FREE TRANSPLANTATION *

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Free transplantation viewed clinically is of different significance than when looked at from the stand-point of the pathological anatomist, so that the question, What is meant by a success in free transplantation? may be and is answered in a different manner by the clinician and the pathologist. Thus the histologist may describe as a result of his microscopic examination, failure in the healing processes, in a case in which the surgeon has obtained a successful result, clinically. If a clinical success were dependent on the pathologist's conception of successful transplantation, the surgeon would achieve success only rarely.

The structure of the transplanted tissue varies in the successes as it does in the failures.

What eventually becomes clinical success can be grouped as follows:

1. The approach to the ideal, where healing of the tissues takes place. Histologically, not only are the masses of cells held together, but vigorous regeneration occurs at the site of the wound flap, where necrosis usually is noted.

2. Healing occurs with a gradual disintegration of the transplanted tissue, but with coincident regeneration of the homologous tissues of the recipient, from those in the immediate vicinity. This condition is a most important one. The best example of it is seen in fresh transplanted bone which gradually disintegrates, slow regeneration taking place from the periosteum of the bone in which it has been implanted.

3. Healing takes place with complete encapsulation. The transplant here breaks down completely, but retains its shape. It becomes isolated like a foreign body, surrounded by a capsule so firm that neither absorption nor substitution can take place. In spite of this condition the clinical result may be a successful one, as, for instance, where fragments of bone are used to obliterate cavities, or when tendons or fasciæ are employed as bands.

In the clinical failures one meets with the following variations in the structure of the transplant:

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1. The transplant may be exfoliated after a few days, with suppuration. The cause is not a wound infection, but a malignant, non-bacterial suppuration, so severe that a gangrenous reaction may be the outcome. This is not seen very often, except when man-to-man transplantation is performed and the donor is suffering with tuberculosis or syphilis. For this reason such individuals are not desirable subjects for transplantation.

I believe in this class of patients who present themselves mostly for homo- or heteroplasty, that the difference in the serum and the cell proteids is markedly increased.

2. There may follow after healing a slow suppuration due to the foreign body, which ceases only when the tissue mass has become completely isolated.

3. A failure may occur after initial healing, because absorption takes place at a more rapid rate than does regeneration from the surrounding tissues. A not infrequent example is seen in transplanting the articular surface of the long bone of the arm, which has been denuded of its periosteum, where the bone is absorbed faster than new bone is generated.

4. After apparent healing occurs there is a disappearance of the tissue with cicatrization. In this instance the clinical result may be successful, as when tendons are transplanted, scar formation takes place, and they regain their normal function.

Aside from the bacterial and suppurative obstacles, one meets with other undesirable processes, as when the tissue mass becomes necrotic because of exuberant granulations which interfere with the blood supply, resulting in suppuration, absorption, and cicatrization.

The clinical result also depends on the type of tissue mass to be transplanted, as the more complicated in structure the tissue the more can we expect ideal histological healing. All types of tissue, as connective tissue, fasciæ, tendons, fat, tubular vessels, peritoneum, cartilage, and bone can be made viable in the homologous tissue of the recipient, and its regenerative powers increased with a consequent successful result, provided that substitution keeps pace with absorption.

It is common knowledge that the best results are obtained by means of autoplasty, in which method the transplanted tissue is grafted into the body from which it has been obtained. One must not believe, however, that a success in the histological sense is always obtained even in autoplasty, as here also come into play the variations in the site of the graft, the condition of the wound, as well as the damage done to the transplant. Only in autoplasty of the complicated tissues, as in trans-

plantation of organs, is a successful result always possible, in the clinical sense.

In homoplasty, *i.e.*, the transplantation of tissues from one animal to another of a like species, success has been achieved only when the transplanted tissue was homologous to the mother tissues in the following types of tissues, connective tissue, fat, bone, etc.; never with nerves, muscle, and organs, in which instances rapid degeneration and cicatrization occur. Fibrous encapsulation is met with more frequently in homoplasty than in autoplasty. This is probably due to the irritation of a foreign proteid, a difference, varying mostly with race, then with distant relatives, near relatives, and least with the individuals of one family. This variation prevents proper nourishment of many tissues, and, as a result, substitution in the regenerative process occurs very slowly while degeneration takes place very rapidly.

In heteroplasty, *i.e.*, transplanting from lower animals to man, or from an animal of one species to an animal of another species, scant success has been obtained. Küttner has been somewhat successful in transplanting tissues from the ape to man. The tissue mass necroses as it does in homoplasty, except that, according to Schöne, the transplanted material can be grafted after a few days into the donor with healing.

A survey of the above circumstances governing the behavior of the transplant makes it evident that the solution of the problem to obtain a successful result lies in the study of the properties of the tissue to be transplanted.

1. It must have the ability, when it is transplanted, to grow upon the foreign soil. The first factor is the viability of the tissue, as it is dependent upon its own lymph and circulation for nutrition. This viability varies with the individual tissue, as the higher the development of the cell—as the ganglion cells, nerve cells, muscle cells or parenchymatous cells—and the richer the tissue is in blood-vessels, the less likely it is to survive. On the other hand, the life of some tissues survives the life of the body as a whole. It is thus possible to transplant successfully such tissue from a corpse to a living organism.

2. The transplant must be endowed with the capacity for extracting nutrition from the soil into which it has been planted.

3. It must be able to regenerate so that the disintegrating tissue is replaced.

These properties are present very markedly in the malignant tumors and in cultures of living cells, as shown by Harrison, Carrel, and Burrows.

Even in tissues rich in the above mentioned qualities, it is important to know by what factors they are influenced. In removing and implanting the graft, many factors can easily enter which either weaken or destroy these properties, as drying, chemical contact, or mechanical injury. The practical surgeon who guards against such factors achieves the best results.

As important as the properties of the transplant are the qualities of the " wound soil " which serves the function of supplying as quickly as possible nutrition to the graft. The first step in the establishment of the lymph flow and the circulation is the early adhesion between wound edges and the transplant. The more quickly and surely this takes place, the more promptly is nourishment assured. Should the cells of the wound be injured because of antiseptic applications, or should they be abnormal because of the presence of scars or hæmatomata, or the seat of previous disease, as tuberculosis, necessary nutrition will be delayed. Very important contributing factors to failure are errors in operative technic, causing infection with a very slight transudate, which is instrumental in destroying the first intimate contact, thus preventing nutrition, partially or absolutely, and predisposing to partial or total necrosis due to suppuration. By means of strict asepsis, this element of failure can be eradicated. Most important, however, is a second factor, which prevents the early intimate adhesion of the wound edges, namely, imperfect hæmostasis. The presence of the slightest amount of blood is dangerous, as it interferes with the nutrition. That this factor has been heretofore disregarded is apparent from the literature. It is the general belief that a smooth, uninfected wound is a sign of perfect technic. This is not true in connection with transplantation. In this instance perfect technic is recognized by a complete gumming and coaptation of the wound edges. For this reason every experimenter in recording the results of his transplantations should convince himself that the transplant is really grafted as it should be, in order that his operation be perfect.

In order to perform transplantation the following rules must be observed:

Strict asepsis, complete hæmostasis in the wound, care in removing, handling and implanting the graft. To this add my rule—the improvement of the nutritive properties by prevention of suture lines, by placing flaps or small pieces of subcutaneous tissue or skin immediately over the graft.

