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Amputation and the fitting of artificial limbs

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A M P U T A T I O N S

and

T H E F I T T I N G O F A R T I F I C I A L L I M B S

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INTRODUCTION

The topic of amputations and the fitting of prostheses seems to me to be one which has or soon will have a place of prominence with at least the most of us. This is a phase of medicine which always assumes a place of high importance during the time of war and a considerable period of time following the end of active combat when the problem of delayed and late amputations arises. We also have the problems which arise many times following the amputation both from the psychological and physiological aspects. Therefore, we are not finished with the amputee following the amputation and the healing of the stump. Many excellent stumps from a surgical standpoint may be spoiled by the lack of proper after-care prior to the fitting of the prosthesis, and because it has not been properly fitted.

Although there are many more amputations performed on the civilian population during peace than upon military personnel in time of war, there are different problems and conditions to be met in the two cases. Civilians have amputations mainly because of disease, malignancies or congenital deformities and the amputation is usually performed at their request after due consideration on their part. However, on military personnel the amputation is performed on a previously sound limb and so rapidly that they do not have time to adjust mentally to it, so new and different problems are presented.

This work deals mainly with this latter type or group of amputations commonly known as emergency amputations although many of the ideas and methods of treatment are applicable to both the elective and emergency types of amputations. It contains the general surgical principles of the amputation, the treatment of the soft parts and bone, the sites of election in both the upper and lower extremities with emphasis on the long bones rather than the hands and feet, the after-care of the stump and its prosthesis.

By definition an amputation is the removal of an extremity in whole or in part. Disarticulation is an amputation through a joint.

There are various criteria for amputations which should be observed. In the arm the important need is for the preservation of movement, whereas for the leg, it is the maintenance of a strong support. Conservative treatment is far more often desirable for the upper limb than for the lower. Any kind of a hand with stumps of fingers, contractions, and stiff fingers is more useful than the best artificial hand. The lesser danger to life caused by injury of the upper limb allows amputation to be rejected in many cases that at first sight seem to need it. In the lower limb there need be less hesitation. In the first place it is possible to provide a useful artificial limb, and in the second place deformed feet often remain painful and there may be harmful ankylosis for which the foot may later have to be amputated. Thirdly, injuries of the leg are generally more dangerous to life than those of the arm.

Three things must be taken into account when amputation is essential: (1) the site of the wound, (2) its characteristics, and (3) the arterial, nervous and bony damage.

In any amputation the surgeon must first consider the safety of the patient and secondly the securing of a stump with the maximum functional value. The rehabilitation of the amputee depends, in a large measure, on this stump being suitable for the fitting of a prosthesis, because it reduces the public prejudice toward the patient's defect and increases his potentialities for occupational fitness.

Trueta (1) summarizes the various requirements between which you must strike a balance:

1. The need for extreme conservatism with the upper limb.

2. The need for conservatism also in the great majority of extremities which can be saved in some shape, the possibility of a precarious functional result being given, within reason, second place. A delayed amputation may eventually solve the problem.

3. The importance of leaving a stump long enough to take a prosthetic apparatus. In all cases in which the stump would be too short conservatism should have first place.

4. The desirability of reserving amputation for limbs whose blood supply has been seriously affected, or which have undergone so extensive a destruction of tissue, including nerve and bone, that conservative treatment would not only be long and difficult but would offer no hope of future useful function.

5. The need for amputation when the wound is so large and bruised that excision is out of the question.

The indications for amputation are many; no hard and fast rules can be set down and one must rely on one's judgement. According to the Council on Physical Therapy of the A.M.A. (2) there are three general indications for amputation: 1. injury, 2. disease and, 3. chronic deformity.

In traumatic surgery, immediate amputation is indicated only by uncontrollable hemorrhage or where the circulation to the part is wholly destroyed, when the bone and soft parts, including the nerve supply, are so hopelessly destroyed that recovery cannot be looked for. No matter how severe the destruction of skin, comminution of bone or contamination of tissues, if the main blood vessels are not destroyed the limb can usually be saved. Traumatic loss of bone substance is not an indication for amputation for according to Kirk (3) from three to four inches of lost substance in a long bone have been replaced by autogenous bone graft after healing of the wound. If there is a question of doubt Kirk (4) advises: do a debridement, control hemorrhage, splint the fracture, dakinize, and await developments. If gangrene later develops or infection is so severe as to endanger life, amputate. Whenever possible operation should be delayed for an hour or two for the treatment of shock. It should not be postponed too long, because pain, fluid loss and the absorption of toxic products aggravate shock by lowering the patient's vitality.

Amputation by the guillotine method is indicated when it is considered that it may prevent blood stream infection resulting from compound fractures in a badly infected, lacerated or contused wound of soft parts; in septic infection of joints; in gasbacillus infection; in uncontrollable recurrent hemorrhage in an infected wound, and in the local infected conditions in an extremity which cannot otherwise be controlled.

In sarcoma of long bones or malignancy in the soft parts, amputation is indicated through the joint above or through the bone above the joint which is uninvolved. Even this holds out little hope for a permanent cure of the disease.

The various types of gangrene due to arteriosclerosis or systemic disease such as diabetes, demand early amputation. Such cases, when the gangrene is in the lower extremity, usually show thrombosis of the main arterial supply of the entire leg, often extending well up into the superficial femoral. In such cases the tourniquet is not used when operating, as the blood supply of the flaps must be normal, which can only be determined by bleeding on section.

In gangrene from vasomotor disturbances following freezing or exposure or from third degree burns with charring of tissues requiring amputation, wait for a definite line of demarcation and the reestablishment of circulation to the part.

In deformities and ankylosed joints following injuries and infections in which function is fairly good without pain, amputation is not indicated. If a deformity cannot be corrected and the extremity is a hindrance to function, or if the pain experienced is so great that the patient cannot use the limb, amputation is indicated. An ankylosed ankle or foot, if at right angles with the leg and free from pain on use, is far better than the best artificial leg.

Amputation is the last resort in all cases and is the admission of the surgeon that he has failed or that he cannot restore function to the extremity.

An amputation is primarily performed to save life or to remove a useless extremity and when this is attained, the next aim is to give the patient a serviceable stump. Carnes (5) states that the requirements of a good stump are adequate healthy tissue with flaps sufficiently long to pad the ends of bone, and a good blood supply. There is freedom from pain, infection and circulatory disturbances. The bone end is covered by skin and subcutaneous tissue which is everywhere movable, snug enough not to crease or work into folds, free from sulci, redundancy, and sinuses, and presenting a linear scar. Muscle and fascia covering it are just enough to form a band of scar tissue over the bone end, adherent, not movable or redundant, and barely palpable. Nerve stumps are removed from pressure sites. There are no painful, projecting bone ends or spurs. The joints are freely and strongly movable by active muscles operating through an effective bony lever. It should not show edema, redness, or callus. When the amputation level is proximal to a joint, the maker of the prosthesis must be allowed room in which to construct a new joint. On the other hand, it should be remembered that leverage, determined by the length of bone distal to a joint, is important in the functioning of an artificial limb.

According to Major V. P. Thompson (6) the shape of the stump end is determined by the tissues utilized in covering it.

The surgeon will bear in mind whether the stump is to be end weight-bearing or not. If the first, then he must cover the end with skin and subcutaneous tissue capable of weight-bearing. He warns against the useless practice of closing muscle flaps over bone because it prolongs the period necessary to condition the stump to its final shape, size and consistency. Skin and the entire subcutaneous fascia will do very well. Closing muscle over the bone end merely delays stump conditioning while it degenerates and fibroses. Its bulk makes the end bulbous. Its slow shrinkage delays fitting of the final prosthesis. Incise muscular fascia distal to the bone level, and incise muscle bellies circularly at the bone level allowing the fibers to retract.

The prosthetic efficiency of a bony lever is measured neither by its length nor by the size of the muscle cross section about it. If the bone is too long, it is poorly clad with soft tissue. The slender, pointed stump end fits snugly in an unyielding socket; the skin is under constant pressure; its circulation suffers and stump troubles ensue.

