Basic Principles of Lower Extremity Bracing*

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All ortheses, however skillfully constructed, are only auxiliary means in the treatment of neuromuscular dysfunctions and musculoskeletal disorders. It is important for the physician, before he selects and prescribes a brace, to make a correct diagnosis, then to carefully consider the indications that present themselves (1), and last, to have a good knowledge of the basic principles governing the fitting and alignment of such ortheses. He should also know the different parts available so that he can prescribe a satisfactory brace which can be worn successfully by the patient within his remaining functional capabilities (2). All braces need modifications, because no disability will remain static indefinitely in a living organism. Therefore, the physician should recheck each patient at certain intervals depending on the course and acuteness of the condition and order such modification individually. *The brace must be fitted and adjusted on the patient; otherwise it will never fit. It should never be ordered by mail or fitted only from a tracing. The orthesis selected should not be more extensive than the disability requires* (3). This means that it must be as light as possible, but strong enough to withstand the stress and torque of the body during weight bearing and locomotion and of any excessive and abnormal muscular activities, such as spasticity. It must fit accurately, be comfortable and be efficient. It must be prescribed intelligently and with forethought to its function and economy. It should be aligned accurately. The design selected should be the simplest that will accomplish the purpose and mission (4). Successful bracing can be obtained only in this way. It is obvious that the basic principles considered in this paper will also apply to various modifications or special devices which are often needed in certain cases to facilitate locomotion.

CHAPTER I. FOUNDATIONS

Ortheses for the lower extremity are composed of uprights and hinges attached to a foundation. This foundation can be a metal arch plate or a shoe.

METAL ARCH PLATE OR SANDAL FOUNDATION

In this type of foundation, the basic attachment is a metal arch support which is placed inside a shoe (fig. 1). The uprights of the brace are welded to this plate. It is hard to make a well-fitting metal plate because of the difficulty of controlling movements between the plate and the foot. This plate requires a larger shoe, in which it must be inserted. It is liable to cause pressure sores, therefore it cannot be used for patients with inadequate skin sensations. The advantage is that shoes can be readily changed. It is used very seldom.

SHOE FOUNDATION

Most of the lower extremity braces are built with the shoes as the foundation. It is, therefore, important to see that the shoe is fitted properly

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and so designed that it can be applied easily. The brace cannot be effective or achieve the purpose for which it has been prescribed unless the patient has a properly selected and comfortable shoe. High top shoes are generally used for children and in cases in which ankle support is needed. They are of special value for many cases in which there is tightness in the heel cords or spasticity in the triceps surae muscles, as in cerebral palsy. The Oxford type or a low quarter shoe can be used for other conditions. All shoes should be sturdy in construction, have adequate width and length and be comfortable; however, they should be snug enough to prevent the foot from assuming faulty positions. They should have an adequate steel shank. In certain cases in which edema or deformity of the foot is a problem, or some cases of spasticity, a specially constructed shoe with laces in front to the toes or occasionally front and back is of considerable advantage. This facilitates application of the brace to the leg and provides adjustment for swelling or deformity.

The female patient often feels inconvenienced because the corrective shoe is not of the latest fashionable design. However, our main consideration must be given to the effectiveness and comfort of the brace. The comfort and quality of the shoe are fundamental to a successful fitting. In the female patient, it may be necessary to use a higher heel than in the male patient. As a general rule, such a heel should not be more than 1¼ inches high (5).

To permit a good weight-bearing functional foot (3), a shoe with the brace attached should:

1. *Allow the body weight to be distributed evenly over the plantar surface of the foot.* The weight of the body should fall through the center of a triangle made by the os calcis, the heads of the first and the fifth metatarsal bones. The orthesis must maintain the normal weight-bearing axis from the tibia down through the talus and out between the first and second metatarsal bones. It should provide a maximum amount of push-off during locomotion, with adequate balance. The balance and stability in the lower extremity is controlled by the forefoot through the muscles which act principally on the first and fifth metatarsals.