During the after-treatment functional dressings, as advised by Roux, are important, as weighting of bones, stretching of tendons.

SKIN AND EPIDERMIS TRANSPLANTATION

The technic is well known and various methods are applied toward the common end. It is only necessary to emphasize that in my experience where there is present granulation tissue it is better razed with a knife than with a spoon, not interfering with the recent necrotic tissue. Not only do I believe this to be a better procedure, but I make it a rule never to plant epidermis on granulation tissue without previously freshening the base. To secure hæmostasis, I adopt the following procedure: after ligation of the visible bleeding vessels, I allow the wound to remain uncovered until there is visible fibrin formation. Then I exert pressure over the surface with a gauze sponge moistened with warm saline solution. As a result all bleeding is brought to a stop, so that the capillaries come in intimate contact with the grafted flap.

The application of strips of epidermis to repair large areas of skin wounds is made possible—especially where prevention of scar formation is sought. This is of importance on the face and about the joints. The indications for epidermal transplantation are of less importance in those regions of the body where the skin contracts or where it cannot be closely fitted, with consequent disability or disfigurement, as on the scalp, forehead, or flank.

Substitution of epidermis for mucous membrane is not practical, since infection and secretion interfere with the healing processes. In the body cavities it has been tried without success, as in the repair of dural defects.

The successful epidermis transplantation terminates in healing with a smooth, pale, and soft skin surface. Uncommonly, one observes a scar-like thickening of the corium with ugly swellings and intense hyperæmia. This is found following the freshening of old wounds, and, in my opinion, in the tuberculous and in those susceptible to keloid formation.

Where epidermis is contra-indicated on account of previous cicatrization with shrinkage of the skin, transplantation of the skin finds its usefulness. Skin transplantation dates back to the Indian times, but its usefulness was first brought to notice in the last century by Bunger (1818), Wolfe, v. Zehenden, v. Langenbeck, and v. Esmarch, when the importance of mechanical sterilization was recognized and finally emphasized by the work in strict asepsis of Fedor Krause. Here also I will not go into detail regarding the technic, as it is well known.

It makes no difference whether one follows Krause, in removing

the flap without fat, or v. Esmarch, in using the fat with the flap. According to Hirschfeld, healing takes place as well with or without the subcutaneous adipose flap. Finally, as I brought out, I made use of padded flaps, as in the repair of facial skin.

For successful healing to take place, the primary adhesion of the flaps is essential. Should this intimate contact and glueing be disturbed within the first twenty-four hours, on account of bleeding or inflammatory transudate, death of the flap usually occurs, followed by marble-like areas and cicatrization as a final result. I have, on some occasions, seen this occur after primary adhesion in cases of post-operative erysipelas, scarlet fever, or measles.

To obtain a successful result, all pre-existing scar tissue must be removed from the surface of the wound, in order to prevent contraction of the flap.

Attachment of the skin occurs more slowly than that of epidermis, the former occurring in from three to five weeks, the latter in one to two weeks. Sensation manifests itself in the edges after about six weeks. Transplanted hair sheds, regenerating only rarely. Transplantation of hair flaps, for example, of the scalp, the pubic skin, or the axillary skin, for the repair of the eyebrows or upper lip, is not attended with certain cosmetic results.

Like the hair, finger-nails with the contiguous skin do not lend themselves to successful transplantation, as Nicoladoni first demonstrated. Even with favorable nutrition of the nail bed, the shape and the growth are abnormal.

The advantage in the use of strips of epidermis over skin flaps lies in the certainty and rapidity with which repair takes place. If all precautions are observed, healing occurs in every case of epidermis transplantation. This certainly does not pertain to skin transplantation, but failure is not always due to faulty technic. In some individuals failure is due to some factors not yet clearly understood. I believe, as the result of my clinical experience, that there are patients in whom, after skin transplantation performed with strict observance of all rules, absorption of the flap with scar formation occurs, or in other instances, necrosis and suppuration with shedding of the flap, there remaining only a few small islands of skin. These results have been noted mostly in the anæmic, in the tuberculous, syphilitic, or diabetic, while drying of the flap occurred mostly in those of advanced age.

The advantage of skin flaps over epidermal strips rests in the greater resistance of the former, since it contracts less and affords a

better cosmetic effect. For this reason I prefer to use skin flaps on the face and fingers.

The important indication for skin transplantation is in the repair of skin defects. Within the body, *i.e.,* for the repair of peritoneum, pleura, or capsule of joints, skin flaps are not useful. The sequelæ usually consist in epithelial cysts and tumors, following encapsulation of the detritus mass of the absorbed epithelium and secretions.

Independently of one another, Lowe and Rehn conceived the idea of utilizing the connective tissue of the skin as a substitute for the repair of fasciæ and tendons. Later, following Lowe's observations, it was found that by abrading the layer of epidermis much detritus was formed, especially from the deep sebaceous glands and hair follicles. Rehn's idea seems better, *i.e.,* to stretch the flap by means of artery clamps and to remove the epidermis with a knife. Should broad skin flaps be needed, as from the upper portion of the thigh, the epidermal layer is first removed with a transplantation knife, the cutis and subcutis being obtained by a second incision. This layer is then implanted on the recipient soil. As Rehn has demonstrated, very large and broad tendons and bands and many connective-tissue areas can be repaired with the abundant material that can be obtained from the edges of wounds made on the operating table. I have been able to use this material for padding out the tip of the nose and the alæ nasi, as well as to utilize the skin of the arm to build up an entire auricle, constructing a solid elastic plate.

These favorable results in epidermis and skin transplantation have been obtained only in autoplasty. Regarding the value of homoplasty, the conclusions are still uncertain. As the result of clinical observations and animal experimentation, I am compelled to say that homoplasty does not yield good results. And the reports in the literature of fortunate healing of transplanted skin or epidermis by homoplasty, as well as the reports of implanted skin or epidermis from the dead body or from animals, are the result of erroneous observation.

This remark also holds good for the reports of successful transplantation of negro skin on the Caucasian, or *vice versa,* as I believe that the pigmentation occurring in the former case is the usual pigmentation seen after ordinary transplantation, and the light color seen in the negro is due to the scar, which in the negro is never pigmented. In the light of our present knowledge, the status of homoplasty and heteroplasty can be summed up as follows:

Histologic evidence which shows proof of healing has not been brought forward. Clinical evidence has been offered, but this evidence

is misleading. Healing has been accomplished by replacement of the flap with normal skin, or the flap has been lifted away by the secretions of the sebaceous and sweat glands at the borders of the defect, with new skin growing under the raised flap: this has been interpreted as successful transplantation. Others have observed that in heteroplasty, for example, of hair or chicken skin with feathers, these skin accessories have grown but for a short period of time. De Francesco has noted the appearance of small feathers, and Perinoff has observed the growth of hair for twenty days after homoplasty. As a result of animal experimentation, Davis allowed himself the conclusion that homoplasty was equal to autoplasty, after Marchand, Henle, Wagner, etc., had expressed themselves against it.

In order to clear up this aspect of the subject, I suggested a number of new animal experiments (Oshima), and for many years have conducted many homoplastic dermal and epidermal transplantations with fresh human material. This was done in operations where the opportunities offered themselves, as in amputations of limbs. In all cases the wounds were covered with strips of skin, care being taken not to allow them to come in contact with the wound edges, and side by side with the homoplastic flap were placed autoplastic flaps of either skin or epidermis. By this means both types of tissue were subject to identical conditions.

