There must be no spring exerting a pull on the screws. Plates should, if possible, be applied to a surface of the bone that is covered by muscle, and they must be stout enough to make bending or breaking improbable. Drills must correspond to screws: soft or cancellous bone calls for smaller drills than hard bone. Lane advised that screws should pierce the distal compact bone only in young children. Particular care has to be taken that the drill-holes for the first two screws correspond with the centres of the holes in the plate, or the fragments may be slightly distracted—an undesirable though fortunately not necessarily a fatal fault. Screws should be driven home tight. The number of screws inserted in each fragment *must* be adequate for the work they have to do. For the femur, at least four screws in each fragment are necessary; for the tibia three screws; and for the radius and ulna two screws in each fragment. One of the commonest mistakes is the use of too short a plate and an insufficient number of screws. Another common fault is inadequate post-operative external splintage, or, if adequate, not maintaining this splintage long enough. These errors all lead to undue strain on the screws, which become loose, with disastrous results. It is not always remembered that with internal fixation of the fragments callus is reduced to a minimum, and in many cases no provisional callus whatsoever is formed. External splintage is necessary for a longer period, if the shaft of a bone is involved, than if a fracture is treated without operation, the apposition of the fragments being equally good in both. In the forearm the fragments may be sufficiently stable when placed in apposition to make a plate unnecessary.

The Vitallium Screw

Vitallium screws, long enough to pierce the cortex on both sides of the medullary canal, are coming into fashion, and some surgeons are showing an inclination to rely entirely on them, no splints of any kind being used. This tendency must be watched: careful judgment is necessary if disasters are to be avoided. Incidentally it is my opinion that the introduction of vitallium should not be regarded as the solution of all our troubles. Great care to guard against sepsis is still just as necessary as it was. I consider that trouble with plates and screws points to a faulty technique on the part of the surgeon. Screws become loose because they are subjected to too great a strain or because they are infected, or both. The theory of electro-chemical irritation around a steel screw is attractive but not very convincing. How do the supporters of this theory explain the by no means rare experience of finding, when removal of steel screws is called for long after their insertion, that one screw is loose while its neighbour can only be removed with the help of a screw-driver? The thread of the vitallium screws reaching this country seems to be quite unnecessarily fine: a coarser thread would, I think, be an advantage. Wires and bands around the shaft of a bone are to be avoided as a rule. Wire rarely affords adequate fixation in the shaft of a bone: disasters following the use of wire are fortunately less common than they were. Parham bands, an attractive device for an oblique fracture of a shaft which is of even diameter in the region of the fracture, are dangerous. If used at all they should be removed later. In the absence of all obvious signs of infection a circular line of absorption of the bone may occur beneath the band, and as there is no subperiosteal callus formed whatsoever, this may weaken the bone to a dangerous degree.

There are definite indications that the pendulum, which I think had swung rather too far from operative to non-operative methods of treatment for simple fractures, is swinging back towards the more extended use of internal fixation. This tendency will need careful watching, or the pendulum may again swing too far.

Finally, I venture to remind my readers that cutting down on a simple fracture is not an operation to be lightly undertaken by any surgeon. Like many another specialized operation, it is a justifiable procedure only in the hands of a surgeon with the necessary training and, above all, one whose technique is above reproach.

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SURGICAL AMPUTATIONS AND THE FITTING OF ARTIFICIAL LIMBS

BY

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I would like first to express my indebtedness to the Ministry of Pensions, including all the surgical, medical, and technical officers, for granting facilities to make use of the data and information collected in the past 25 years, and in particular to Dr. R. Langdale-Kelham, the senior limb-fitting surgeon to the Ministry, with whom I have worked for some time and who has given me the opportunity of studying the question of fitting of limbs in detail. It is hoped the information and suggestions incorporated in this paper may be of some service to surgeons and possibly to amputees.