2. *It should provide a foot aligned with the ankle joint.* The alignment must conform to the patient's axis of the foot in relation to the long axis of the tibia. It should maintain properly aligned supination of the foot, otherwise, it may cause serious complications. The heel should be well positioned in the lateral plane, thus preventing valgus or varus of the ankle. The balance of the shoe should not be disturbed by the brace. If necessary, wedges should be used to obtain a three-point weight-bearing plantar surface and a good weight-bearing axis (6, 7). However, when using wedges it is necessary to evaluate not only the degree of correction they provide, but also the amount of unbalancing they create in the shoe. It is obvious that wedging of one heel of the shoe will cause the shank and sole to slant at a different angle than originally provided, thus changing the alignment of the shoe. This may cause severe disabilities and complications. It is often better to use wedges inside the shoe. These will correct the disability without unbalancing the weight-bearing surface of the shoe. If wedges are used on the outside, they should be placed between the brace attachment and the sole. Otherwise, the whole brace will become maligned.

3. *It should provide good lateral stability to the foot in spite of the muscle imbalance present.* This can be obtained only on weight bearing because it is almost impossible to control a dynamic force of imbalanced muscles by a static force of the shoe or brace.

4. *It should retain the optimal amount of motion in the ankle, considering the necessary stability that must be maintained.* The optimal degree of motion in the ankle is achieved when, on ambulation, the foot is well aligned, showing no abnormal deviations. It is important to allow as much motion as possible because in this way better gait and push-off are obtained, which provides a more normal appearance. Also, in most cases the body balance is better preserved by permitting more motion in the ankle.

Metal Foot Plate

The basic part of all attachments of braces to shoes is a metal foot plate which is secured to the outer sole of the shoe with the heel removed. This basic foot plate is secured by three to five rivets, depending on the type of attachment. At least one of the rivets must go through the steel shank of the shoe to provide proper anchorage and good stability. The basic foot plate should be placed horizontally to the walking surface of the heel. When fastening the foot plate to the shoe by rivets, care should be taken not to twist the steel shank, as this will cause malalignment of the shoe. This will prevent the shoe from having proper contact with the walking surface. The basic foot plate must be so fixed to the shoe as to provide proper alignment of the brace and normal physiologic toe-out of the patient. The amount of toe-out varies in each person, and depends on the amount of torsion in the tibia or femur or both.

In the femur, the degree of torsion is determined by the angle formed by the axes of the knee joint and the femoral neck. The axis of the knee joint is placed approximately through the femoral condyles and is usually maintained during locomotion in the longitudinal and horizontal planes, even in the presence of severe deformities around the knee. The torsion angle of the femur varies from 37 degrees anterior (antiversion) to about 25 degrees posterior, with an average torsion of 14 degree of antiversion of the neck of the femur. The axis of the hip joint bears no constant relationship to the direction of the femoral neck.

The longitudinal axis of the ankle joint is almost always laterally rotated in relation to that of the knee. In the horizontal plane, this axis does not meet the tibial shaft at a right angle but passes obliquely and medially upwards. This causes the lateral malleolus to lie $\frac{1}{4}$ to $\frac{1}{2}$ inch inferior and posterior to the medial one. Because of this relationship, the resting foot assumes a physiologic position of plantar flexion and some inversion.

The position of the foot during walking is not only determined by the amount of torsion or declination angles of the tibia and femur, but is also influenced in the absence of bone and joint involvement by hereditary factors and age. In the very young child, there may be an internal torsion of 10 degrees. As the child grows up, this internal torsion changes to external torsion, which may reach 25 degrees at puberty. However the average toe-out is between 8 and 12 degrees. Therefore most braces are provided with a toe-out of about 10 degrees unless contra-indicated by some malalignment of the bodily segments. The toe-out position compensates to some degree for the normal external rotation of the foot and leg on the femur during locomotion. If the brace is attached to the shoe without regard to the amount of torsion present, the patient will usually have a functional varus and will walk with a varus foot, that it, he will walk on the outer border of the shoe and his gait will be unstable. In addition, the extremity will be internally rotated in the brace and the patella will no longer be in the center of the brace. The medial condyle will be located posterior to the mechanical axis of the brace.

