wound under these circumstances is seldom obtainable and the surface of the exposed portion of the cavity should be provided with a thin layer of Schede's moist blood-clot. The antiseptic properties of the material used in packing the cavity exerts a potent influence in maintaining asepticity after secondary implantation.

Conclusions.

1. Antiseptic decalcified bone is the best substitute for living bone grafts in the restoration of a loss of substance in bone.

2. In the treatment of bone cavities, antiseptic decalcified bone is preferable to Schede's blood-clot, as it is not only a perfectly aseptic, but at the same time, also a strongly antiseptic substance.

3. Implantation of a disk or plate of antiseptic decalcified bone into a cranial defect may be relied upon as a hæmostatic measure in arresting bleeding from the vessels of the diploë, it constitutes a good temporary substitute for the lost portion of the cranium, it prevents the direct union of the brain or its envelopes with the pericranium, and, finally, it furnishes the most favorable condition for the production of new bone from the margins and the closure of the remaining defect by a firm and unyielding membrane.

4. The packing of an aseptic bone cavity with chips of antiseptic decalcified bone guards against unnecessary loss of blood and exerts a potent influence in the prevention of infection by pus microbes that might have remained upon the surface of the wound or in the tissues.

5. Capillary drainage by an absorbable drain should be established after implantation for the purpose of preventing the accumulation of more blood in the wound than is necessary to form a temporary cement

substance between the bone chips and between the contents of the cavity and the surrounding tissues.

6. In the treatment of an aseptic bone cavity by implantation of chips of antiseptic decalcified bone, the packing answers the purpose of an antiseptic tampon and furnishes the best medium for the growth and development of the tissue resulting from the regenerative process initiated by the trauma.

7. Secondary implantation can be successfully practised in the treatment of a suppurating bone cavity after suppuration has ceased, and the cavity can be transformed into the same favorable conditions for healing as an aseptic wound.

THE VALUE OF CREOLIN, HYDRONAPHTHOL, AND SODIUM FLUOSILICATE AS GERMICIDES.[1]

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Sodium fluosilicate and hydronaphthol are often used as germicides, but their germicidal properties, so far as I can learn, have never been demonstrated. They have both been shown to be efficient antiseptics.

The germicidal and antiseptic properties of creolin have been tested by Esmarch, Eisenberg, and others. It has been demonstrated to be a germicide of nearly equal power with carbolic acid.

The following experiments were undertaken to determine the germicidal power of sodium fluosilicate, hydronaphthol, and creolin as compared with one another and as compared with some of the older germicides which they tend to supplant, such as the bichloride, carbolic acid, and thymol.

Method.—The bacteria used to test the germicidal power were the bacillus typhosus, the pneumococcus (Friedländer's), the streptococcus erysipelatis (Fehleisen), the staphylococcus pyogenes aureus, and those of decomposing beef bouillon which had been previously sterilized and then exposed to the air of the laboratory for two weeks. Pure cultures were then made in sterile beef bouillon of the B. typhosus, streptococcus erysipelatis, and pneumococcus.

The staphylococcus pyogenes aureus does not grow readily in beef bouillon, therefore a pure culture of this was made in nutrient gelatine which had been steamed so long that it remained liquid. In this the staphylococcus grows abundantly.

[1] The experiments given in this paper were performed in the bacteriological laboratory of the Yale Medical School.