Amputations and Rehabilitation

Amputations have been recorded in many surgical textbooks over a number of years, particularly since the advent of aseptic surgery. The types and sites of similar amputations have varied, with the result that a difficult problem is left in many instances for those called upon to supply the prosthesis. It is stated that a good limb-maker should be able to provide a suitable prosthesis for any type of amputation, whether following a surgical operation or due to a congenital deformity. This is quite true, but it is definitely established from results of limb-fitting during the past 25 years that only certain lengths and types of stumps render the amputee free from further surgical attention. Also, latterly the artificial limb has been improved and re-designed to cause less strain and give more comfort to the wearer.

When an amputation is performed upon any limb it starts a new phase in the life of the amputee. He must rehabilitate himself, and rehabilitation is obtained only by co-operation between the patient, surgeon, and all responsible for the treatment of the stump up to and including the actual fitting of the prosthesis. There are three main objectives: first, the surgeon should provide a stump which will not require any further surgical attention; secondly, the nursing staff and others concerned should treat the stump by correct bandaging and exercises, so that it may be fitted in the shortest time with a prosthesis of a design suitable for the patient's future work; thirdly, the patient should be taught to use the prosthesis correctly to enable a speedy return to his original work or some other suitable employment, and so remove the fear of being styled a "cripple."

With the exception of Service cases from the last war it can be stated generally that surgeons have not been able to follow up and watch closely the results of amputations they have performed. Once the operation scar is healed the amputee leaves the hospital with little instruction upon the care of the stump or of the prosthesis he obtains. If the stump breaks down for any reason the amputee consults his own doctor, who may have had little experience in the treatment of such cases.

During the latter part of the war of 1914-18 the Ministry of Pensions set up an organization, with its main centre at Roehampton and 17 centres in the provinces, to provide all Service amputees with prostheses, to supervise the fitting, and to repair broken or worn parts. A very important feature was the regular inspection of the amputations, with the appropriate treatment when required. Records of this work were carefully summarized, with the result that valuable information was obtained, as I shall attempt to show.

Above-knee Amputations

Weight-bearing.—Nature has so developed the human body that, when walking, the weight is borne by the foot, and when sitting by the ischial tuberosity. If the lower limb is amputated at any level the weight ought therefore to be supported by the ischial tuberosity. About 20 years ago most amputees took the weight upon the end of the stump, but within five years over

75% of such cases were corrected. A number had to be re-amputated for surgical reasons, while others were altered before the end of the stump had deteriorated. One seldom now sees a case in which the weight is taken by the end of the stump: such amputations as the Stokes-Gritti and the transcondylar were re-amputated. This above-knee stump fits into the "socket" of the prosthesis, made of metal or wood, carefully shaped so that the ischial tuberosity rests on the inner edge, the patient thus sitting in the socket. Upon walking he naturally lifts the stump a trifle out of the socket, producing a slight "piston" action which is by no means detrimental to the stump except when the scar is terminal and adherent to the amputated end of the femur. Also there should be no scar tissue near the ischial tuberosity, the head of the great trochanter, or the upper part of the thigh, if this can be avoided.

Musculature.—The muscles of the thigh are used by an amputee to control the prosthesis in exactly the same manner as by a normal walker. The flexor muscles enable the stump to lift the prosthesis upward and forward, the lower part being swung forward at the knee-joint. The heel is then pressed on the ground and the extensor muscles push the socket backwards, extending the knee-joint and maintaining it in full extension. Diagram 1 shows the stump control of the prosthesis and the

DIAGRAM 1

position of the scar. The adductors and abductors control the balance of the amputee on the limb as with a normal person; therefore during amputation as much as possible of these muscles should be left. With the ideal stump length, discussed later, only a small portion of the adductor magnus is removed, as shown in Diagram 2. The extensor muscles should be

DIAGRAM 2

DIAGRAM 3

severed so as to end about half to one inch above the scar in order to avoid adhesion between the muscle ends and the scar tissue.