While there was noted degeneration of the skin flaps with scar formation in the animals, the clinical experiments were also negative. In the clinical failures, however, not only was the flap shed, but it was shed in a striking manner, with acute gangrene.

Second, shedding of the transplant occurred as the result of a thick pus layer, which originated from the exuberant granulation of the wound—this being noted after apparent adhesion and healing in from one to three weeks. Perhaps an attempt at nutrition took place after an initial adhesion but was prevented by the formation of granulations. The entire process is suggestive of that which occurs in foreign body suppuration and shedding.

The third method of shedding is noted when, after the third week, following apparent healing, liquefaction of the dried epidermis or skin flap occurs without pus production. As in scab healing, the liquefaction occurs under the necrotic flap, when the floor of the wound has been covered with new skin. It is true that the latter appears under the protection of the flap but it is created by the body tissue, namely, from the cell rests of the skin and from the edges of the wound of the recipient.

Formerly, a frequent observation was the appearance, during or after the fourth week, in an apparently well-healed skin flap, of strange, red, scaly areas in the epidermis resembling pus. As the flap contracted because of cicatrization, these red areas became larger and changed their positions in the scar tissue. It became macroscopically evident that one dealt with production of granulation tissues scattered throughout the flap, as with the mechanical motion this tissue would bleed. Microscopical examination of the above described skin flaps showed this structure up to the forty-fifth day. This scar formation, I believe, is the best possible result, excepting scab formation (natural substitution), that one can obtain from skin homoplasty.

I obtained favorable results only with epidermal flaps from the fresh fœtus. Here was seen plainly enlargement of the epithelial islands after the superficial layers desquamated. In spite of this attempt at regeneration from its own resources, the entire flap was cast off in the third week. Exactly similar results were obtained by Stern in his experiments with the amnion.

After these experiments I regard the usefulness of homoplasty in extreme doubt, and believe that the above-mentioned conclusions are the results of faulty observations, and the new skin formation, interpreted as implantation, is the result of scar substitution under incrustation of the flap. This does not exclude the fact that the foreign epidermis acts as a stimulant to the proliferation of the cells of the recipient. There is even greater doubt of the possibility of skin transplantation from the corpse, as reported by Gluck.

The inherent virtues of the homoplastic transplant are important factors in this consideration, since the structure of the donor's cell protoplasm undergoes early softening, resulting in healing by substitution with scar formation. I have proved clinically that racial differences play an important part, by using the skin from a freshly amputated limb of a Slav and implanting it on other individuals. In a Prussian, suppuration followed, while in a Slavish child healing with scar formation occurred. The most possible favorable result was met with in like races. More encouraging results were reported by Schöne in transplantation in animals that were blood relations, since skin flaps could be easily interchanged between near relations of like sex. In the human family I have never applied homoplasty that was not free from subsequent objection.

There is no question that it is of clinical importance, if it were possible to prove the conclusions which have been advanced relating to the successful grafting of homoplastic flaps of skin; and if it is true

that homoplasty yields results as certain as does autoplasty, we might soon look forward to transplantation of other tissues by this means.

Up to date experiments in this connection, mutual immunization of donor and recipient, etc., have failed. In my clinic, certain complicated investigations in animals in connection with homoplasty and heteroplasty gave only partial results, none of which was permanent. Donor and recipient were immunized against one another's sera, and during the transplantation operation and while healing was in progress serum from the donor was injected under the graft. It was thus possible to obtain perfect adhesion, with a consequent result that the flap held for a longer period of time, *i.e.,* for about eight weeks. The size of the injections was diminished, so that while the flap received its accustomed nourishment, it had a chance at the same time to accommodate itself to the changed conditions. Whether or not anything more can be accomplished along these lines remains to be seen.

MUCOUS MEMBRANE TRANSPLANTATION

The obstacle to healing in mucous membrane transplantation lies in the infected surface upon which the graft must be placed, the results being more unfavorable than in skin transplantation. One can perform blepharoplasty by implanting a free or pedunculated flap of skin and mucous membrane from the lip. Utilization of portions of intestine as flaps naturally results in fistulous tracts in the wound.

Stressler and I independently have made use of the normal healthy vermiform appendix of a patient for the repair of a congenital or acquired defect of the urethra.

In a man of twenty-seven years, I found cicatrization of the bulbous portion of the urethra after rupture with leakage, the lesion also being the site of a large abscess. After excision of the stricture, there remained a urethral defect eight centimetres long. The healthy appendix of the individual was removed, the interior was scraped carefully, and the serous and muscular coats were stripped, in order to encourage nutrition through the medium of the raw surface. After the open lumen of the base of the appendix had been sutured to the central extremity of the urethral defect, the tip was drawn through the urethra by means of a suture. To prevent the flow of urine over the implanted tissue cystostomy was performed. In spite of the fact that no sounding was done, the patient, two and one-half years later, still has a normal stream. He testifies that after healing occurred there was no appreciable contraction of the graft, and at no time was there obstruction to the urinary flow.

One cannot expect satisfactory healing in every case, as the condition of the wound may not be favorable for implantation after the injury, since it is then the seat of scar tissue. The conditions of the soil are even worse in congenital defects. It is an absolute necessity to prevent the flow of urine over the graft for some weeks by means of a bladder fistula.

Mucous membrane homoplasty, in the experience of Axhausen and myself, yields no better results than those described under the skin. Legeuer and Tanton report successful transplantation of vaginal mucous membrane to repair the urethral defect of a male, but admit that sound dilatation was needed, and that six months later (the present time) sounds are still being used.

The field of usefulness of mucous membrane transplantation is not large. One must have recourse to the use of pedunculated mucous membrane flaps when large defects are to be repaired, as in the mouth, cheek, or bladder; or to pedunculated flaps of skin for others.

FAT TRANSPLANTATION

Fat transplantation was attempted with success by Czerny in 1893, when he implanted by autoplasty a lipoma on the wound surface following a breast amputation, thus substituting the lipoma for the breast tissue. Axenfeld, Neuber, and Bier also tried a similar procedure with small pieces of fat.

The first transplantation of large flaps of fat, as well as the therapeutic application of this procedure, was originally worked out by Lexer. He has demonstrated the first successful result, in a case where he padded out a sunken cheek with fat, following fracture of the angle of the jaw, three years after operation.

Rehn arrives at the following conclusions regarding the histology of the fat flaps transplanted by homoplasty and autoplasty:

After autoplasty part of the transplanted fat tissue remains unaltered; in the remainder, changes as found in homoplasty are observed. In spite of pressure atrophy, cell infiltration, and cystic degeneration, the embryonic fat cells, some arising from the older fat cells, others attached to the connective-tissue fibres, emerge as victors and regenerate. In homoplasty this process is exceedingly long drawn out. While there appears, after fifteen days, vigorous fat tissue in autoplasty, in homoplasty the constructive and regenerative processes are still in their infancy.

One takes the flap or pad of fat to be transplanted together with the subcutaneous tissue, being careful not to squeeze or tear it, and

implants it in the previously prepared wound, in which there is complete hæmostasis. And if the rule is followed that the transplant does not lie directly under the suture line, one can obtain excellent results, even when large flaps are transferred.