Amputations can well be divided into two classes: (1) the closed method with suture of the soft parts at the time of amputation, and (2) the open method or guillotine in which the extremity is removed and the wound left wide open. The conditions necessitating amputation make this classification useful.

1. The closed method is applicable when the amputation is one of election, more or less, and through healthy tissues where the soft parts are closed, primary union is expected, and the surgery of the stump is completed.
2. The guillotine or open method, amputating at the site of injury, is the method of choice in traumatic surgery in times of stress, in severe shock, and in the presence and for the control of infection. The extremity is removed and the whole cross section left exposed for dressing. Further surgical treatment of the stump is necessary.

Opinions differ as to the best method of treatment of the soft parts, the periosteum, and the bone in an amputation treated by the closed method. Amputations have been more or less standardized during and since the last World War through the study by those in military service of the functional value of a large number of all kinds of stumps. According to Verrall (7) it has been shown that much of what was done in the War of 1914-1918 has not stood the test of time, and that many amputations, satisfactery enough in younger people, become impermanent as age advances and circulation becomes less adequate.

In the closed method of amputation the saw line, which is the point selected at which the main bone of the extremity is to be sawed through, is the first point to be determined as upon its site depend the length, size and type of flaps to be made in the soft parts. The site of election for the saw line of any given bone of an extremity is that which insures the best stump length from a functional standpoint.

The skin incision should be so fashioned as to give suitable flaps. The total skin flap length should not exceed the diameter of the extremity at the saw line and should frequently be less as very little muscle may be retained and the incision heals better if sewed under slight tension. From a prosthetic standpoint the suture line should be ideally posteroterminal, just behind the bone end in the lower extremity and terminal in the upper extremity. Those individuals who are using ischial weight-bearing or side bearing mostheses however claim that a terminal scar is entirely satisfactory in the lower extremity. Kirk (4) states to obtain a posterolateral scar in the lower extremity the long auterior and short posterior flaps in the relation of two to one or three to two give the best results. If either flap be too long, the circulation to the skin may be poor causing the stump to be susceptible to delayed healing, ulceration and circulatory changes. In the upper extremity auterior and posterior skin flaps equal in length give the desired result. The bases of the flap in both instances are equal in width. After the skin flaps are cut their edges are dissected free from all the underlying fascia to facilitate closure. The flaps should always be trimmed if necessary to make a snug closure.

The fascia is next cut, making the necessary flap to cover the stump end. Complete fascial closure is necessary. It is inelastic and will not stretch like skin, which fact must not be forgotten when flaps are cut.

The muscle in an amputation stump over bone end never again functions as muscle, but soon becomes converted into scar and fibrous tissue. A thick pillow-like pad of muscle, the preservation of which was almost universally taught in the past, should never be used according to Kirk (4). It offers no advantages and soon becomes a large, hard, flabby, edematous, and usually tender mass, interfering with proper fitting and constantly becoming pinched and sore. According to Kirk (4) the muscles must be anchored to the stump end, otherwise they will contract and the stump end will become conical. This is best accomplished by cutting a thin muscle flap from one group, long enough to cover the bone end, and by cutting the remaining muscles circularly so that they will retract equally to the saw line. The muscle groups are then sutured to this muscle flap. This anchors them, giving equal muscular balance and along with the fascia forms a thin fibrous covering over the bone end, preventing the skin from becoming adherent. However Major V. P. Thompson (6) states that if the stump is to be end weigh-bearing, the surgeon must cover the end with skin and subcutaneous tissue capable of weight bearing, avoiding the practice of closing muscle flaps over bone. He feels that closing the skin and the entire subcutaneous fascia and allowing the muscles to retract will provide a suitable stump and do it in a shorter period of time. This seems to be the general opinion and since it gives excellent results and takes less time than the method advised above by Kirk.

The blood vessels should all be tied separately using a double ligature on the larger vessels or transfixing them. Great care must be taken in securing as complete hemostasis as possible. Otherwise the increased pressure will cause tension to be placed on the suture line and will also provide a very good culture media for any infection. Thus healing of the stump will be delayed and in some cases it will be necessary to open the wound and tie off the vessels. If good flaps are provided with careful hemostasis, no drainage is necessary. However, if hemostasis is not good drains should be placed at each corner of the suture line and gradually be removed as drainage decreases.

The most frequent cause of painful stumps is neuroma which forms on the severed end of the nerves of the extrmity. These neuromas are the result of the physiologic attempt at repair that occurs in all sectioned nerves and on which the success of nerve suture depends. After section the axis cylinders in the nerve sheath grow downward and, meeting obstruction, turn on themselves, forming a nerve bulb which consists of new axis cylinders and scar tissue. Pressure or pull on these neuromas cause pain locally and in the area which was the normal distribution of the nerve itself. The neuroma perse may give no symptoms unless adherent to scar tissue or where so located that it is subject to trauma. The sectioned nerve when not adherent to the scar and lying above the stump end in its usual intermuscular septum produces no symptoms unless traction on the neuroma occurs from pull of adherent muscles.

Various methods have been described for the treatment of sectioned nerve ends to lessen the formation of neuromas and the pain incident thereto. However, no method is entirely and always satisfactory. These methods are briefly summarized by Kirk (3) but his source of information is not revealed. Bier covered the cut end of the nerve by a plastic on the sheath. A flap cut from the sheath on one side of the nerve is brought across the sectioned axis cylinders and sutured to the sheath on the opposite side. Ritter removed a wedge-shaped piece from the center of the nerve, bringing together the lateral nerve sheath with sutures. Bordenheur flexes the nerve on itself and sutures the end into a hole cut in the nerve sheath above. All of these methods are time-consuming and not applicable to the smaller nerves.

The British recommend crushing the nerve and its sheath with forceps, cutting with a sharp knife and allowing the nerve to retract. This method is excellent in very small nerves.

Huber and Lewis showed experimentally in animals that when the nerve end is injected with absolute alcohol the axis cylinders are killed and neuromas do not form. This injection must be done carefully with a very small needle, circling around the nerve like the spokes of a wheel going into the hub. Care must be taken to introduce sufficient alcohol among the axis cylinders and under the nerve sheath to cause the latter to become distended; the leaking of the alcohol from within the sheath must be prevented to obtain this result.

The Council on Physical Therapy of the A. M. A. (2) states that in their opinion the nerves should be injected and then cut as high as possible. This agrees with Lockwood (8) who thinks that the nerves should be gently freed, injected with absolute alcohol for 2 cm., and sectioned just below the injected area.

However Verrall (7) states "At one time it was considered correct to shorten nerve ends and even to inject them with alcohol. The latter practice leads to an alcohol neuritis and must be abandoned. A nerve bulb must form on the end of a cut nerve, and all we can do is to place the bulb where it will receive a minimum of pressure. This site will generally be the end of the stump on which the socket does not press. The less trauma to the nerves the less trouble they give latter." This view is also held by Gordon-Taylor (9) who maintains that a nerve should be cut squarely across and not pulled down, ligated or subjected to injections, while Norman T. Kirk (10) advocated just the opposite.

Therefore with all of the different views the occasional amputator is justifiably considerably confused and might therefore conclude that it does not make much difference, except under certain conditions. An example of such a condition is cited by White (11). This condition being a high tibial amputation, in which the retraction and cutting of a nerve would be likely to place the inevitable neuroma in a weigh-bearing location.

There is no ideal method of treating nerves in amputations. It seems that the clinical results following the use of absolute alcohol have not been as successful as found experimentally.

Nerve trunks of any size usually contain a "bleeder" and if the trunks are sectioned and allowed to retract into the intermuscular septum, hemorrhage nor infrequently accurs and is arrested with difficulty and not without trauma. These vessels should be tied seperately without inclusion of the nerve in the ligature because according to Lockwood (8) this is a direct cause of painful convalescence.