Stump Length.—The experience of the past 20 years and the periodic examination of stumps clearly indicate that the ideal

length is between 10 in. and 12 in., as measured from the tip of the great trochanter to the amputated end of the femur. Such a length requires no further surgical treatment and affords adequate control of the prosthesis. A number of amputees with a longer stump experience circulatory troubles, while many have had to undergo re-amputation.

Scar.—With the ideal stump there is an ideal site for the scar, as depicted in Diagram 1. The larger anterior flap method ensures a transverse posterior scar about 1½ in. from the end of the stump. If complete haemostasis is obtained no drain is required and the wound will heal quickly. There are many reasons for choosing this position, the chief being that the scar will never have any direct pressure exerted upon it by the use of the prosthesis and also that there will be no traction over the scar such as would occur if it were terminal.

Flaps.—The flaps need only contain enough tissue to maintain their own nourishment; any superfluous tissue may cause discomfort in the wearing of the prosthesis.

Sciatic Nerve.—Various methods of dealing with this nerve during amputation, such as crushing, ligaturing, or injecting the end of the nerve with alcohol or similar substances, have been described in textbooks. Some of these procedures are unfortunately still in use, with the result that there is often a great deal of pain, and in numerous cases "phantom foot" is felt. The nerve should never be crushed, ligatured, or stretched. It should be treated as carefully as possible, being very delicately dissected out of the musculature and severed a little shorter than the cut muscles to prevent adhesion of the nerve-end. The artery of the nerve may in exceptional cases need tying.

Short Above-knee Stumps

If a stump has to be shorter than the ideal just described the amputation should be guided by the above principles, the chief consideration being to leave as much of the adductor musculature as possible, while at the same time removing all pathological tissue to obviate any further surgical intervention. It must be stressed that there should be no complete disarticulation of the head of the femur unless this bone or part of the joint is diseased. After amputations which leave about 4 in. of femur a special prosthesis is designed, because this short stump cannot be accommodated in the ordinary type of socket and there is no stump control. This short stump is flexed to 90 degrees from the normal position and a socket fitted half-way round the pelvis. The projection of the end of the femur, together with the natural contour of the body with the femur in position, allows the patient to wear the socket comfortably. With a complete disarticulation the socket tends to slip down and rotate on the body with every step taken. Whenever possible it is desirable to leave a part of the head of the femur for the comfort of the patient (Diagram 3).

Below-knee Amputations

With an ideal amputation and a correctly fitted limb it should not be possible to detect that a prosthesis is being worn. Examination of hundreds of cases shows that long stumps break down from circulatory disturbances, while a chronic bursitis is the result of taking the weight of the body on the head of the tibia. Modified Syme's amputations and long stumps that have taken end-bearing often call for re-amputation. The following are three important points:

1. Weight-bearing in the past has been largely taken by the head of the tibia, with a leather corset fitted round the thigh for some support. Many cases are being seen in which the resultant bursitis is too painful to allow of a continuance of this method. A longer corset is now fitted which will take the full weight on the ischial tuberosity.

2. The calf muscles should be cut away to produce a conical-shaped stump with their ends just above the resultant scar. A soft flabby stump is more uncomfortable and more difficult to fit than a thinly covered one.

3. Stump length is measured from the inner articular surface of the tibial head to the amputated end of the tibia, and all that is required is 5 to 5½ in. The fibula must be at least half an inch shorter than the tibia, otherwise bony union occurs, causing pain at the stump end or, at times, at the head of the fibula. The head of the fibula should not be removed except for pathological reasons. The front sharp edge of the amputated tibia

should be bevelled to prevent its wearing through the skin. The scar should be about 1 in. from the end of the stump on the posterior surface, formed by a large anterior flap with no superfluous tissue. This site will prevent adhesion to the bone-end. The nerve should be treated with extreme care and not be subjected to trauma by crushing or ligaturing.