The clinical application has proved of value in numerous instances:

1. To pad out depressions of the face; for example, after comminuted fracture of the frontal bone, in which case an incision is made at the hair line, the skin is dissected away from the underlying scar tissue, and the fatty pad is inserted.

Defects after breast amputation can be likewise repaired provided the skin is in good condition. Filling out of the orbit after ocular enucleation has also been successfully performed.

2. Plugging up of bony cavities, the result of repeated operations for chronic inflammation, instead of leaving ugly bony packing, has been successfully accomplished by Chaput, Potherat, Makkus, and others. Hesse substantiates these good results. The implanted fat attaches itself to the fibrous tissue, which apparently is scattered throughout the bone. From my experience more rapid, more certain healing without sinuses occurs after this method than after the use of iodoform gauze packing.

3. To prevent adhesions: In this connection, from my own experiences, fat transplantation plays a very important rôle. Fat insertion to prevent rigidity of joint after operations for ankylosis succeeds with best results in the loose joints of the arm, although favorable results have also been obtained in the hip and knee (Murphy, Lexer, Röpke). In operations on the knee, fat pads prevented recurrence of fixation of the patella. Likewise, fat implantation on the freshened acetabulum has relieved the ankylosis of congenital dislocation of the hip due to hemorrhage (Lexer). What changes take place in the flap of fat introduced into the joints is not known. There was no sign of the oft-mentioned watery-like fluid. Whether or not it will make its appearance later I cannot say.

In progressive myositis ossificans, the only improvement I could obtain was increased range of motion by resection of the larger bony nodules and filling in the dead spaces with fat tissue.

I obtained marvellous success in protecting nerves and tendons by means of "areoloplasty" in preventing adhesion (Eden, Rhein). In this field the greatest successes have been achieved.

Extensive clinical investigations have demonstrated to me the value of fat implantation in brain surgery. In spite of the numerous plastic materials that have been tried to remedy dural defects, none serve so

well as fat tissue, especially when the pia is scarred, or is injured during the operation; or, when there exists also brain injury in the immediate vicinity of the dural defect. No graft, be it peritoneum, fascia, or fat tissue, can be implanted on the abnormal pia without the subsequent formation of adhesions or scar tissue. The transplant attaches itself to the injured pia, as it does on the bony side, but a thick flap of fat acts as a bolster and prevents the growth of tough, injurious scar tissue between the brain substance and the calvarium, at the same time effecting a complete closure of the subdural space (Rehn). This in my opinion places free fat transplantation for the repair of dural defects with co-existing brain injury or a pathological pia, as the method of choice before all other operative methods.

I have also had the experience to place a fat pad in a brain defect due to an open, dilated ventricle, closing the opening with a flap the size of a fruit plate. At the same sitting a skull defect was repaired with a bony graft, necessitating the healing together of two foreign tissues.

TRANSPLANTATION OF MUSCLE

Muscle is not favorable tissue to transplant by autoplasty, since it soon deteriorates because of insufficient nutrition. Even if, following the suggestion of Jores, the muscle is frequently stimulated by faradism, the end result is cicatrization because of the absence of the necessary nerve attachments. Success is not constant, even if the muscle be transplanted with its main nerve, so that it receives its impulses from the central nervous system. The possibility, however, of such transplantation was demonstrated by suturing the nerve to another nerve-trunk. The faradic current must be employed to exercise the functional powers, after such conductivity has been established.

Investigations by Wrede and Stiassing along these lines yielded negative results, while Göbel ascribes success to stimulation of the regenerative powers of the defective tissue rather than to the transplant.

It is very convenient at times, when there is a scarcity of fat tissue, to utilize pieces of muscle for packing bone cavities. Implantation is attended with as little irritation as when fat is employed.

NERVE TRANSPLANTATION

The reasons submitted as against the successful transplantation of muscle hold good for successful nerve transplantation. Transplantation of nerves can be utilized for bridging over defects, and they act

as do other tissues used for the same purpose, as, for example, segments of fresh veins, but there appears to be no advantage in using them. In order that other nerves are not injured, homo- or heteroplasty must be practised. Noteworthy reports have been recorded by Durour in heteroplasty.

Practically, we can in many cases of injured parts of muscles or where muscles as a whole have been destroyed, make use of transplantation by means of a pedicle, and, in the case of nerve defects, of other tissues as above mentioned. In those instances where entire muscle groups and nerves have been destroyed, muscle transplantation would be the ideal method of repair.

VESSEL TRANSPLANTATION.

Vessel transplantation has been made possible by the perfection of the blood-vessel suture (Carrel, Stich).

The first attempt was made by myself in 1907, when I resected an aneurism of the axillary artery and set in a section of the saphenous vein. The operation in itself is not difficult, but great care must be exercised in handling the graft, as the slightest injury predisposes to thrombosis.

Indications for vessel transplantation in arterial defects occur after resection for aneurism, removal of large arteries with tumor masses, especially where it is imperative that the circulation must be maintained. This is always the case when there are present conditions which militate against the establishment of collateral circulation, as arteriosclerosis, hemorrhagic infiltration, and cicatrization. Since autoplasty here deserves precedence, and one cannot employ the segments of other arteries of the patient, the saphenous veins must supply the grafts. The dangers attending ligation of the arteries of the arm or leg or common carotid will be minimized, in a certain percentage of cases, where there are present hindrances to the establishment of collateral circulation, if the surgeon can attempt to replace the arterial segment with one of vein.

The value of vessel homoplasty lies in the fact that healing and replacement take place only from the inherent blood-vessels and connective tissue. Thrombosis is of frequent occurrence. With heteroplasty no better results have been obtained.

Vessel transplantation is applicable for:

1. Replacement of arterial deficiencies as described.

2. Attempts have been made to repair congenital and acquired defects of the urethra by insertion of segments of fresh saphenous

vein. The results varied, due partly to unsatisfactory hæmostasis, and partly to coincident inflammation. It is not necessary to divert the urinary flow by means of cystostomy, as when an appendiceal graft is employed. Possibly this is due to the early adhesion of the adventitia to the walls of the wound. Constriction does not always follow, due to contraction and narrowing, and can be prevented by the use of sounds. Occasionally a mucous membrane covering is provided by the mucosa of the urethra.

3. Repair of ureteral and gall-duct injuries have been attempted by Makkas, Tietze, and Floercken without great success. Failure has been due to immediate utilization of the tube for urinary or biliary flow, which could be prevented only by nephrotomy or drainage.

4. Vessel transplantation is of value to bridge over defects of tendons or nerves. In the latter instance it is of the greatest value even in homoplasty, while I have long since abandoned insertion of vein or artery segments in the former, since free tendon grafts yield far better results and are more serviceable.

5. Henle and Payr have made use of vessel segments as drainage tubes in hydrocephalus, to direct the ventricular secretion into the venous circulation.

6. Koenig used fresh pieces of vein to protect uncertain suture lines, as, for example, in the urethra.

TENDON TRANSPLANTATION

The thought that tendons are amenable to transplantation by auto- and homoplasty occurred to me in 1907, when I noted how well they healed after my first knee-joint transplantation. This served as a stimulus to undertake the clinical and experimental investigation of tendon transplantation. The conclusions of my assistant, Ed. Rehn, which are of importance, follow:

The implanted segment of tendon heals,—even in homoplasty,—but marked differences in its properties are noted, dependent upon whether the part is immobilized or early motion is permitted. In the former case, adhesions occur, the segment is invaded by fibrous and scar tissue, so that it is tightly bound down, while early stimulation by motion results in the growth of a strong tendon, and regeneration is aided by the early appearance of blood-vessels along the suture lines. In no other part of the body does early functional stimulation play so important a rôle.