The bone or bones of the extremity are sawed through at right angles to the extremity and not at right angles to the bone. This makes the bone end parallel to and even with the stump end, the best plane for direct pressure and end-bearing. The periosteum at the saw line is entirely cut through around the bone with a knife. The soft parts are then retracted gently. If too strong traction is made, the muscular attachment to the periosteum will detach it from the bone and give rise to the formation of bony spurs. The bone is sawed through, care being taken against splintering of cracking the bone. The periosteum is again cut through circularly to the bone, using a knife, a quarter of an inch above the sawed ends. This cuff of periosteum is then removed, care being taken not to shred it and that it is completely removed. The bone end is then rounded off with a rasp. All pieces of loose periosteum and bony spicules must be removed. If any are allowed to remain in the soft parts, they may live and proliferate causing pain, or they may act as foreign bodies. This treatment of the end of the bone is a controversial point. Kirk (10) states that the bone should be treated as above, traumatizing the periosteum as little as possible. Schmorell, a German surgeon, advocates the covering of bone surfaces with periosteum, admittedly with sound physiologic reasoning, except that there is always a suture line of the periosteum, and there is no guaranteeing that an osteophyte will not grow there. White (11) feels that Schmorell's method is an unnecessary requirement and unjustifiably prolongs an operation in which time is frequently so valuable.

The stump must then be closed. Fascia may be closed with muscle but should preferably be closed seperately. Complete fascial closure is essential and continuous suture is never used. The subcutaneous tissue should be approximated and the skin closed with dermol or silk. All layers must be sutured snugly enough to take up all slack in muscles and skin, but not tight enough to cause necrosis.

In the treatment of wounds and combined fractures amputation is seldon needed except where injuries are grave and multiple or the main blood vessels of the limb are destroyed and therefore there is an imminence of gangrene. No matter how severe the destruction of skin, comminution of bone or contamination of tissue, if the main blood vessels are not destroyed, the limb can usually be saved. Whenever possible after injury the operation should be delayed for an hour or two for the treatment of shock. It should not be postponed too long, because pain, fluid loss and the absorption of toxic products aggravate shock by lowering the patients vitality.

In immediate amputations the type depends on the time which has elapsed since injury, the level at which amputation is indicated, and the general condition of the patient.

The criteria set up by the M. R. C. Committee (12) for performing an open or closed type of operation is the time of operation following the injury. Ordinarily the first six to eight hours after injury may be regarded as a safe period, with a reasonable prospect of first-intention healing of an amputation stump, so that within this period primary skin suture is permissable. If over eight hours, or if early evacuation of the patient seems probable a flap amputation with delayed primary skin suture should be performed.

Although the number of amputations performed among the civil population of our country far exceeds that in the army during the last war or the number that may be anticipated among our armed forces during the present war, war conditions impose a different outlook on the surgeon from those of peace with regard to how the amputations shall be done. While the requisite of a good amputation stump remain the same, different methods must be employed to obtain them. Due to the primitive conditions for surgery in the combat zone you cannot suture the stump. The same applies to amputations in the presence of infection wherever done. According to Wilson (13) there were 70,000 amputations among civilians in 1942 as against 4,000 in World War I. However most of those in 1942 were done as elective procedures and were done in a sterile field under sterile conditions permitting primary closure of the stump which was impossible due to infection in the World War I. Also the severe shock which accompanies these severe injuries of war and which is sometimes also seen in industrial surgery following severe trauma necessitating amputation requires the rapid removal of the useless extremity and the control of hemorrhage with the minimum increase in shock.

In war surgery the procedure of choice according to most authorities is the guillotine amputation. It is primarily designed to eliminate destroyed, infected and non viable tissue and to provide adequate drainage by remaining open. The flapless guillotine became popular on the battle fields of France in the

First World War due to virulent, severe, and manifold infections, particularly by gas bacilli, following the traumatized and lacerated wounds caused by high explosives. Drainage of infected or potentially infected tissues has always been a fundamentally sound surgical principle. Occasionally a deviation from this principle results in a sensationally short period of convalescence; most often however it results in prolonged recovery, endangers survival or results in death. The occasional success of a procedure which is a violation of sound principle does not justify the procedure in surgery.

The guillotine or open amputation is an operation based on the sound surgical principle of drainage for infection. The efficiency of the guillotine amputation as a life saving procedure and a "length preserving" operation was definitely established in World War I. In fact, according to Kirk and McKeever (13), so lethal were the consequences of primary closure of battle wounds that it was necessary for the Surgeon General of the A. E. F. to issue an order prohibiting the closure by primary suture of any battle wound.

Experience to date in World War II indicates that the sulfonamide drugs have not altered the basic surgical principle of "drainage for infection". Closed amputations of extremities traumatized beyond repair is dangerous to life and wasteful of useful functional bone length even though the sulfas are used systemically and topically. However this does not mean that these drugs should be discarded. Observations made on penicillin indicate that more should not be expected from its use.

Kirk and McKeever (13) in one group of 150 amputees, which included patients from all theatres of operation as well as the zone of the interior found the following facts:

1. The systemic status of the patients whose amputated extremities had been left open was universally excellent.
2. The only patients showing the exhaustion of prolonged infection were those in whom the development of infection made imperative the opening of a previously sutured stump.
3. The guillotined extremities all presented a good granulating surface, which was easily and in a short time prepared for closure.
4. The only severely infected stumps were those in which closure was attempted and failed. Their preparation for ultimate closure took longer than the preparation of those extremities which had been left open to granulate.
5. In no instance was the closure of a properly managed guillotine stump complicated by severe infection, nor did it require lavish sacrifice of length.

The guillotine amputation is definitely indicated for any extremity which requires removal when infection is already established or in which the probabilities of contamination make the chances for primary healing questionable. Thus it is the operation of choice for any extremity which must be removed because of a severe joint infection or an infected compound fracture or for a severely traumatized extremity in which amputation becomes necessary because of injury to the circulation or soft tissues. The guillotine operation is also to be chosen when operating conditions are not adequate.

The guillotine amputation is a two-stage procedure. The first stage is removal of the damaged portion of the extremity. After the open cross section resulting from this stage has healed by granulation and scar contracture, the second stage consists in the operative procedure to produce the final stump for a prosthesis. This may be a simple plastic closure or it may be a reamputation at the site of election.

The principles governing the technic of amputations in the field according to Harris (14) are :

1. Save as much of the limb as possible to permit the widest possible scope for the subsequent definitive operation.
2. Treat the wound by the standard principles established for dealing with war wounds,--debridement, removal of foreign bodies and dirt, open drainage, and chemotherapy.
3. When the infection has been controlled, manage the resulting stump with its open wound in such a manner (by traction or secondary suture) that healing will occur as quickly as possible, and with a minimum of deformity of the stump. The application of these

principles will vary slightly, depending upon the circumstances for which the amputation in the field is undertaken.

The technic of the first stage or of the actual removal of the undesirable portion of the extremity is aimed at producing a slightly concave open cross section of the extremity, with the skin slightly longer than the superficial muscle, the deep muscle slightly shorter than its overlying muscle. A circular incision is made through the skin at the lowest level compatible with viable tissue, and the skin is allowed to retract; the fascia is then incised in a circular manner at the level to which the skin has retracted. The superficial layer of muscle is then cut at the end of the fascia and permitted to retract. At its point of retraction the deep layers of muscle are cut through to the bone. After the deep muscles have retracted, the periosteum of the bone is cleanly incised and the bone sawed through flush with the muscle. The bone is not treated by the aperiosteal technic. No cuff of periosteum is removed as in a closed amputation. Bone denuded of periosteum will sequestrate in the presence of infection, and the removal of a cuff of periosteum will result in a ring sequestration. Clean sharp incision of the periosteum is important. Bone left uncovered in the stump by elevated tags of periosteum due to rough handling will also sequestrate, and the shreds of percosteum in the muscle will cause infected osteophytes which delay healing. The entire cross section is left open. For a compound fracture or for an infected fracture, the site of amputation is at the site of fracture. The incision does not have to be transverse to the long axis of the leg but may be altered to meet circumstances. In a traumatic amputation a debridement only may be necessary.