Stump Treatment

Care and treatment of the amputated limb are almost as important as the amputation itself, and should begin from the day of operation. The stump does not require a pillow or pad to rest upon, but ought to lie extended, while in the case of a below-knee amputation a back splint is often necessary to prevent flexion of the knee-joint. After the stitches have been taken out and the wound is healing, active exercises should be started while the stump is still bandaged. Movements of the joints must be encouraged, to tone up the muscles and assist in tissue reduction in the stump. Massage has been shown to be inadvisable. Furthermore, it does not reduce the oedema, but rather irritates the nerves, and should therefore not be given at any stage during recovery.

A temporary walking-leg or plaster pylon has been used in former days with the claim that it reduces terminal oedema and oedema of the stump as a whole. This pylon could not be ordered until the wound was healed and the scar consolidated, which with an above-knee amputation often took a month or more. Then the pylon was ordered and made in a week or so. The patient wore the pylon, in an effort to reduce the oedema, for a further month. I have kept careful record of measurements of stumps which had pylons fitted and of the amount of oedema reduced. In some cases the oedema actually increased; in some it remained stationary; while in a few there was a slight reduction but the patients had acquired the very distinct "pylon" swing, which was very difficult to overcome when the completed prosthesis was worn. It will be seen, therefore, that it was about 10 weeks before the artificial limb could be ordered. The pylon is now only used in special cases.

The modern method devised by the Ministry of Pensions and adopted by the E.M.S. is to bandage the stump with crêpe bandages from the time the stitches are taken out. It has been proved from records compiled at Roehampton that an above-knee stump requires only three weeks' bandaging to render it fit for measurements to be taken for an artificial limb. Thus with this above-knee site actual limb-fitting can take place in less than 8 weeks from the day of amputation, resulting in a great saving of time and expense, and the earlier return of the amputee to work.

In bandaging above-knee stumps it is imperative to use crêpe bandages 6 inches wide. At present they are not made long enough, so that two have to be sewn together. The bandage must be wound tightly and evenly, otherwise the necessary firm application to the stump cannot be obtained (Diagrams 4-11).

DIAGRAMS 4-11

The end of the bandage must be applied to the upper front surface of the stump and be held securely by the patient's thumbs. It is then passed down the front of the stump, back over the end, pulled tightly with even pressure to the upper

part of the posterior surface of the stump, and held by the patient's fingers. This process is repeated by bringing the bandage down the back of the stump, over the end to the starting-point—still being held by the patient's thumbs—and drawn down over the end to the back of the stump.

The patient must not allow the tension to slacken in the bandage, which thus supports the tissues in the end of the stump. The bandage is next applied round the upper part of the stump to hold the first applications, and firmly enough to allow the patient to remove his hands. It is brought round the end of the stump very tightly so as to compress the tissues, but not too tightly round the upper part. If the bandage was finished off in this manner it would tend to slip down and off the stump when the patient walked about. To prevent this it is applied round the waist as shown in Diagram 10, and finally round the stump (Diagram 11). Particular care should be taken that the crossing of the bandage on itself when applied round the waist occurs at the side of the body and not on the front, otherwise there will be a tendency to flex the stump. This bandage should be reapplied three or four times a day to take up the new shape which results from reduction of the oedema. Figures are available which show that stumps treated in this way have uniformly shrunk 2 in. in circumference in less than 14 days, thus rendering limb-fitting possible.

The application of a 4-in. bandage to an above-knee stump is useless. Furthermore, the method of applying a crêpe bandage tightly at the upper part of the stump and bandaging downwards will retard the reduction of oedema because it imposes a constriction on the upper part.

To treat a below-knee stump a 4-in. crêpe bandage is applied as in the above-knee method. Three slings are used to support the oedematous tissue, and the bandage is applied tightly and firmly around the end. The bandage is taken above the knee to prevent it slipping off the stump, but the front of the knee over the patella is left free so as to afford mobility to the knee-joint.