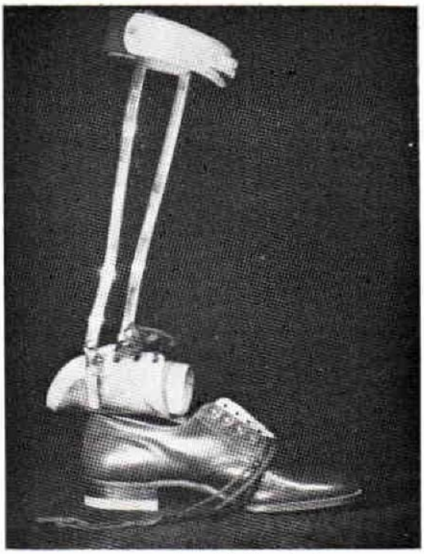

Figure 1. Sandal Foundation.

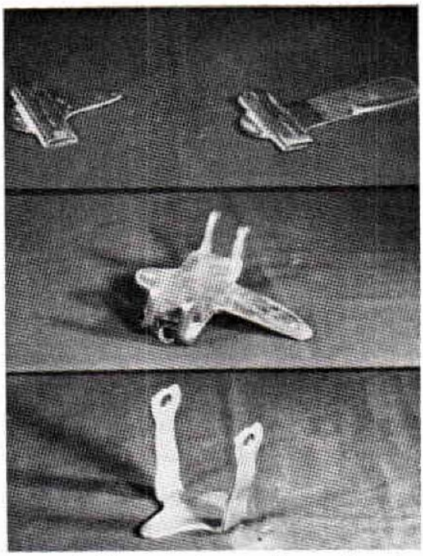

Figure 2. Shoe attachments. Top, rectangular socket; Center, round socket with double stops; Bottom, fixed stirrup.

TYPES OF BRACE ATTACHMENTS TO THE SHOE

Basically, there are three ways of attaching a brace to a shoe. They are the round channel or socket, the flat or rectangular channel or socket, and fixed stirrup (fig. 2).

Round Channel or Socket

The round channel or socket attachment consists of a cylindrical tube which is welded to the basic foot plate. When necessary, stops are attached to this plate. The uprights or points, as they are sometimes called, are round rods bent at a right angle for slipping into these round channels.

Flat or Rectangular Channel or Socket

The flat or rectangular channel or socket, also called split stirrup, is again composed of a basic foot plate aligned to provide the proper toe-out. A rectangular channel is welded to this plate in the same way as the round channel attachment. The only difference is that the points or uprights must be flat to fit this channel. There is no motion in this channel. There is considerable stress in this area. The motion is provided by an ankle joint, suitably located.

Both the round and rectangular channels allow the braces to be easily removed and provide for an interchange of shoes. This is a desired feature because each patient should have at least two pairs of shoes so that he can wear them alternately. The average person does not wear one pair of shoes every day for 4 to 6 months; this does not provide for proper hygiene of the feet. Detachable braces also allow the patient to obtain new shoes and have the channels placed in them without going without his braces. This is a great advantage to a patient who lives far away from a brace shop.

Fixed Stirrup

The stirrup type of attachment is a fixed way of anchoring the brace to the shoe. In this method, the basic foot plate has solidly attached metal side arms on each side (8). These side arms of the stirrup extend from the basic metal plate at a right angle. However, in rare cases they may extend at approximately 50 to 60 degrees from the vertical, being placed more distally. This allows the basic metal plate to be attached further forward on the shoe, thus giving more support to the arch of the shoe. The conventional stirrup attachment is stable and does not provide for interchangeable shoes; however, various modifications have been devised to make it removable.

CHAPTER II. HINGES

In the brace for the lower extremity, hinges may be used at the ankle, the knee and the hip. It is not possible to duplicate, mechanically, the exact action of any anatomical joint because each and every anatomical joint operates in at least two planes and shows translatory and rotary components on movement. Therefore, an important essential for satisfactory fitting of the brace is the successful placement of the mechanical hinges as nearly accurate as possible to the median axis of the anatomical joints. Such alignment will allow the brace to provide proper and adequate support with the least interference with normal function and activity of the extremity.

It also must be remembered that every hinge is a mechanical device and must obey the laws of mechanics. It can operate only in planes provided by its construction. The majority of hinges have only one plane of operation. In addition, it is absolutely necessary to the proper working of any mechanical hinge, whether ankle, knee or hip, that the gliding surfaces of the pair be in the same parallel plane, one with the other. The component parts of each hinge should be aligned in the same longitudinal axis (fig. 3); otherwise, there will be friction, limitation of motion and mechanical failure. There should be no attempt, therefore, to force a hinge in any way to conform to the extremity; otherwise bizarre patterns of locomotion may occur. Hinges may be of different construction. The box joint is a sturdier hinge than the lap joint. In certain cases *e.g.*, cerebral palsy, ball-bearing hinges can be used.