As the result of my clinical experiences, application of tendon transplantation is feasible in the following:

1. In the repair of torn ligaments, autoplastic and homoplastic insertion of tendons is attended by success, as, for example, in the patellar ligament, deltoid ligament accompanied by fracture, while repair of ventral hernia is possible if the fibres are laid in the same direction as the original tissue.

2. Tendons can be substituted for muscles for the cure of paralysis, or tendons can be replaced or strengthened in this way, or especially in defects of the tendons due to neglect, misplaced sutures, or where suppuration with necrosis of the tendon sheath has occurred. In these cases autoplasty with fresh tendon segments gives natural and most favorable grafts. These operations must be followed by passive motion.

Healing with resultant motion is attained by tunnelling out the wound, removing only small sections at a time, in order that the insert be not covered by a long suture line and consequent long scar.

My experience has been as follows:

If the tendon defect in the finger is covered by a large long scar, as is usually found after abscess of the tendon sheath, the adherent tendon must be liberated, and the cicatricial tissue must be removed down to the bone and capsules of the joints, after which the whole wound is covered with a pedunculated or free skin flap. This is then followed by the tunnelling above mentioned. If there is present deformity of the finger, due to suppurative necrosis of the flexor tendons, a small oblique incision is made over the inner side of the palm, down to the adherent tendons, and the latter are freed from the scar tissue and stretched. The skin is then raised by means of an elevator to the tips of the fingers while they are held extended. After the tendon graft has been firmly sutured to the flexor profundus tendons it is guided through the canal with a small sound to the finger tips and there sutured to the subcutaneous fat close to the bone. In order to obtain an ideal result, so that the graft is attached to both phalangeal joints, another segment is sewed to the stump, and guided through the canal to the middle phalanx, where two small lateral incisions are made and the distal extremity is sutured deeply, under protection of the nerves and vessels.

It is a simpler matter to implant the extensor tendons. Where multiple tendons are to be repaired, it is necessary to build up a skin flap. If primary union occurs within a week, active and passive motion is instituted and continued as long as is necessary.

After mobility has been obtained after transplantation of the flexor tendons, one can apply transverse bands about the joints to hold the tendons in place, or a like result can be accomplished by having the

patient wear a ring, so that when an object is grasped it presses against the ring (Rehn). In this way the profundus is brought into action strongly. A procedure that yields good results is a transverse bridging of the skin over the median joint, *i.e.*, two long pedunculated skin strips are placed crosswise over the joint. The scar between the flaps should lie immediately over the normal skin fold of the joint. This bridging acts just as does the transverse band, in that it allows bending of the tendons. In cases where there existed no previous ankylosis, or where the bones had not suffered extensive injury, we were rewarded with satisfactory results (Rehn). When ankylosis of the phalangeal joints is present, it must be remedied by insertions of fatty flaps before the tendon repair is begun.

Tendon transplantation is also of value for lengthening tendons, where muscular deformity has occurred as the result of contraction, as after ischæmic paralysis in the forearm. After the tendons have been divided, and the deformity of the fingers has been corrected, insertions are made into the defective flexors. In children with thin tendons, I lengthen the tendons by a Z-shaped incision.

The source of the material for this form of transplantation is easily accessible, but not always available. One can remove without harm the tendons of the palmaris longus by making two small tenotomy incisions. Also, the extensor tendons of three to five toes can be utilized without disturbance to the function of the foot.

Tendon homoplasty is apt to cause adhesions because of the irritation of the foreign tissue, for which reason it is more useful in the repair of ligaments than for freely movable tendons.

FASCIA TRANSPLANTATION

Fascia transplantation is similar to tendon transplantation. To Kirchner belongs the credit of the original experimentation and clinical proofs in this field. The indications are numerous: repair and strengthening of ligaments and capsules of joints; repair of tendons and dura mater; reinforcement of suture lines as in large hernia (Könog, Hohmeier); building up of aponeuroses for the transfer of muscle function, as in the frontal muscles for ptosis; application of fascial flaps between articular surfaces after post-operative injury to the synovial membrane; in mobilization of joints; as a base for hæmostatic sutures in organs; suspension of the pylorus at the site of excision (Wilms). Attempts have been made to utilize fascial flaps for large defects of the pleura, the diaphragm, or trachea. They are not of practical value for the replacement of tendon or nerve sheaths, since dense adhesions are formed (Goldmann).

The source of the material is the fascia lata, with its strong fibres from the outer side of the thigh. Homoplasty carries no advantage over autoplasty, because of the availability of the material. According to Rehn's experiments on animals it is practically possible.

PERIOSTEAL TRANSPLANTATION

In 1859 Ollier attempted periosteal transplantation, and later investigators have confirmed Marshaud's findings, that periosteum belongs to that class of tissues which permit implantation, and that it pursues its function of bone production provided that the soft medullary tissue does not come in intimate contact with bone.

Its application is like that of fascia, exclusive of tendons and ligaments. Periosteal flaps inserted between torn synovial membranes of the elbow-joints have acted well, according to Hofmann. Fractures have been enveloped with periosteal flap to increase callus production.

Practically, autoplasty has been proved, and homoplasty is not far behind, since we know the bone producing property of periosteum that has been transplanted together with bone.

PERITONEAL TRANSPLANTATION

I first attempted implantation of peritoneum for the repair of a dural defect, acting upon a suggestion from Kocher. Normal peritoneum was not used, as a hernial sac and a hydrocele sac were at hand. Adhesions resulted, just as they did in attempting to build up a new capsule about a knee-joint. According to Drandt, the use of peritoneum to repair dural defects with normal underlying pia, whether it was implanted on the inner side or the outer, or even if both layers were employed, resulted in the same way. Kolaczek, however, in implanted peritoneum over normal pia, noted few or no adhesions.

I question the value of repair of dural defects with peritoneum, fascia, or periosteum, since the underlying pia is usually injured, cicatrized, or necrosed, and dense adhesions follow between the skull and brain. For this reason, as above mentioned, I prefer the method of fat transplantation, since the graft acts as a pad and prevents areas of adhesions.

Transplanted omentum is liable to adhesion in the free peritoneal cavity, as shown by Springer. It, therefore, is an excellent material to use for the repair of injuries of the intestinal wall not accompanied by perforation or to strengthen the suture lines in gastric surgery (Sabaki).

BONE TRANSPLANTATION

In the art of transplantation, bone implantation is the most ancient; in point of knowledge and practical use, it is more important than even skin transplantation.

In the interesting history of bone transplantation, the following facts are worthy of mention: In 1809, Merrem obtained successful healing of bony plates in the skulls of animals after trephining. Later Walther, in applying these experiments to man, obtained partial healing in spite of coincident suppuration. Ollier then, in 1858, attempted with success bone transplantation in animals and in man and worked out its applicability.

The conclusions of Ollier consisted in the fact that fresh bony tissue covered with its periosteum remains viable, that denuded of periosteum it necroses and acts like a foreign body, becomes absorbed, and is replaced by bone only because of contact with the osteogenetic walls of the wound.