For no surgical procedure is the proper post operative care more important than for the first stage of the guillotine amputation. Skin traction is absolutely essential after the operation. According to Kirk and McKeever (13) it must be applied immediately and kept up continuously. However Kessler, et al (15) state that because of the large amount of serum exuding from the wound, the application of skin traction is not immediately practicable, and skin traction can be delayed twenty-four hours without danger of retraction. Harris (14) cautions that skin traction must not be applied until infection in the wound is under control if infection is a factor and it usually is in war surgery where the guillotine amputation is used. Skin traction in no way interferes with dressing the infected wound and it can be released for dressings. With the skin traction the skin is gradually pulled down over the muscles, the end of the bone becomes covered by granulation tissue and the skin margin closed by scar contracture.

If skin traction is not continuously applied, the concave cross section of the leg becomes a greatly exaggerated convex cross section with an inch or two of uncovered bone protruding and a large collar of granulation tissue intervening between the constantly receding skin margin and the bare bone. Such a ngelected stump requires a reamputation at a higher site, with unwarranted sacrifice of ultimate length.

The second phase in preparing the open amputation for use of a prosthesis consists in an operative procedure to cover the end of the bone with healthy pliable skin, which has good circulation and normal sensation. This closure is usually a fairly simple matter. When there is an area of clean granulation tissue covering the bone end, when there is no redness or edema of the skin margins and when bacteriologic studies show a low bacterial count, particularly of streptococci, the tissues will tolerate a surgical closure. These conditions can usually be brought about by careful postoperative care in six to eight weeks following the first operation. Before closure however roentgenograms of the bone end should be obtained to rule out sequestration. According to Thompson and Alldredge (16) it has been found possible to excise extensive scar and granulation tissue and even sequestra from a stump and to close the skin over the end, if the patient is given pencillin for twenty-four hours before, and fourteen days after operation. Frequently, however, the bacteria present in the stump are resistant to penicillin, and it is safer, and usually preferable, to remove all sequestra and to control active infection before closure is attempted. Closure is usually accomplished by excising the scar en bloc to good skin, the skin undermined to mobilize it and sutured over the end of the bone. If attached to bone, remove a thin section of bone so that the bone will not project under the skin.

Pedicle skin grafts are of little value in covering a stump end. The stump end is avascular and the graft is lost. If the graft is attached, imperfect sensation and the small vascular margin of safety of the flap will not tolerate the trauma of wearing a prosthesis. The pedicle blisters and ulcerates under the pressure of the artificial limb bucket.

The reasons for good and poor stumps have been very adequately summarized by Major V. P. Thompson (6). He states that "Good stumps are made by good Surgery" and follows with his proof for that statement:

1. Amputate through viable tissue, neither losing probably useful length nor risking the patient's life in attempting an elective closed amputation when a simple circular open one will conserve both.
2. Incise directly through each layer of tissue, the skin, fat and muscular fascia, the muscle, periosteum and the bone at successive levels, not slicing or undercutting or making extensive flaps. Cut the periosteum cleanly, leaving no shreds or flaps behind, and no spurs will form. Observe careful hemostasis.
3. Avoid tension; it prevents free circulation. Long flaps are not necessary.
4. Trim excessive soft tissue off now; it will save doing it later.
5. Use the open method in cases of infection or potential

infection.

6. Use traction to maintain soft tissue length beyond the bone.

7. Use active motion as healing permits; it improves circulation, frees joint motion, builds muscle. Graduated friction and pressure accustom the stump for weight-bearing.

8. The skin must be kept clean; soap, water, air and sun minimize minor cutaneous infections.

As for poor stumps, Major Thompson says that, "Poor stumps often result from surgical errors" and goes on to list the various errors:

1. Wrong choice of level and type of procedure.

2. Excessive soft tissue dissection, periosteal stripping, trauma, strangulation ligatures and sutures.

3. Soft tissue closure under tension..

4. Redundant soft tissue.

5. Failure to use the open method when in doubt as to circulatory status and infection.

6. Failure to utilize traction or splinting.

7. Neglect of post operative conditioning of the stump, joints, muscle and skin.

Although the basis for an ideal stump starts at operation, it remains for physical therapy to add or detract by the type and amount of after-treatment provided. The care and treatment of the stump should begin from the day of operation.

The hazard of flexion and contracture of proximal joints demands careful attention to post operative position of the stump. This treatment is a point on which few authorities seem to agree. Yount (17) stated that he elevated the stump for four days to minimize hemorrhage and edema, Sullivan (18) stated that he permits a supporting pillow until pain is gone. Craft (19) advised that no support be used. He believes that in a thigh amputation the stump should lie extended. Jepsen (20) suggested the use of a towel over the end of the stump of the thigh, weighed down on each side by sandbags to ensure extension. It is generally agreed that after amputations below the knee the stump should be supported in extension on a posterior splint. Fixation of the upper extremity is unnecessary as a rule.

In the use of physical therapy apparatus the Council on Physical Therapy of the A. M. A. and the subcommittee on Physical Therapy of the National Research Council (21) have recommended the use of heat furnished by a baker or infrared generator at a temperature of 96° F for a period of twenty minutes every two hours. By this means circulation is increased, fibrosis of muscle is minimized, edema is decreased and healing of wounds is promoted. Hot baths are to be avoided, as they tend to soften the skin and delay fitting of the prosthesis. Whirlpool and contrast baths, however, may be used to advantage, and are especially valuable in low grade inflammatory conditions or ulcerations, and in many cold, cyanotic, painful stumps. The whirlpool bath presents the added value of hydre massage, and is used at a temperature of 110° F daily for at least six weeks. Gradually cool the water in from fifteen to twenty minutes. For open stumps Titus (22) recommended use of some bactericidal agent in the water.

The contrast bath is of value after the skin presents a normal appearance and contraction of tissue has been secured by the whirlpool bath and massage.

The Council on Physical Therapy (23) recommended immersion in hot water at a temperature of 105° to 110° F for five minutes and in cold water at a temperature of 60° to 70° F for two minutes, the cycle being repeated three and one half times. Titus (22) expressed a preference for a gradual increase in difference of temperature of the tubs at each session until the patient can tolerate water at a temperature of 100° F in one and water with floating ice in the other. Immersion is maintained in one until it becomes uncomfortable and then in the other; it is repeated during a five to ten minute treatment. Vogel (24) expressed the opinion that except in rare instances of a neuroma or an accompanying circulatory disturbance, heat and baths are contraindicated, as they tend to soften rather than toughen the stump. She apparently stands alone in a viewpoint which is contrary to that of other writers on the subject.

There is much difference of opinion regarding the value of massage in the post operative care of the stump. The Subcommittee on Physical Therapy of the National Research Council (21) recommended massage for six to seven days after operation. Yount (17) stated that he waits till the tenth day, Titus (22) stated that massage is always indicated, Sullivan (18) said that he waits until the wound is healed, Verrall (7) said that massage is of doubtful benefit, and Craft (19) said that it should be avoided. In Craft's opinion, although massage does reduce edema, pain in the sciatic nerve dates from the onset of massage, and lesions of nerves have been increased.

When massage is given, it should be preceded by heat and should be applied for ten to fifteen minutes daily. A position of muscular relaxation is desirable. Krusen (25) expressed a preference for stroking of the tissues toward the stump to prevent contracture; Vogel (24), for stroking in the direction of venous flow. Massage about the suture line should be avoided at first and massage in other locations should be sufficiently light to avoid tension on the newly healed incision is the advice of Rudolph (26). As soon as the stump permits, the range of all movements is increased as rapidly as possible to the patient's tolerance but one should avoid vigor sufficient to cause pain. Lubricants soften the skin and maintain tenderness; consequently, their use is to be avoided. Alcohol is used generously during and after massage.

Krusen (25) expressed the consensus, holding that massage improves circulation and accelerates healing. It accustoms the patient to handling the stump, relieves sensitiveness, minimizes adhesions and keeps tissues pliable and the stump flexible. However, Brunnstrom (27) states that massage should not be used as a routine procedure since it may cause a traumatic neuritis in the nerves of the stump. In selected cases use massage as an aid in decreasing edema and loosening scar tissue.