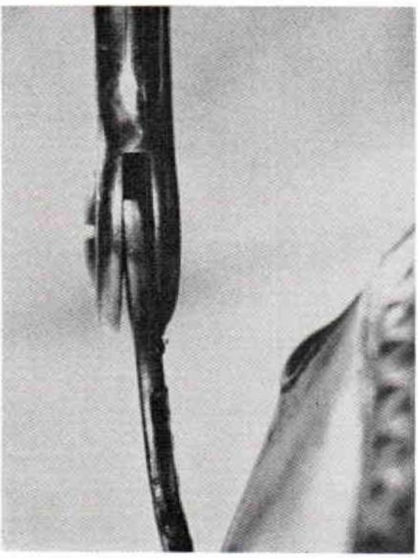

Figure 3. Malaligned ankle hinge showing friction of sliding surfaces and stress of the component parts.

Figure 4. Round caliper brace with double stops.

HINGES AT THE FOOT

A lower extremity brace may articulate at the foot, either by a heel or round caliper hinge or an ankle hinge which is often called incorrectly a stirrup hinge. Because of the placement of the hinges, either method has certain advantages and disadvantages.

The Heel or Round Caliper

The heel or round caliper permits motion in the heel of the shoe. This method readily allows for a change of shoes (fig. 4). It is easy to fit and to adjust. Also, it is inexpensive to maintain. The disadvantages are caused by a malalignment of the hinge to the anatomical joint. The hinge is located in the heel of the shoe, which causes its mechanical axis to differ from the anatomical axis of the ankle joint. Since the mechanical and the anatomical axes do not correspond and do not lie in the same plane, the arcs of motion that are described around these pivots will not be similar, but will tend to be divergent. This incongruity of motion will tend to create undesirable stresses, because during locomotion the upright bars move backward and forward with each step, and may cause compression of the calf band. This lack of synchronized movement between the extremity and the brace will tend to cause in the long leg brace an upward movement of the thigh uprights which will thrust the upper thigh band against the gluteal fold on weight bearing and a downward drag during the swinging phase. In the short leg brace, the calf band and cuff may ride up and down. This undesirable movement may cause chafing and irritation of the skin in the areas of contact. This is particularly dangerous in the patient with deficient cutaneous sensation, for example, the paraplegic, quadriplegic or brain-damaged patient (fig. 5).

Since the shoe is rotating around a lower axis and the foot around a higher pivot, the foot has a tendency to slip during locomotion. On plantar flexion the foot moves forward and may cause cramping of the toes. On dorsiflexion, it moves backward, forcing the heel to slip out of the shoe. This tendency for slipping of the heel may interfere with complete immobilization of the knee with a knee lock. However, in most braces, the calf band