Dead bone, *i.e.*, macerated and boiled bone obtained from the cadaver, or fresh bone which has been sterilized, lends itself to transplantation, but it acts as does a foreign body, which slowly undergoes substitution; it is rapidly destroyed by vigorous granulations, by means of a "gnawing" process. Foreign body suppuration with extrusion of the dead graft, long after primary union, occasionally occurs. Likewise bone transplanted from animals, as, for example, that of the dog, is tolerated by man. Küttner obtained good results only with bone of the ape. I obtained union of segments of long bones, *i.e.*, in the defective bone, only when the periosteum of the recipient was intact. Homoplastic and autoplastic transplanted bone will heal without partial absorption only when the fresh graft is transferred with its medulla and periosteum.

The function of the graft and its covering lies in the fact that it replaces the missing tissue and enables the body to build up new bone. For this purpose the transplant is endowed with long life and vigorous powers of regeneration, and the implanted graft retains its shape until the edges of the recipient's defective bone regenerate, in spite of the fact that the implanted bony tissue disintegrates and becomes necrotic, as Marchaud, Barth, and others have established.

A further advantage in including periosteum is that it aids in the cementing of the graft to the wound edges and stimulates invasion by blood-vessels, thus establishing early nourishment.

These clinical conclusions have been substantiated in many respects by histological investigations. Barth recognized the fact that

included periosteum plays an important rôle in transplantation, and later experiments by Axhausen, Frangenhein, and others have demonstrated positive proofs in this respect.

As Ollier has shown, the best material to use for bone transplantation is the bony tissue, including the medulla and periosteum. Autoplasty, concluding from our experiences, is the method of choice, and one does not find any difference whether the graft is implanted as one piece or in fragments. Necessary substitution can take place only through the agency of the implanted elements of the periosteal and medullary layers. In fragments of bone transplanted by autoplasty this occurs in a lessened degree. Petroff, experimentally, found a distinct difference in homoplasty and autoplasty in that substitution took twice as long in the former. It is certain that the best form of healing, together with survival of the bony tissue, with slow absorption and equal regeneration by means of the inherent elements of the graft, occurs usually with autoplasty; and, furthermore, that the application of large denuded (of periosteum) living pieces of bone—equally in auto-, homo- and heteroplasty, or with the use of dead bone—when imbedded in bare (not covered with periosteum) spaces, is accompanied by so rapid an absorption that substitution cannot keep pace with it, so that the continuity of the entire piece becomes broken.

Clinical success, therefore, in the repair of large denuded bony cavities, can be achieved only by the use of living bone covered with periosteum. Should, however, the periosteum of the recipient be intact, it is immaterial what method of transplantation is employed, as the respective graft heals as does a foreign body, and is soon replaced by the periosteum of the defective bone, in fact often thickened.

In spite of this, preference should always be given to the living homologous bone, as the foreign body, which irritates the periosteum and thus stimulates its bone formative processes, otherwise soon disintegrates. By autoplasty skull defects can be repaired, with periosteum covered plates obtained from the outer table nearby (repair of skull defects, Lexer). In children, where the skull is so thin that even pedunculated, skin-covered flaps cannot be removed, periosteal bony flaps may be transferred from the tibia. Röpke suggested resection of a portion of the scapula for the repair of skull defects, in order that the graft be covered by periosteum on both surfaces. For smaller defects, those concerning the small bones, as, for example, of the carpi, or for the repair of saddle nose, rib resection can be performed. The fibula yields good fragments without periosteum. Large, broad fragments can be obtained from the anterior portion of the tibia; the cavity

naturally healing from the medulla (Bier). Entire phalanges of the toes permit of transplantation into the fingers (see joint transplantation). Autoplastic material is scarce. In homoplasty use can be made of amputated limbs which are not the seat of inflammation or malignant growths (serious injuries, dry gangrene, dry diabetic gangrene).

The field of usefulness for free bone transplantation is large. Only the most important indications are mentioned.

1. Repair of cavities in the cranial bones. One or more segments of the external table covered with periosteum are transferred from the immediate neighborhood. The cortex of the tibia or a portion of the scapula also is available. In the latter, it is of advantage, as the fragments are surrounded by periosteum.

2. Filling in of sunken spaces in the face. In saddle nose, in sunken spaces in the forehead following operation, or in bony defects due to tuberculous osteitis of the facial bones, in recession of the superior maxilla due to hare-lip, after the soft parts are raised, small fragments of bone may be imbedded.

Bony plates may be imbedded in the skin of the arm, later to be transferred for the repair of nasal and facial defects, as recommended by the Italians.

3. Repair of defects of long bones and the inferior maxilla. In the long bones, even when the periosteum is destroyed, large defects can be repaired, coincident with amputation. Only one needs fresh amputation material in order to obtain bone of sufficient thickness. Since such extensive defects are, as a rule, the result of operative interferences for centrally situated sarcoma, successful repair does not always follow. If a graft is not at hand, contraction of the defect can be prevented by the insertion of pieces of ivory or horn, and later fresh periosteum covered fragments can be substituted.

Where the above substitute is not used, and contraction of the soft parts occurs on account of bands, care must be observed that cicatrization is prevented in the wound intended for the transplant, since, owing to the deficiency of blood-vessels, nutrition is interfered with. Cicatricial tissue also prevents the formation of a strong callus on the part of the recipient, as it is necessary that vigorous growth occur into the graft. In defects of the long bones, long pieces of thin transplant (fibula or femur) have been utilized, being selected because of the functional obligation of the limb to carry the weight of the body. In the arm, on the other hand, thicker segments are indicated, since they become thinner and disappear. For this reason, in defects of the long bones of the arm where the periosteum is wanting, very thick fragments

should be imbedded. For the shorter bones, where defects, as a rule, are due to tuberculosis or suppuration after injury, pieces of rib or fragments of the tibia (mostly autoplastic) are useful.

In repair of the inferior maxilla, free bone transplantation is applicable, but one has to deal with intercurrent infection of the wound from the oral cavity. In 1908, I recommended the trial of transplanted fragments of ribs covered with periosteum, by homoplasty. Several authors (Goebell, Dumont) later reported successful results by using rib segments or clasps of tibial fragments. Secondary imbedding in the resection wound is naturally less prone to the danger of infection than primary. However, on account of the situation of the lower jaw, the latter is more imperative.

4. Fastening of bony fragments. Fresh fragments of bone, particularly of tibia covered with periosteum from amputated limbs, or costal or tibial segments from the same patient, have been used by Lexer to fasten the fragments of old or recent fractures, especially of the neck of the femur. One-half of the length of the transplant is forced into the medullary cavity of one fragment, the remainder into the medulla of the other fragment, of the fractured bone. Should insertion into the latter be difficult, the medulla can be enlarged by splitting the shaft beneath the periosteum. This "bone bolting" is useful in immobilization of the ankle-joint of the paralytic foot (Lexer); a canal being bored from the heel, through the os calcis, and astragalus to the lower end of the tibia. This canal should not be made too wide, as the bolt must be inserted forcibly so that blood and detached marrow cannot collect between it and the bone, since bone will unite with the surrounding bony tissue only when it lies in intimate contact with it, otherwise granulations appear in the walls of the canal, interfere with nutrition and predispose to rapid absorption. Some of the failures reported by authors are due to this technical error. It is a strange fact that this bolt stimulates thickening of the spongy portion of the bone, while it is absorbed in the upper ankle. Therefore ossification rarely takes place in this joint, as a rule, only the necessary immobilization. This procedure is simpler than the usual arthroplasty, and with proper care yields satisfactory and permanent results. Bony bolts can be used in the place of nails to fasten bones, as after the resection of joints.