Stump Exercises.—A recent development in the care of stumps after amputation is a course of exercises adopted to re-educate the remaining muscles of the stump and thus prepare it to control the artificial limb. A narrow sleeve, about 4 in. wide at the back and 2 in. at the front, from which a cord passes over a pulley and suspends a weight of 7 to 14 lb., is placed on the stump as shown in Diagram 12A. The stump is

DIAGRAM 12

extended against the pull of the suspended weight to assist the musculature in regaining its strength—the weights, rate of exercise, and duration varying with the increase in muscle tone. The adductors are similarly exercised by the patient's standing with his side toward the pulley, the stump being drawn towards the midline of the body. If the patient is at home the exercise can be carried out by allowing the cord to pass over the back of a chair upon which somebody is sitting to steady it (Diagram 12B).

Arm Amputations

Arm stumps are not weight-bearing, and are subject to quite different strains and stresses from those of the lower limb. Long arm stumps are not so liable to circulatory disturbance, except the very long ones which are produced by disarticulation through the wrist and elbow. The ideal length of an upper-arm amputation in an adult is 8 to 9 in., measured from the tip of the acromion process to the amputated end of the humerus. If the stump has of necessity to be made shorter, at least half an inch of humerus should be left below the axillary fold, thus enabling good control to be maintained over the artificial arm.

If a still smaller length has to be fashioned, every endeavour should be made to leave some part of the head of the humerus. The scar should not be on the anterior or posterior aspect of the stump because pressure is exerted on these surfaces in using the arm. A terminal scar from equal anterior and posterior flaps is ideal, with again little tissue in the flaps and a conical stump. Adhesions of the musculature to the end of the humerus must be avoided. This latter consideration is the chief objection to guillotine operations, which are otherwise satisfactory.

The length of the lower-arm amputation is measured from the tip of the olecranon to the amputated end of the ulna, and should be about 7 in. with the elbow flexed. The radius should be at least half an inch shorter than the ulna to obviate cross-union, and a conical stump be produced for the comfort of the patient and to permit him to use the prosthesis. The scar should be terminal in a line across the ends of the bones, and the flaps should contain no superfluous tissue. The nerves must be cut across cleanly to avoid the "phantom hand."

If an amputation has to be carried out with a shorter length than that suggested above, it will not prevent the amputee from using an artificial arm if at least three and a half inches is allowed to remain, but in such a case more muscle tissue must be trimmed away and a real bony stump left. If as a result of an accident, disunited fracture, or other cause a surgeon is confronted with a disarticulation of the elbow- or wrist-joint, an ideal site amputation is preferable, because these disarticulations do break down repeatedly. Furthermore, artificial arms must have a rotary mechanism at the wrist, and an above-elbow prosthesis will have the elbow-joint together with a rotary arm mechanism. These points are often forgotten when disarticulation amputations are performed.

In all arm amputations the patient should be encouraged to use the proximal joints and truncated muscles as early as possible. Crêpe bandaging with 3-in. bandages is used when the stitches are removed. An arm amputee usually has a more despondent outlook than a leg case. It is for this reason that such cases should be fitted with prostheses as quickly as possible, otherwise there is a tendency to rely too much on the remaining hand. An arm can in the average case be fitted and used within a month of the operation.

Amputations of parts of the hands which have suffered trauma are indeed difficult. If any two working digits, or the thumb or part of it with a digit, can be saved it should be done to form the basis of a working hand. It is, however, surprising what appliances can be fitted to mutilated hands which may have only the minimum of a digit.

Amputations in Children

Children may have a limb amputated as a result of trauma, bone disease, congenital deformation, or aerial bombardment. These cases should all be treated early, for a child will quickly learn to use a leg or an arm with great ability. A plaster pylon or peg-leg should not be advised for the use of a child.