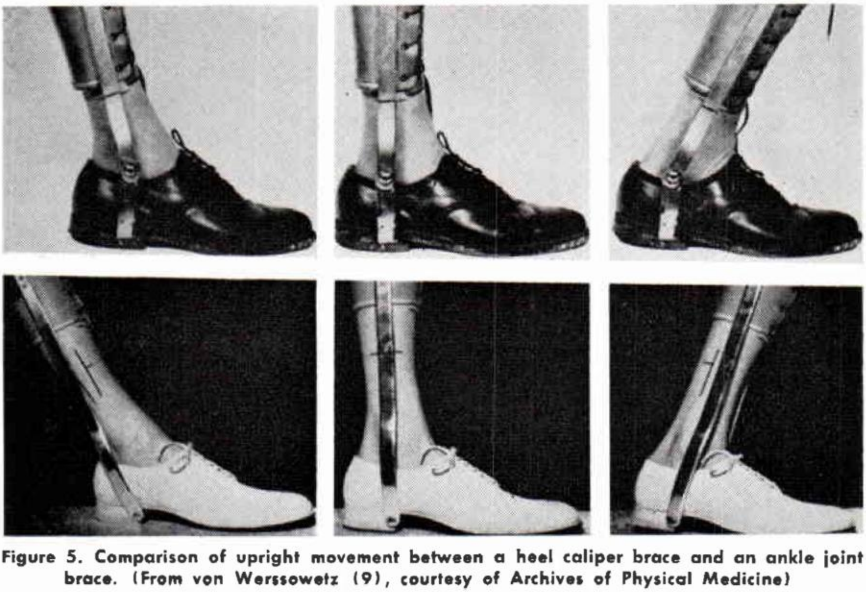

Figure 5. Comparison of upright movement between a heel caliper brace and an ankle joint brace. (From von Werssowetz (9), courtesy of Archives of Physical Medicine)

is not fitted tightly; therefore, some slight motion is present which permits this incongruity of axes to allow some vertical displacement of the uprights during various phases of gait without too much movement occurring between the foot and the shoe. A brace with a caliper hinge, as any detachable brace, has a tendency to be more easily malaligned below the calf band because it is somewhat distorted with each stretch for changing shoes.

Ankle Hinge

The ankle hinge or so-called stirrup hinge is placed on the level with the anatomical ankle joint. This vertical placement is important when functional motion in the ankle is to be permitted, as it appears to be sounder mechanically and physiologically. If the mechanical joint is placed correctly there will be very little, if any, displacement of the upright and of the foot on motion.

The mechanical ankle joint should approximate as closely as possible the anatomical axis of the ankle. The axis of the mechanical joint should be placed at about ½ to ¼ inches above the tip of the lateral malleolus and should bisect the ankle joint, coming out above the level of the tip of the medial malleolus. There are some clinicians who consider the anatomical axis to be placed about ½ inch lower than stated above and who feel that it lies at the apex of the fibular malleolus. Theoretically, for best results, the axis of the anatomical joint and the hinge should be the same. Practically, however, this is impossible to obtain because the axis of the anatomical ankle joint runs obliquely and diagonally between the malleoli, from posteroinferior surface on the lateral side to the anterosuperior surface on the medial aspect of the foot. Most bracemakers today are aligning the hinge slightly diagonally to the shoe, thus providing for the physiologic toe-out.

Free Motion Hinges at the Ankle

Both the heel and the ankle hinges may be free, thus permitting motion. Free hinges are used when muscles of the foot and the ankle are of good functional strength and there is a necessity to: a) correct imbalance of the foot and prevent deformities; b) provide lateral stability of the ankle; c) give support to the knee. Imbalance of the foot may be caused by unequal pull of the muscles, abnormal attachment of the tendons, contractures or elongation of the periarticular tissues, various osseous anaomalies and persistent assumption of faulty posture. These will have a tendency to cause deviation in the normal alignment and when permitted to continue, will eventually cause structural deformities. Involvement of these structures at the ankle often will result in diminished lateral stability and will require appropriate support.

In the athetoid child (10) the joints must move easily and freely, with little or no resistance, therefore ball-bearing free joints are often used. Free hinges at the ankle must be used when there is a necessity to provide support for the knee which because of weakness may require locks, or may be showing deformities such as knock knee or back knee.

Spring Hinges at the Ankle

The ankle hinges can be made dynamic by addition of springs of appropriate tension to correct the imbalance of the muscles or to prevent or release tightness and contractures at the ankle (5, 11, 12). These springs may be attached to the upright bars or may be incorporated into the hinge mechanism, which makes them more versatile and easier to operate. Springs can be used to help either dorsiflexion or plantar flexion. Only springs which are easily adjusted should be used. The tension of the springs should be such that the foot is positioned at a right angle or in slight dorsiflexion when the foot is at rest and non-weight bearing.

Figure 6. Adult dual action spring-controlled ankle hinges attached by a rectangular socket.

When the foot shows weakness in both dorsiflexors and plantar flexors, even with muscle imbalance present, dual action springs may be used (fig. 6). These joints were designed by Unger and Hanicke (13). The principle involved is the use of two springs acting in opposite directions, each spring being adjusted to counter-balance the muscle imbalance present and the tension of the opposite spring. The use of dual action springs can provide a balance at the ankle which approximates, to a much greater degree, the natural action of the foot. Dual action, spring-controlled ankle hinges are excellent for most patients with neuromuscular involvement, such as poliomyelitis, polyneuronitis, muscular dystrophies and other neurologic disorders, as well as in post- tscaumatic paraplegias and quadriplegias. Some have been successfully used in spastic cerebral palsy. The brace with such a hinge provides good motion and helps greatly in maintaining standing balance.