The Medical Department of the U.S. Army in the World War (28) states that limitation of motion of the proximal joint of a stump was a condition that was actually feared during the first World War. It seems that the person whose thigh has been amputated will invariably place his stump in the position of flexion, abduction and external rotation, finding support of the stump with a pillow, relaxing the musculature and avoiding movement. Prolonged maintenance of this position produces adaptive shortening of the muscles, the capsule contracts, and the joint becomes more or less fixed. Infected periarticular tissues further enhance fixation. Brunnstrom (27) states that the reason for this flexion contractures is that the natural reaction to an injuring agent and pain is withdrawal. The stump is sensitive, and to protect it, the patient, consciously or reflexly, pulls it closer to him. The patient must lie on his back or prone and do not allow him to stay on his side for any length of time.

Hip flexion contracture is often seen in amputations above the knee and rarely in below knee amputations. Supporting the stump on a pillow and sitting up in bed tend to maintain the stump in a flexed position, therefore you should keep the patient flat in bed to prevent these contractures. These may also be due to direct muscular imbalance as well as faulty bed posture.

Hip abduction contracture is also due to both faulty bed position and muscle imbalance. When skin traction is applied to the stump without pelvic fixation, the pelvis will tend to tilt toward the side of the traction. The muscle imbalance may be due to severance of the adductor muscles. The abductor muscles, inserting into the greater trochanter, are intact, and tend to pull the stump into an abducted position.

Straight alinement of the pelvis and thighs is obtained by "squaring" the pelvis, by avoiding the use of a pillow under the stump, and by encouraging the prone position. When attempting to overcome contractures, manual stretching of tight muscles is avoided. Instead the pattern of "reciprocal innervation" is made use of to secure relaxation. True contractures, involving capsule and ligaments, are overcome by the application of plaster or by continuous traction.

Pressure exercises are universally advised. These exercises consist of gently tapping over the dressing of the stump with the palm of the hand; pressure is gradually increased so that by the time the patient secures his prosthesis he is able to tolerate vigorous pounding with the ulnar surface of the closed fist without pain. The end-bearing stump may be subjected to gentle pounding on a pillow placed on a hard surface, the height of which should be adjustable. Later a hard pillow is used. After that a few layers of toweling are used and finally the stump is placed directly on a hard surface. It is generally agreed that the fitting of a temporary or a permanent prosthesis should be arranged as soon as possible. Craft (19) states that the modern method devised by the Ministry of Pensions to promote the formation of a good stump for a prosthesis is to bandage the stump with crepe bandages from the time the stitches are taken out. Only about three weeks bandaging renders a stump fit for measurement for an artificial limb. These bandages must be tight and reapplied three to four times per day.

Mitchell (29) has summarized some disabilities, as to cause and effect, which could have been avoided by proper attention to details mentioned above:

CAUSE	EFFECT
1. Bad design of skin flaps.	1. a. Healing by secondary intention with or without terminal lowgrade osteitis. b. Painful scar. c. Intertrigo from loose folds. d. Late breakdown.
2. Skin grafting of bare areas.	2. Stump will not stand artificial limb.
3. Too early reamputation.	3. Post-operative sepsis
4. Failure to use skin traction in guillotine operations	4. a. Pain and misery b. Loss of length at reamputation.
5. Failure to use post-operative splintage. (applies to knee expecially)	5. Flexion deformity.

In amputations of the upper extremity we are dealing with stumps which are not subject to weightbearing but have a quite different stress and strain. It is not brought into as constant use and the work done by it is far less than a stump of the lower extremity.

Almost any stump in the upper extremity can be fitted with a working or cosmetic appliance. There are, however, certain stumps which are not satisfactory from a surgical standpoint, others are fitted with difficulty, and some, owing to their length, do not give the maximum functional results.

In dealing with amputations of the upper extremity McKeever (30) makes two positive statements without qualification. They are:

1. The loss of a major portion of an upper extremity produces greater economic displacement than any single amputation of the lower extremity. Individuals without a hand are, with but few exceptions, excluded from employment which requires meeting the public.
2. The prostheses which are available for the arm amputee substitutes less satisfactorily for the loss than do those designed for the lower extremity.

The more functional an arm prosthesis becomes, the more it offends cosmesis; and the more nearly the prosthesis approaches the lost hand in shape and appearance, the less useful it becomes to the patient.

In amputations of the upper extremity it is a fairly safe rule according to Verrall (7) that as much as possible of the limb should be preserved. The possession of one perfect digit is preferable to the best artificial limb, as a prosthesis can be made to which this digit is apposable.

An anterior or posterior scar should be avoided because pressure is exerted on these surfaces in using the arm. A terminal scar from equal anterior and posterior flaps is ideal with little tissue in the flaps and a conical stump. Adhesions of musculature to the end of the bone must be avoided; this is the chief objection to the guillotine amputation in the upper extremity. However, if the guillotine stump is treated with early traction, it heals with a terminal scar and will frequently require no further operative treatment prior to fitting. The scar tissue will be dense and strong enough to stand any strain required of it. The appliances for the forearm and arm cause pressure on, and are fitted snugly to, the lateral surfaces. There is no weight thrown on the end of the stump or pull upward on the skin, causing traction on the end.

Certain classical sites have been designed by custom. These sites are essentially arbitrary and are conditioned largely by the requirements of limb wearing. They represent the optimum mechanical conditions as to bone length and muscle action for the support and leverage necessary to utilize a prosthesis.

Contrary to general surgical experience Kessler (31) feels that the length of the stump is not so important, except when it is near the joint and he sites as an example a disatriculation of the wrist which is unsatisfactory because of difficulty in fitting an artificial limb to the styloid prominence of the radius and ulna. This is also agreed to by Kirk (4) who goes further with the explanation of the example used by Kessler. Kirk says that besides the irregular contour of the styloid process of the radius and ulna, the skin covering this stump is thin, tender, poorly nourished and easily traumatized, and when the artificial hand and working tool are fitted, the limb is longer than its fellow.

Ideal sites for amputation are eight inches below the acromion for the arm, and six to seven inches below the olecranon for the forearm. Skin is very elastic, and short equal flaps from the flexor and extensor aspects of the forearm should be used. The same should be applied in the arm.

In amputations through the lower third of the arm and in wrist disarticulations, the stump is usually cold, cyanotic and tender because of its poor circulation and small amount of subcutaneous tissue. The skin frequently breaks down and ulcerates. Bones in the lower third are covered with practically nothing but numerous small tendons which make a very poor stump-end covering.

Amputation at the junction of the middle and lower thirds of the forearm yields the best stump from a prosthetic and surgical standpoint, giving the best all-round function if part of the hand cannot be retained. The circulation is good, the skin tougher, there is more subcutaneous tissue, more muscle substance and less tendon structure underlying the skin. The two bones should be equal in length.

An amputation of the forearm less than two inches below the elbow is useless according to Kessler (31) because of lack of leverage, the biceps being inserted just below that point. On flexion of the forearm, the biceps tendon will push the forearm bucket off the stump.

It is more or less a debatable question as to whether a disarticulation through the elbow joint, or an amputation through the condyles, or just above the epicondylar ridge provides the most satisfactory stump. A disarticulation at the elbow presents a stump with a large mass at its end in proportion to the rest of the arm, due to the bony conformation of the lower end of the humerus. It is more difficult to fit with a prosthesis and throws the new elbow joint lower than its fellow and for these two reasons, Kessler (31) believes that a disarticulation of the elbow should not be done. Kirk (3) however, states that it offers a knob on its end to retain the prosthesis on the arm stump after the bucket of the prosthesis has been laced in position, lessening the number of retaining straps on the shoulder. It is longer, affording more leverage, and as a stump without a prosthesis it has its advantages in being longer, larger, and more useful than that resulting from an amputation through the condyles of the humerus. Owing to the conformation of the bone considerable healthy skin and fascia are necessary to cover the stump end.

An amputation through the lower third of the arm, transcondylar just above the olecranon fossa, with removal of the epicondylar or supracondylar ridges above the flare of the condyles, presents a symmetrical stump sufficiently short to allow the elbow of the prosthesis at the same level as its fellow, thus giving a better appearance and permitting the prosthesis to be more easily fitted, though shoulder straps are necessary to retain it. Much less healthy tissue is necessary for closure than in disarticulation at the elbow joint. In the upper arm a long stump is necessary in order to get enough leverage to activate an artificial arm. A stump shorter than three inches below the axilla has no power to activate an arm.