Other applications of bone transplantation are the replanting of dislocated bony splinters, which must be removed on account of severe injury or pressure on nerves or vessels. It has been attempted (Albee) to repair vertebræ, the seat of tuberculosis, by imbedding plates of tibia, or to fasten the vertebral joints after dislocation through the medium

of pieces of the spine of the scapula (De Quervain). Recently, Perthes reported the successful cure of flat-foot by means of bone transplantation. The inner border of the foot is shortened by removing a section of the navicularis. Osteotomy of the os calcis is done and the outer border of the foot is lengthened by driving the fragment of the navicularis into the incision in the os calcis.

CARTILAGE TRANSPLANTATION

According to Marchaud, in cartilage transplantation the perichondrium plays the same part that the periosteum does in bone or the tendon sheaths in tendon transplantation, since it favors regeneration of the parts that tend to disintegrate. Repair can also occur, as shown by Axhausen, by reproduction of the living cartilaginous cells, so that successful transplantation of cartilage does not depend entirely upon the presence of perichondrium; a fact that has an important bearing on the satisfactory outcome of implantation of articular cartilage.

Since cartilage from the ribs is so easily available, it is, as a rule, unnecessary to resort to homoplasty, although it yields good results.

Cartilage transplantation can be utilized for filling out sunken areas on the face; or for imbedding between the torn layers of the synovial membranes of the smaller joints, when other tissues, like fat, are not available. For nasal repair, a small piece of costal cartilage forms a good tip. A sunken tip can be raised by the insertion of cartilage into the septum. In the repair of saddle nose, fragments of cartilage have the preference over bony segments, as they can be more easily fitted. One may substitute pieces of cartilage for bone in the repair of phalanges, carpal or tarsal bones.

The advantage of cartilaginous union over that of bony is problematical, since its properties, regarding durability and usefulness, are the same as those of periosteum and osseous tissue. This fact is of the greatest importance in determining the future growth of transplanted (homoplastic) joints during the growing age (children). Experimental evidence leads to varied conclusions (Helferich, Enderlen, Rehn, Borst, Heller, von Tappeiner). The majority found more or less necrosis at the site of the union, with disturbance of the reproductive processes (in homoplasty). Heller found the greatest interference in homoplasty, less in autoplasty. Rehn obtained very favorable results. He transplanted by homoplasty the radial epiphyses of young guinea-pigs of the same brood, and demonstrated the endurance and the reproductive powers of the cartilaginous border.

Even though the majority of investigators rule against the practical

application of cartilage transplantation, Küttner was able to perform heteroplasty by transferring the fibula of an ape into a child, which one and one-half years later, under X-ray, showed complete viability of the epiphyseal line. In one case, in whom I performed homoplasty (repair of an ulna by means of the shortened fibula of an older child) two years after showed by X-ray adhesion of both cartilaginous areas, but disturbance of growth was not noted, although the central portion of the bone was completely absorbed.

Saer has accomplished recently, by means of autoplasty, substitution of the head of the fibula for a severely injured distal extremity of the radius in a child. This procedure is rather too recent to be commented upon.

No definite opinion can be given regarding the ultimate applicability of implantation of cartilage, because the number of operated cases have been small, and have not been observed for a sufficient length of time, and animal experimentation has given rise to varied results. At any rate one is dealing with a very susceptible tissue, since the slightest interference with nutrition disturbs its growth.

JOINT TRANSPLANTATION

Joint transplantation is the outcome of the work done with cartilage and bone transplantation. It necessarily follows that if one can perform homoplasty with large segments of the long bones, it is possible to transplant the bone with its articular surfaces.

The earliest experiment in this field was attempted in November, 1907. It occurred in a case of defect in the tibia involving the entire upper third of the tibia, including the articular surface, due to a central sarcoma. The former procedure in like cases was to engage the lower end of the femur into the tibia by boring, thus permitting of union between the bones with considerable shortening of the limb. In order to obviate the latter result, and, if possible, to restore the mobile functions of the joint, a similar portion of tibia was removed from a freshly amputated limb and implanted with its articular cartilage and periosteum.

Then the thought arose to advance a step further. If it were possible to achieve healing of this large segment of bone with its articular extremity, like success might be attained by transplanting the articular surfaces for the repair of joints.

This idea I carried into play on the same day, as I had at hand a freshly amputated limb, and had on numerous occasions attempted to use other tissues and, lately, fat, to mobilize joints. After resection

of the synovial sac, the articular surfaces of the tibia and femur, with their attachments the crucial ligaments and the meniscus cartilages, together with the cartilaginous fragments of thumb thickness were dissected and implanted in their entirety over the previously prepared defect. The first method I called half transplantation and the second whole joint transplantation.

By half joint transplantation, I implied transplantation of bony extremities, utilizing their articular membranes as much as possible, while in whole joint transplantation I attempted imbedding of long bones with both articular surfaces. This work was successfully carried out by others (Küttner, Rovsing, Wolff, Enderlen, etc.) as well as by myself.

The source of the material has been freshly amputated limbs. I have discarded the use of material from the fresh cadaver, first, because of the difficulty in obtaining sterile tissues from the morgue, and second, because fibrous encapsulation took place in one case of knee transplantation. It is another matter to utilize a limb or segment of bone from one who has met his death by injury, provided all the rules of asepsis are observed.

Küttner has further worked out the utilization of the fresh cadaver, and reports successes in half transplantation. This author employed homoplastic material under great difficulties, and in fact performed heteroplasty with tissues in which the albumen is closely related to that of man, *i.e.*, from the ape.

Autoplasty is applicable only to the finger-joints, as the toes can be substituted for them. Shortly after my first report, Buchman reported transplantation of the toe-joint into the elbow, after having arrived at the same conclusions as I had. Judet coincidently demonstrated limb transplantation in animals. Two specimens, the first being removed because the patient objected to the idea of carrying about the bone of another individual, the second because of the incidence of sarcoma, on examination showed the following changes:

The upper third of the tibia, implanted one and one-half years ago, which was healed into the knee with excellent functional results, showed spots of cartilage which had been isolated by areas of necrosis. The periosteum of the implanted fragment is thickened, and the fragment is firmly united to the bone of the recipient by callus. Osteogenesis is demonstrable from the periosteum. The cortex as well as the ramifications of the spongy layer is necrotic; at the site of the medulla there is present in the canals of the spongiosa fresh fibrous tissue, in the interstices of which there is bone regeneration. The articular cartilage

is in most part well preserved. The menisci are adherent to the capsule, as is the recipient's patella to the implanted tibial fragment.

The findings in the second case are similar five months after implantation of the lower end of the femur, except that there is present a spontaneous fracture due to the sarcoma.

The relation of the firm union of muscle, tendon, and ligament with the graft to restoration was noteworthy in these specimens, as well as in those of Küttner. Clinically, there were no unfavorable sequelæ, excepting a fluid exudate in the knee of my first case. The limbs were soon endowed with normal function, the leg was useful in walking and standing without aid. X-ray after two to three years showed irregularities in the borders of the implanted grafts, exactly like the deformities of arthritis deformans.