At present, dual action spring hinges come only in adult sizes. These bring the foot up to a right angle at rest from either plantar or dorsiflexion. For children, two single action spring joints can be used, one on each upright but acting in opposite directions against each other, that is, one placed in the conventional manner, the other in a reversed position (fig. 7). Theoretically, there may be some question whether a dual action spring ankle joint does not create a tendency to over-stretch weak muscles. This, at first, may seem to be a logical assumption; however, in a flail or severely involved foot there is equal danger of producing tightness and contractures which could result in structural deformities. With the dual action spring hinge, it is possible to regulate the tension or the degree of motion in each direction so that a balanced movement is obtained. If the allotted range is held well within the limits of the average functional range of motion of the normal foot, then there can be no undue stretching of any muscle because this range is physiologic and is performed normally and constantly by these muscles. Permitting motion to be within the physiologic limits of dorsiflexion and plantar flexion helps to prevent and eliminate tendencies toward the development of contractures. Normally, the allotted range is 15 to 20 degrees of plantar flexion and 20 to 25 degrees of dorsiflexion.

The main disadvantage of all spring joints is casting; they are often hard to shape adequately in and about the ankle for a close fit. Another disadvantage of these hinges is a possibility of getting sand, dirt, or lint or other foreign matter into the castings of these joints. This will interfere with their proper action.

Limited Motion Hinges at the Ankle

When limited motion in the ankle is desired, stops may be used. It must be remembered that stops are static and function only at one phase of the step. They do not provide positive action. Stops can be placed either on the heel caliper or the ankle hinge. Stops may even be provided in hinges with springs. The correct selection of stops depends on present muscular imbalance and prospective functional activity. Muscle imbalance will determine the type of stop used. There are three types of stops: the posterior, the anterior and the double.

The posterior stop is used when the dorsiflexors of the foot are weak and the patient has an equinus or a dropfoot deformity. The stop should allow no more than 5 to 10 degrees of plantar motion. The patient will have to elevate the involved extremity a little bit higher to clear the floor, or otherwise he will drag his toes. There are various methods to provide such limited motion.

The anterior stop is used when the plantar flexors are weak. Here, the extent of permitted motion varies, depending on a number of factors, and usually is no more than 10 to 15 degrees. Anterior stops will not prevent or materially minimize the development of calcaneal deformity, especially

Figure 7. Child dual action spring-controlled ankle hinges.

if it is due to muscle imalance where there are weak triceps surae and strong short plantar muscles of the foot. Anterior stops permitting a range of 20 degrees may be used occasionally to control the extent of hip motion, thus providing stability when there is an isolated involvement of the hip muscles, particularly the extensors, even when there is poor strength in the trunk. These are used in selected patients with spinal cord injuries.

The double stop may be used in a flail foot or one with limited motion in flexion and extension. The only logical use for such a brace with double stops is in a few isolated cases in which the patient has completely flail lower extremities and a good sense of balance. In such cases, a brace with double stops may permit a patient with such severe disability to use a shuffle or a swing-to gait by stabilizing the lower extremities. Such a gait is not very practical and is never independent, although it may permit the patient easier transference from wheelchair to bed, and other activities under supervision of an attendant.

Stops and Functional Activity

In general, stops interfere with locomotion and markedly hinder the patient when going up and down a hill or a ramp, because they do not permit the body weight to assume a proper relation to the base of support. Anterior stops, particularly, should be avoided because they severely interfere with getting into and out of a sitting position and with walking with the hips properly tucked under, that is, in slight hyperextension, which most severely involved patients must do with crutches and braces. An anterior stop also forces the patient to use excessively the metatarsophalangeal joints and causes him to walk on the ball of the foot. This often causes the shoe to break down in the sole where the steel shank ends. As the result of this distal shift of the foot activity, the patient usually tends to compensate by pivoting on the heel when walking.