Vanghetti, an Italian surgeon, observed that if the distal portion of the muscle or tendon be freed from its insertion and covered with skin, the muscle retains its voluntary power of contraction. Skin-lined apertures by plastic methods are made through muscles or tendons such as biceps, triceps or some flexor or extensor group. A ring is then fitted through this canal and the patient learn to voluntarily contract the muscle groups. The amount of pull the patient can exert is often comparatively great, but the excursion occasioned by the contraction is small. By means of cords from the ring through the muscle flap, the artificial arm and hand are worked by muscular contraction.

Adams (32) describes the technic of the kineplastic amputation:

1. The skin flap should not be over 3.5 cm. square;

otherwise, there is likely to be some irritation from the pins. Also, one should not pass the skin tube through too much of the muscle belly, and the tendons should be avoided.

2. The edges of the skin tube should be carefully closed before it is canalized through the muscle.

3. Excess tension in closing the skin flap should be avoided.

4. The prosthesis should not be applied until all symptoms of discomfort and redness have disappeared from the skin tube.

The success of this procedure lies in complete cooperation.

Another type of amputation of the forearm is the Krukenberg amputation and it is adaptable to forearm stump of almost any length. In this procedure the forearm is split into "fingers" and grasp and prehensile function is carried on between the two pinchers thus formed.

Summarizing upper extremity amputations we find:

1. The economic displacement of an individual with a major amputation of the upper extremity is much greater than of one with an amputation of the lower extremity.

2. Prostheses are less satisfactory in upper extremity amputations than are those for the lower extremity.

3. Disarticulation through the wrist and elbow produce poor stumps.

4. The forearm stump of choice is one at the junction of the middle and lower thirds.

5. The humeral stump is one just above the flare of the humeral condyles.

6. Arm stumps from the level of the pectoral insertion to the shoulder have no functional value.

In amputations of the lower extremity the function of the stump is to carry the body weight in whole or in part and to act as a lever to produce locomotion in walking.

In amputations at or near the hip joint the patient will not wear an artificial limb in over half of these cases. However, where the hip-joint is intact one should contemplate the wearing of a tilting-table limb and make the best stump for this purpose. At lest the head of the femur should be left, the neck being sawed through, as its presence prevents the stump from sinking in. If possible, however, the amputation should be just below the lesser trochanter. Retention of the great trochanter and the flexed stump (ilio psoas) provide joints to which the socket can be fitted closely, helping to prevent the stump slipping out of it. The hip stump should present a buttock equal in size and contour to its fellow, with the skin rounded out and smooth without sulci or redundancy. The tuberosity of the ischium covered with its normal covering of soft parts forms its base and there should be no excess of muscle or other soft parts near the groin to become pinched by the prosthesis. The scar is as far as possible from the rectum to prevent soiling.

Amputations through the thigh should ideally be ten and one-half inches long; this length being measured from the top of the greater trochanter. Except in the rarest cases a stump measuring less than five inches from the greater trochanter cannot be fitted with a limb giving hip control, and if this amount cannot be retained the amputation should be performed at the hip joint as outlined above. At a point below this a stump should never reach lower than four inches above the adductor tubercle as a longer stump interferes with the mechanism of the artificial knee-joint and is ill nourished. Thorek (33) has described for a low thigh amputation a technic simulating a guillotine procedure, except that sufficient bone is removed to permit end closure in layers without drainage after careful hemostasis. A circular incision is made just above the knee after the inner hamstrings are cut. The one drawback to this amputation seems to be its unpopularity with makers of artificial limbs, who ordinarily can fit a prosthesis better to a shorter stump.

In below knee amputations progress has been made in the last century by the improvement of artificial limbs. Formerly an amputation was performed allowing for the fitting of a peg-leg on which the patient knelt, and such is still our only method for obtaining a good natural weight-bearing end to a stump. For this a stump of under three inches of tibia should be left. From 1920 to 1930 according to Verrall (7) we regarded a tibial length of seven inches as ideal, but it has been found, he states, that as the patient grows older this stump becomes ill nourished and that one of five and one-half inches is better.

In below knee amputations the fibula must be at least a half 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. However, Lieutenant Commander Harry B. Mason (13) states that the fibula may be fixed to the tibia by roughening the lateral and medial aspects of the bone ends of the tibia and fibula respectively and transfixing the fibula to the tibia by the use of a vitallium screw. His reason being that this will prevent the chance of a floating fibula, which at times detracts from the usefulness of the stump by its mobility.

There are two main types of end-bearing stumps namely the Stokes-Gritti which is above the knee, and the Symes which is transmalleolar which are thought by some to be the ideal stumps. The Canadians are especially partial to these two types of stumps. Their reasons for liking these being as stated by Le Mesurier (34) that amputations at these two levels leave stumps that are particularly adapted for end-bearing in that the end of the bone is broad and smooth and covered by tissue accustomed to pressure. End-bearing stumps at other levels will not tolerate weight-bearing on the end for more than a few years. In the Toronto district, the largest amputation center in Canada, Le Mesurier states that there has not been a single Syme stump reamputated since 1921. However this may well be due to the fact that all "bad" Syme stumps were gathered together and reamputated in 1919 and 1920. One important thing in an end-bearing stump is that it should be fitted with a decent end-bearing leg, but it is difficult to get limb-fitting firms to show any interest in this type of leg especially for a Symes type of amputation. The disadvantage of the Syme's amputation is the weight of the limb and its bulkiness at the ankle. The English dislike a long stump on account of circulatory disturbances and use ischial bearing protheses for most of their below knee amputations. The Americans prefer a slightly longer stump and take most of the weight on the sides of the below knee stumps. However, in very tall individuals end-bearing stumps provide better balance. In double leg amputations where one or both amputations will be above the knee, end-bearing stumps are of value.

Partial foot amputations of the classical Lisfranc or Chopart types are unsatisfactory because of the loss of leverage behind the tarso-metatarsal joints.

At a recent meeting of allied surgeons in Toronto, Canada, four "sites of election" were agreed upon as producing satisfactory stumps. These are summarized by Brunnstrom (27):

1. Symes--a transmalleolar amputation. To cover the amputation surface a posterior skin flap which includes the fatty subcutaneous tissue of the heel is utilized. This gives a good end-bearing stump.
2. Midleg--an amputation through the middle third of the leg about six inches below the knee. In all Midleg amputations the fibula is retained although it is cut shorter than the tibia. Longer stumps are to be avoided, since such stumps usually have poor circulation, are

sensitive, and are hard to fit with a prosthesis. Shorter stumps, through the upper third of the leg, are unsatisfactory because they do not provide sufficient leverage for knee action.

3. Stokes-Gritti--the femoral condyles are removed and the patella is fused to the end of the femur. It gives a good weight-bearing surface.

4. Midthigh--junction of the middle and lower thirds of the femur, although true Midthigh is satisfactory. Skin flaps but no muscular tissue is used to cover the end of the stump.

At the same meeting in Toronto, the Committee disapproved:

1. Disarticulations of the hip and knee,

2. Any amputation through the tarsal bones, leaving only the calcaneus and astragalus, which invariably causes an equinus position of the stump.

The above "sites of election" and "disapproved sites" only partially correspond to the surgical principles cited by the Council on Physical Therapy of the A. M. A. (35). These principles are:

1. Disarticulation leaves surfaces accustomed to pressure from contiguous bones.

2. In amputations in the continuity of long bones the end is much more likely to withstand pressure if amputation is performed through the cancellous portion near either

end than if it is performed through the middle portion where the cortex is thick and the medullary cavity is well defined.

Two methods have been used more or less to prepare the stump for fitting with a permanent appliance. One is to allow the stump to atrophy from non-use for a period of six months to a year, using types of stump "shrinkers" during this period. The other and seemingly the best method is to fit the stump early with some type of prosthesis, either a temporary prosthesis or a permanent appliance, and thereby obtain an early physiological shrinkage along with a development of the muscle of the stump required in the use of the appliance.