Summary

Records compiled by the Ministry of Pensions during the past 25 years definitely show that periodic examinations of amputated stumps are desirable.

The most suitable and trouble-free lengths of stumps, the position of the resultant scar from correctly fashioned skin flaps, and the treatment of the severed nerve are indicated.

In the past, stumps have received but little supervised attention with regard to their preparation for the fitting of a prosthesis.

A new method of crêpe bandaging is now used, the results of which prove its efficacy in reducing the oedema in a much shorter time than by previous methods. Pylons are not necessary, generally speaking. A course of exercises assists in preparing the stump musculature to control the artificial limb.

Arm amputations, not being weight-bearing, necessitate a different position for the scar. The stumps require bandaging and exercises to encourage the greatest range of joint mobility. The artificial arm should be fitted as soon as possible.

Children should not be fitted with non-articulated peg-legs. They should have a prosthesis at an early age, whether they be arm or leg cases.

RENAL IMPAIRMENT DUE TO CRUSHING LIMBS IN ANAESTHETIZED DOGS

BY

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Impairment of renal function in dogs under nembutal anaesthesia ensues immediately after a period of 4 to 5 hours, during which both hind limbs have been tightly bound with rubber tubing from ankle to hip and the thigh muscles compressed in a vice and hammered for a few minutes. Removal of the bandage is followed by a large fall in arterial pressure, and by either anuria or severe oliguria. In the latter event the urine is deeply pigmented, presumably with myohaemoglobin, which is freely excreted by the normal kidney, and the creatinine clearance is very low, which might be attributed in part to the low arterial pressure. Restoration of the arterial pressure with intravenous gum-saline or ox serum usually initiates or increases the urine flow; but even if the flow is raised to its initial value with diuretics the creatinine clearance, and therefore the concentrating power of the kidney, recovers to only about one-quarter of its original value.

The low arterial pressure following release of the limbs is not responsible *per se* for the damage to the kidney, since maintenance of even a lower blood pressure for an hour by means of a histamine infusion does not involve reduction in creatinine clearance during a subsequent period at normal arterial pressure. The reduction in urine flow after release of the limbs does not in itself account for the renal damage, since prevention of this reduction by diuretics does not materially affect the degree of the ultimate damage.

The damaged kidneys respond to large doses of diuretics with large increases in urine flow but only small increases in creatinine clearance, which may reach about one-half the normal value. In these respects we did not detect a significant difference in the efficacy of intravenous administration of hypertonic sodium chloride, isotonic sodium chloride, sodium bicarbonate, or sodium sulphate. The depth of colour of the urine from damaged kidneys was not consistently related to the severity of the damage as indicated by fall in creatinine clearance. The nature of the pigment was not examined in this series of experiments. Dr. Rimington has, however, identified the pigment in urine secreted under similar conditions in a later series as mainly myohaemoglobin.

Post mortem there was extensive injury to and oedema of thigh muscles, but no fracture of bones. The kidneys showed a brown cortex and a distinctively bluish-pink medulla, often with a narrow light-coloured zone between the two. The kidneys were notably flaccid, in contrast with the tense kidneys normally found after experimental poisoning.

Microscopically, the kidneys were characterized by the presence of material within the lumina of the tubules which might have been capable of blocking some of the tubules. The material was particularly concentrated in the terminal portion of the proximal convoluted tubules. The distal and collecting tubules were usually free and distended. There was, however, no consistent relation between the extent of the deposit and the impairment of renal function; and, indeed, extensive deposit occurred in some kidneys which were functionally undamaged. In the only dog in which the anuria could not be antagonized even by huge doses of diuretics there were mitochondrial changes in the proximal tubule cells, indicating the action of a poisoning agent.

Discussion

In these observations on 21 dogs we used the reduction in creatinine clearance as the chief indicator of renal damage because, like the inulin clearance, it is probably a measure of the glomerular filtration rate in the dog unless there is leakage of