It is obvious that a thorough evaluation of the patient's general condition, strength, balance awareness, stability, and functional abilities and capacities is necessary before a stop is prescribed. Often stops can be used to advantage with spring hinges to limit excessive motion caused by the overactivity of some muscles.

The Advantages of Dual Action Hinges

The dual action hinges can be used to provide any desired effect at the ankle. That is: a) a free joint by removing both springs; b) a spring assistive joint by using either one spring in a given direction or both springs; c) a limited joint by removing one or both springs and substituting them by rods of appropriate length, which will act as stops. It is obvious that this is a great advantage as it permits an accurate adjustment of the degree of motion at any time without any guess work. It also allows easy change from one type of assist to another as the condition requires, without a costly reconstruction of the brace.

HINGES AT THE KNEE

The artificial hinges should be aligned perpendicular to their axis and be so positioned that they are at the optimal level from the ground. Usually the medial hinge is slightly lower than the lateral one. They should also be parallel to one another. It must be remembered that artificial joints have only motion in one plane, rotating about a fixed point, and they cannot imitate the normal motion of the knee which includes rotation and sliding movement.

There are certain factors that must be considered in selecting an artificial knee hinge.

1. The hinge should not be bulky. This is especially important when bilateral braces are required because this may cause tripping of the patient, who then will walk with a broad base.

2. The hinge should be able to stand stress and strain without frequent breakdown.

3. All hinges should have stops to prevent hyperextension unless disability requires differently (14).

4. The hinge should have a dependable lock, if indicated. A single knee lock may be used in neuromuscular disorders which are manifested by paralysis and weakness of the muscles. They should be placed so that the patient may have easy access to them, that is, depending on the disability of the upper extremities and the ability of the patient to manipulate them independently. They may be placed either on the lateral or on the medial sides (as in hemiplegics). In patients who have no atrophy, or are too heavy, or both, a double lock should be used because a single lock imposes too great a stress on the hinges. To increase the stability, a knee pad or strap must be used.

5. The hinge should not have excessive or sharp projections of the lower bars, as they will damage clothing (15).

The artificial knee hinge should be placed in the median axis of the knee articulation (16). This takes place approximately through the femoral condyles and not through the joint space; therefore, to secure a properly functioning brace, it is necessary to place the artificial hinges opposite the mid-point of the femoral condyles. The best method of determining this point in a person of average weight is to identify the prominences where the collateral ligaments are attached to the femur (fig. 8). If the location is chosen correctly, there will be little, if any, motion in this spot when a

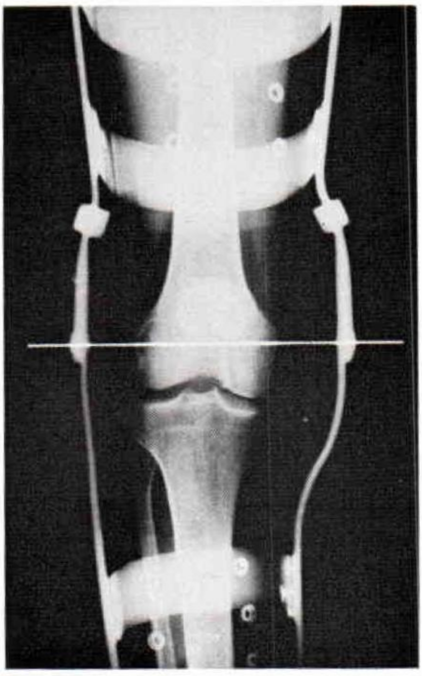

Figure 8. X-ray of knee showing alignment of the hinges. (From von Wersswetz (9), courtesy of Archives of Physical Medicine)

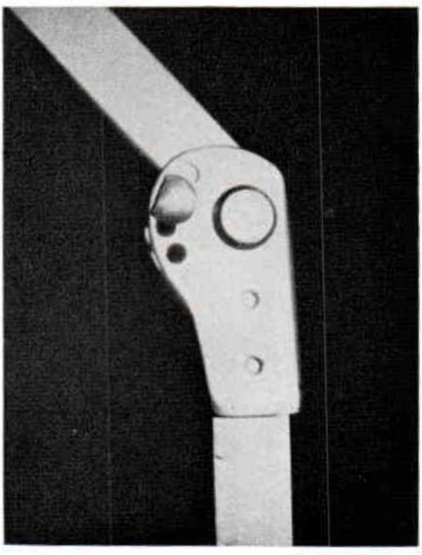

Figure 9. Dial control knee hinge.