To fit an appliance, however, to a boggy, tender stump, and to make the necessary adjustments to it so that it will continue to fit a rapidly changing stump, requires the personal contact of the patient and the appliance maker. The changes, according to Kirk (4), are usually most marked during the first three weeks following fitting, but they continue for the next four to six months. The cost of this method is almost prohibitive in civil life and this is probably why the shrinkage atrophy method of dis-use has been used. However, much greater efficiency from the stump results if the stump is fitted as soon as possible.

The interval of time which elapses between the loss of an extremity and the application of a permanent prosthesis is a very difficult period of physical and mental adjustment. Anything that can be done to shorten this period and make the adjustment simpler, more rapid and more complete is well worth while.

All factors which tend to establish early painless weight-bearing should be understood and applied. Early weight-bearing is essential in toughening up a stump to make it fit for prolonged weight-bearing. However, according to Kirk (4), the patient should not attempt to wear the artificial leg continually from the time he is fitted for the first ten days even if it "doesn't hurt". The skin will chafe, the bony weight-bearing points become bruised, contused and sore and the stump is soon incapacitated. When the leg is removed, the stump should be tightly bandaged with a white flannel or elastic bandage after a cold bath has been given it or swelling will occur and the leg be "too small" the following day.

According to Lt. Col. T. Campbell Thompson (36), in army General Hospitals an adjustable fiber leg is ordered as soon as the amputee is admitted or when an amputation is performed. The leather bucket or socket for this leg is then made as soon as the stump is well healed. As the leg shrinks, a new socket is made whenever the old one becomes too large. When these well-made, easily changed fiber legs are not available, temporary plaster pylons are most valuable in toughening up the stumps and shortening the period during which the patient is entirely dependent on crutches. The main disadvantage with the use of a pylon is the fact that the patients tend to acquire the very distinct "pylon swing", which is very difficult to overcome when the completed prosthesis is worn. However, these temporary sockets made of plaster-of-paris to which are fixed wooden ends similar to the lower ends of crutches are cheap, can be reapplied, and the patient, by being enabled to get about, retains movement in his joints and encourages the shrinking of the stump. A patient should not wear a pylon till up to three months after the amputation and his stump is in a condition to permit the fitting of a permanent limb. He states that the mere act of measuring a patient for a leg, and his knowing that it is being made, cause him to look forward to brighter days instead of spending his time bemoaning his lot.

The functions of the lower extremities are two, namely, weight-bearing and locomotion, the latter depending on the mobility and stability of the remaining joints and on the integrity of the neuromuscular apparatus. A muscle can exert no dynamic function in a stump unless, first, its normal length is preserved, second, its origin and insertion are both attached to bone, and, third, its course crosses a movable joint. The remaining muscles must be re-educated and thus prepared to control the artificial limb. Craft (19) uses a narrow sleeve, about four inches wide at the back and tow inches in the front, from which a cord passes over a pulley and suspends a weight of seven to fourteen pounds, and then the stump is extended against this pull. Both major functions of the lower extremities are dependent on the relative absence of pain.

In understanding the proper fitting and alignment of the amputation prosthesis of the lower extremity it is of value to understand the mechanics of normal locomotion and its relation to the pathomechanics of the gait with a prosthesis.

Normal gait is a constant alternating play between the two lower extremities in which they alternately assume the function of support and propulsion according to Steindler (37). Only one extremity at a time is used as a propelling force, whereas the other one swings forward. At the completion of the swing, the leg again touches the ground, first restraining the downward and forward tendency of the center of gravity, and then again assuming the role of a propeller of the body.

In normal walking there is a phase when both legs are in contact with the ground making the supporting phase longer than the swinging phase.

The forces which initiate and control locomotion are external and intrinsic. The external forces are gravity, normal counter-pressure of the floor, and friction between the foot and floor. The intrinsic forces are supplied by the muscles of the lower extremity, which act by extending the joints, propelling the body forward and upward. Also they restrain the forward propulsion at the end of the swing.

According to Thomas (38) who cites Steindler (37) the mechanics of walking may then be described as follows: Walking is initiated by inclining the trunk forward until the center of gravity has passed forward beyond the supporting base, bringing about a loss of balance. This is accompanied by a sudden extension of the joints of the supporting leg, propelling the body forward and slightly upward. At the same time, the opposite leg is lifted from the floor and swings forward in front of the supporting leg. At the completion of the swing, the leg again touches the floor in a partially flexed position, restraining the downward and forward tendency of the center of gravity. As the center of gravity moves forward over the supporting foot, the leg again is extended, generating the upward and forward propulsion of the body, and the cycle is repeated. Therefore, the human gait is a constant play between loss and recovery of balance.

The efficiency and ease with which the amputee walks with his prosthesis depends mainly on the alignment and fit of the artificial limb. The other factors which are important are the site of amputation, the length and condition of the stump, muscle strength, mobility of adjacent joints, and the mental attitude, skill, and aptitude of the amputee.

Thomas (38) states that in amputations below the knee, with a stump of sufficient length to give good leverage, there is little disturbance in gait. The function of the quadriceps muscle is undisturbed, and this muscle is the only one of importance in forward propulsion of the leg. There may be some difficulty in walking on an uneven surface because of the lack of lateral or subastragalar motion in the foot.

Success in walking with an amputation above the knee is dependent largely upon stability and control of the artificial knee joint. The pathomechanics of the gait with an above-the-knee prosthesis may properly be compared to that of the gait of an individual with a paralysis of the quadriceps muscle. According to Mayer (39) as cited by Steindler (37) the paralyzed quadriceps may be compensated for by gravity without greatly interfering with standing and walking. By contracting the gluteus maximus, extending the thigh on the pelvis, and at the same time plantar-flexing the foot by contracting the gastrocnemius and soleus, the common center of gravity is made to fall in front of the knee joint, thus acting as an extensor.

In above-the-knee amputations with a direct stump-controlled prosthesis (pelvic suspension), a similar situation exists as in paralysis of the quadriceps. The gluteus maximus acts upon the stump and thigh piece of the prosthesis, extending the thigh. Although the calf muscles are absent, a substitute for their action is provided by placing the artificial foot in slight plantar flexion and maintaining it there, limiting dorsal flexion by regulating the thickness of the anterior rubber cushion in the instep. Stability in the knee joint is further aided by placing the transverse axis of the artificial knee joint well posterior to the knee center.

The surgery of leg amputations has been largely conditioned by the problem of prosthesis. Previously the peg-leg variety was used and still is by poor individuals. Support was carried on the end of the amputation stump, or in the case of a short lower leg, on stumps on the flexed knee. Largely influenced by this tradition, amputations have been so performed as to secure adequate end-bearing stumps. This meant that terminal scars were avoided and adequate padding of the stump provided. There arose then the necessity for making unequal skin flaps. Padding of the stump was secured by utilizing large muscle flaps to cover the end of the bone. This idea was later carried a step further by providing bony covering, with the patella covering the end of the femur, in the Gritti-Stokes amputation, and the oscalcis covering the tibia in the Pirogoff amputation.

Now the old tradition of the peg-leg and end-bearing stumps has given way to the production of artificial limbs which owe their value to the support provided by the lateral surface of the stump supplemented by special pressure-bearing areas. This is in general the opinion of surgeons in the United States, but the Canadians still favor the end-bearing stump.

The pressure-bearing areas in the lower leg are the tibial tubercle, the internal condyle, and the head of the fibula. In the thigh the ischium supplements the support obtained from the entire circumference of the thigh stump.

With a side-bearing prosthesis there is no fear of terminal scars. Equal flaps or a circular skin incision may be made with impunity. Since padding for the end of the stump is not required, muscle flaps are unnecessary. Moreover, muscle is not biologically adapted for pressure bearing. If it is snugly prepared, it quickly degenerates into a fibrous mass. If redundant, it becomes pinched between the stump and the limb socket producing pressure sores.

The British prefer ischial bearing prostheses for all lower extremity amputations. Their reasoning is expressed by Craft (19). For weight-bearing nature has developed the human body so that when walking the weight is borne by the foot, and when sitting, by the ischial tuberosity. Their theory then is that if the lower limb is amputated at any level the weight ought therefore to be supported by the ischial tuberosity. Thus the patient sits in the socket.