Naturally, the long bones can be transplanted in their entirety with both articular surfaces. This does not as yet pertain to the large bones as it does to the smaller ones. After injury of a phalanx with loss of function it formerly was the custom to amputate, as it interfered with the other fingers. Now, one is able to obtain a phalanx from an amputated limb, as I first showed in 1907, or autoplasty can be done by removing a toe, or a segment of rib cartilage, or other fragments can be utilized. Others (Wolff, Sievers and Goebell) also report successful work in this field.

Finally, half transplantation is useful in replanting injured parts of joints after luxation-fractures, as of the head of the humerus, part of the lower extremity of the humerus (Lexer, Perthes, von Haberer). Here the favorable wound bed plays an important part, as hemorrhage, infiltration, necrosis and cicatrization prevent the rapid establishment of sufficient nutrition.

In whole joint transplantation, where both opposing articular surfaces are transplanted, it follows naturally, that the articular cartilage must lie within the capsule of the joint. It was therefore feared that fibrous tissue would originate from the surrounding tissue, invade the joint cleft, destroy the cartilage and hinder mobility. On account of this fact, I attempted in the first case after healing of the joint, to implant fresh hydrocele sac to act as the articular capsule. Of course, induration occurred about the graft, but as shown after re-operation, this in itself acted as a sort of capsule, and prevented invasion of the joint cleft by scar tissue.

Up to the present time progress in whole joint transplantation has been limited to the knee-joint. From a clinical stand-point, I can testify to complete healing in a knee-joint, six years after transplantation.

The X-ray shows transformation partially by means of absorption, and partially by means of excessive growth at the site of union, similar to the changes occurring in arthritis deformans, but motion and function are perfectly free and satisfactory.

The joints are useful, because change in shape in this abnormal situation is prevented on account of its pre-existing form, and because mobility of the leg aids in this prevention.

The mechanism of the new knee-joint is in no way normal, since there occurs no rotation on the condyles. In a normal sense, there is present a pseudo-arthrosis, in which there occurs anterior gaping on motion. For this reason, I remove an elliptical segment of the thigh, and place on this the rounded portion of the stump of the femur. Thus, the patellar fascia of the transplant is anterior to the circumference of the condyles. This case, however, in spite of faultless healing and function, is of too recent occurrence to base any opinion on its permanence.

The greatest difficulty following fortunate implantation lies in the restoration of the severely injured extensor muscles, which with the tendons are occasionally destroyed by intercurrent suppuration, or which because of long standing ankylosis have become atrophic and fatty.

For this reason motion may be only passive, or flexion and extension may be restricted. Where the musculature is well preserved function is naturally more satisfactory than where operations are necessary to first restore the possibility of active motion.

Following the transplantation of both raw joint surfaces successful healing occurs, and if the graft is properly fitted material capable of substitution is deposited. The implanted portions grow according to their inherent abilities, and the substituted material is not subjected to stiffening or shrinking, this fact being in line with animal experimentation.

All ankylosed joints are not equally suitable for transplantation. Those after resection for tuberculous arthritis are subject to suppuration, because of remaining tuberculous foci, or due to weakening and cicatrization of the tissues about the transplanted material.

Knee-joints, the site of transverse scars, exerting traction on the resection line, are unsuitable for transplantation.

Toe-joints only can be used for finger-joint transplantation by autoplasty. One can even attempt transplantation of the capsule in this instance (Göbell), a method which resulted as a failure in my hands with homoplasty.

Satisfactory material for transplantation is difficult to obtain, since the limbs of elderly individuals are the seat of atrophic fatty changes in the cartilages, or the more or less crippled joints are of low vitality and have poor regenerative qualities, being subject to rapid absorption and complete necrosis. These difficulties are the exception in total joint transplantation, since under favorable circumstances satisfactory results are obtained.

I have established the fact that good results can be obtained in restricted joints, by freeing the articular adhesions and implanting fat, fascia, periosteum or muscle. In the after-treatment, because of the tendency to contraction, one must institute early passive motion, while during the operation, care must be observed to prevent recurrence of stiffening, by means of sufficient articular separation. The latter, again, may be followed by abnormal lateral mobility.

Experimentally, it is extremely difficult to perform joint transplantation upon small animals, since the transplant is readily injured by handling, and especially because complete hæmostasis is difficult The experiments of Judet, Wrede, Dalla Vedove, Duguing, Borst for this reason are unsatisfactory.

One cannot draw any conclusions on account of the difficulty of transplantation in small animals, from the occurrence of the total necrosis that is found. These failures demonstrated one fact, that success does not depend necessarily on the survival of the transplant. It has been shown in animals (Wrede, Judet, Axhausen, Rehn) and in man (Lexer, Küttner) in support of this fact, the successful transplantation of bone and cartilage, and in the latter, preservation of cartilage, periosteum and bone marrow with osteogenesis. Of clinical importance is the property of substitution as established by Borst.

TOTAL LIMB TRANSPLANTATION

Transplantation of fresh limbs *en masse* has been attempted from various points of view, but up to the present time autoplasty only has yielded results, *i.e.,* replanting of an amputated limb (Carrel and Jianu in dogs, Jianu in man, in whom there was not complete separation, in that the skin and veins remained uninjured).

The question of replantation of divided limbs comes up after severe accidents, but naturally, when the tissues are not macerated. Whether or not it is possible to replace an amputated limb by homoplasty, using one from the cadaver, remains to be seen. Until the outcome of this speculation is decided, it will be interesting to follow homoplastic limb

transplantation in animals and to note the effect of the foreign blood circulating in the grafted tissues.

Animal experimentation so far, along these lines (Carrel, Lexer) has been devoid of success, and promises practically nothing, since, besides ischæmic inflammation and contraction, it is followed by hemorrhagic infiltration and nerve disintegration.

ORGAN TRANSPLANTATION

The large domain of organ transplantation, unfortunately, has not as yet won practical recognition in spite of the hope that the possibility had been realized that entire organs could be transplanted through the medium of the main artery and vein with the respective vessels of the recipient (Carrel, Stich). Borst and Enderlen have established the fact that only those organs are preserved which have been removed from an animal and replanted into the same animal shortly after. Our knowledge of to-day emphasizes the difficulties of homoplasty in general, in that the highly differentiated tissue of organs always disintegrated.

Likewise the idea of Sauerbruch, of parabiosis (union of two similar animals by means of arterial and venous anastomosis) in order to mix the bloods, and thus to supply the homoplastic implanted organ in the recipient, with the nutritive substances of the donor, has as yet not yielded results (Enderlen). And if these difficulties were surmounted, and the homoplasty were successful, could one expect permanent continuance of function, when innervation of the glands is absent?

Only the organs with internal secretions, the ductless glands, functionated after transplantation (epithelial cells, ovaries, thyroid gland). But function did not persist, it is to be regretted, in that it remained only so long as the important substances were secreted from the slowly disappearing grafts. Experimental investigations have conclusively demonstrated in these cases disappearance of the transplant.

The clinician will be wise not to count upon prematurely awakened hopes for some time to come. It is possible that the outlook in homoplasty may be improved in one way or another, as has occurred in skin transplantation, and that it may bring us near the goal.