For below-knee amputations in which the stump is very hard and healthy, a socket, knee hinge and thigh corset may be sufficient and there is less bulk. In these cases the weight is taken on the heads of the tibia and fibula and the lower edge of the patella; but according to Verrall (7) experience has shown that this rarely possible and that it is better to take some of the weight on the pelvis by fitting a limb with a bearing on the tuber ischii.

For thigh amputations there are only two types of prosthesis, the choice between these depending on the patient's power of bracing back the stump and so controlling the extension of the knee. If strength is good, the limb is suspended from the pelvis and the knee movement checked by an adjustable brake at the knee. In other cases the limb is suspended from the shoulders and working on an eccentric in the knee joint. If the stump is very weak, a rigid pelvic band can be added.

In hip disarticulations and amputations where the stump is very short a "tilting table" limb is to be used. The pelvis rests in a socket, and below this the leg is attached by a simple hinge, capable of being locked or released by a catch easily operable through the clothing. The catch is released for sitting, and fixed for walking in which the hip is rigid and progress made by a swing of the pelvis.

In double leg amputations if one of the stumps is below the knee, then the individual may get along with the aid of a pair of "full" limbs. However in these cases "short" legs are usually recommended. These are legs without any knee joints and much shorter than the regular length so that there is less mass and inertia to overcome in lifting up and moving the limb.

Limbs may be made of willow or basswood or they may be made from aluminum alloys or similar metal. These limbs are light and should not weigh more than six or seven pounds. The standard construction of an artificial leg usually consists of the socket, knee piece, skin piece and foot. These constituents are briefly described by Thomas (40): The socket is that portion of the limb into which the stump is fitted. It is usually constructed of willow or basswood although some metal and some plastic sockets have been made. The socket is carefully cut out to fit the contours of the stump. The wood socket is covered with tightly stretched rawhide, which greatly adds to its strength. The knee piece is an important control mechanism allowing knee motion with stability. The proper fitting and alinement of the knee joint axis is of the tumost importance. Knee motion is usually controlled by a strap of leather, with elastics on either end, which is attached to the pelvic belt and passes over a roller fastened to the skin piece inside the knee. As the knee is flexed pressure is applied to the control strap pulling the skin piece forward for the next step. Knee joint control is also effected by the proper setting of the joint axis. The farther posterior the axis is set the more positive is the knee lock when weight is applied. The foot in most general use today is made of wood with a joint in the forefoot of rubber belting and with limited motion at the ankle. Rubber pads or bumpers are placed in heel, instep and forefoot. Increasing the "fixed equinus" of the ankle by raising the front pad in the instep tends to throw the knee into hyperextension and increases knee joint stability.

Limb makers object to Symes and Gritti-Stokes operations because of the difficulties in making a prosthesis that is comfortable and that conforms to the shape and length of the opposite limb. Another difficulty encountered with a prosthesis for the Syme operation is preserving sufficient strength at the ankle to take care of the excessive strain when weight is borne on the ball of the foot.

In Gritti-Stokes amputations weight is carried on the end of the stump and on the sloping surfaces of the thigh. The socket for such a stump is usually made of heavy leather with a front opening for lacing and with a felt pad on the end for weight-bearings.

The stump is protected by a woven stump sock of virgin wool.

These socks should be changed daily and kept scrupulously clean to avoid skin irritation and infection. The weight must be taken off the head of the fibula, if it is a below-knee stump, and too much must not be thrown on the tubercle or long sharp crest of the tibia. As shrinkage occurs, additional stump socks are worn, otherwise the stump sinks in the bucket and weight is no longer borne on the proper bearing surface. When the patient requires more than three stump socks, if in the thigh, the bucket must be made smaller or in the below-knee stump, a leather lining must be placed in the socket or a new one made.

In the successful fitting and use of prostheses not too much importance should be placed on the particular type of limb, materials used or certain special features, such as complex joint controls. The more important considerations from the point of view of both patient and surgeon are whether the socket properly fits the stump and whether the limb is well constructed and of proper alinement and length.

In amputations of the upper extremities the stumps are not weight-bearing and therefore are subject to quite different stresses and strains from those of the lower limb.

In artificial arms you 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 disarticulations are performed.

The common type of prosthetic appliance used is a cosmetic arm without any prehensile function in the hand, which may be equipped with a rubber hand which can be placed in the various positions by the sound hand.

The most common type of mechanical arm is described by Kessler (31) and is one in which the hand mechanism is activated by a cord attached to the opposite shoulder. Adduction movements of both extremities produces a pull of this cord which opens the hand mechanism while a spring produces closure of the hand by releasing the shoulder movement.

Where no mechanical hand is to be fitted, forearm amputations are provided with a hinge at the elbow and a simple corset around the arm. The patient is supplied with a "dress" hand having a thumb working on a spring with which various objects can be held. A C-hook is very useful as it can be used for pulling, pushing or torsion. Where the arm is weak, it is advisable to fit an adjustable lock at the elbow to enable the joint to be fixed at any angle desired.

Artificial arms must be fitted as early as possible. If they are not, the patient comes to depend too much on the remaining hand. Usually they can be fitted in a month.

To summarize upper extremity prostheses:

1. Artificial hands are of little value.

2. The most useful appliance for a prosthesis is a hook.

3. The practical attitude to take toward an arm prosthesis is that it is a "tool-holding device".

In conclusion it may at first seem that amputation is a plain confession of surgical failure to save a limb. This may have been true in the past, but is certainly not so today. Amputation in war surgery especially has been progressively relegated to cases in which, as a consequence of trauma, the limb has already been lost through the destruction of its blood supply, or rendered useless by extensive injury to its anatomical structures. Limbs are very rarely amputated nowadays for infective complications in the extremities. It is for this reason that Trueta (1) makes the statement that the amputation rate in war surgery has enormously decreased in the last century and a half.

Previously, all too often, the surgeon was satisfied with the healing of the stump and the discharge of the patient believing when this was accomplished that he had done everything possible and that his efforts had been highly successful. The patient was told to wait until the stump "shrank" and then to see a "leg-fitter". However, intensive study of amputations from the prosthetic as well as the surgical standpoint was necessitated by World War I. Now the surgeon must bear in mind the ideal sites for amputation, how to produce an ideal stump, correct post operative care of the stump and the psyche of the patient. Otherwise the patient who could be restored to active life may become only a burden to his community. The surgeon and the limb-fitter must work in the closest cooperation.

From the psychological standpoint the surgeon is dealing with individuals in varying frames of mind depending on the reason for the amputation. The main psychological problems arise in those individuals in whom an amputation is performed as an immediate result of an accidental injury. The patient, who has been previously well, active and physically whole, is suddenly confronted by the prospect of going through life maimed. The patient will regain his self respect and self reliance if such an attitude is apparently expected by those about him.

There are patients in whom amputation is performed because of chronic disease in the extremity. The major surgical problem in these cases is usually the saving of life; the creation of a functional stump and the use of a prosthesis are of secondary consideration.

There are still other patients in whom amputation is performed in a deliberate attempt to substitute a useful prosthesis for a useless, unsightly or hopelessly deformed extremity.

Therefore the actual removal of the limb is a small part of an amputation. In addition to asepsis observed in all surgery everything must be done to insure a stump which can be fitted with a prosthesis. The prosthesis must be provided as soon as possible and the patient taught to use it before he becomes dependent on some other type of locomotion or learns to use his opposite hand or the stump without a prosthetic.

Only recently a committee has been organized to study the problems associated with providing war veterans with artificial limbs. On this committee are experts in the field of engineering along with surgeons and inventors. There has been a failure to apply much of the knowledge that has been available on prosthetic devices. In addition to the fact that many makers of prostheses have held to their own patents on devices, there have been many new discoveries in alloys made. This committee intends to incorporate all of the advances which have been made into the making of artificial limbs and bring about standardization of parts and mechanisims to simplify maintenance and repair. Even though the number of amputations is decreasing we are still striving for better prosthetic devices.

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