patient flexes or extends the knee. It is important to place this location accurately, because, otherwise, the brace will interfere with the locomotion or will be uncomfortable in a sitting position.

a. If the hinges are placed too high, they will interfere with flexion of the knee, and the uprights will be forced upward causing the lower thigh band to press unduly into the posterior aspects of the thigh.

b. If the hinges are placed too low, then the thigh band will be pulled away from the posterior aspects of the thigh, and the calf band will have a tendency to press into the calf muscles. The brace will have a tendency to move up and down on flexion and extension of the knee.

c. If the hinges are placed too far forward, they will cause pressure on the calf muscles by the band and will pull down the uprights. The hinges will protrude forward in the sitting position. This can be corrected by making the bands more shallow.

d. When the hinges are placed too far back, they will have a tendency to create excessive pressure over the anterior cuffs, or knee pads. This can be corrected by providing deeper bands.

Knee hinges may be free, limited or locked.

Free Knee Hinges

Free hinges are used when the muscle strength is sufficient for functional range of motion and is sufficient to stabilize the knee adequately for a short period of time, but insufficient for longer functional locomotion, of if there is a tendency toward deformities like genu recurvatum or genu valgum, or if there is instability in the knee. It is used also to minimize undesirable involuntary or incoordinated movements caused by muscle imbalance, such as occurs in cerebral palsy. Free hinges may be single or double. The double hinges have been used to facilitate motion and approximate it to the normal gliding action of the knee. They seem to provide more comfort to some selected patients. However, there are certain disadvantages, of which the bulk and the difficulty in gaining a synchronized movement of the joints are most important. Ball-bearing free knee hinges are often used in certain patients with cerebral palsy (9).

Limited Motion Knee Hinges

The limitation may be flexion or extension. Limited flexion motion knee hinges are used when there is a necessity to protect the knee and its adjacent structures from excessive stress, e.g., after tendon transfers or other operative conditions. In such cases, the knee is allowed full extension but the flexion is limited to prevent buckling. This limited flexion motion hinge is ofted called a dial-controlled knee (fig. 9). The hinge consists of a pin going through a dial which has an opening at various degrees of motion so that the range can be adjusted to the patient's needs. As strength and stability of the knee increases, the range of motion is also increased.

A limited extension motion knee hinge may be used in a large group of patients whose disabilities or progress of recovery is such that lock hinges are too restricting, yet free hinges are too unstable. Such hinges (fig. 10) are called off-set knee hinges (17, 18). The basic principle of an off-set hinge is to have its axis behind the load line. This arrangement will permit stabilization of the joint on weight bearing and preserve free range of motion. Stabilization is secured by a stop on each hinge which controls the amount of hyperextension. This stop can be adjusted to meet the needs of the individual. It is not necessary to provide more than 5 degrees of hyperextension. Usually 2 or 3 degrees will suffice. These joints can be used successfully at the knee as well as the hip. They can be used successfully in monoplegia, hemiplegia, paraplegia, as caused by such diseases as poliomyelitis, cerebrovascular accidents and cord injuries (19).

Locked Knee Hinges

Locked hinges at the knee are used when there is:

1. Lack of normal extension or stability, or both, of the knee on weight bearing because of: a) weakness or paralysis of knee extensors (primarily quadriceps), especially when associated with normal or spastic knee flexors; b) weakness or paralysis of knee flexors (hamstring) causing severe genu recurvatum; c) weakness and paralysis of both flexors and extensors of the knee.

2. Interference with normal extension of the knee because of short heel cord (gastrocnemius tightness).

The locks selected should be simple and sturdy. There are a number of different knee locks to stabilize the knee. It has been stated that locks should be used on both the lateral and medial uprights to prevent torsion and distortion of the brace. These complications may occur in heavy, stocky or obese individuals, who are muscularly active, as is found in some post-traumatic or other conditions of the lower extremity requiring bracing.

Figure 10. Off-set knee hinge with a free ankle hinge in a supportive brace used in post-traumatic conditions.

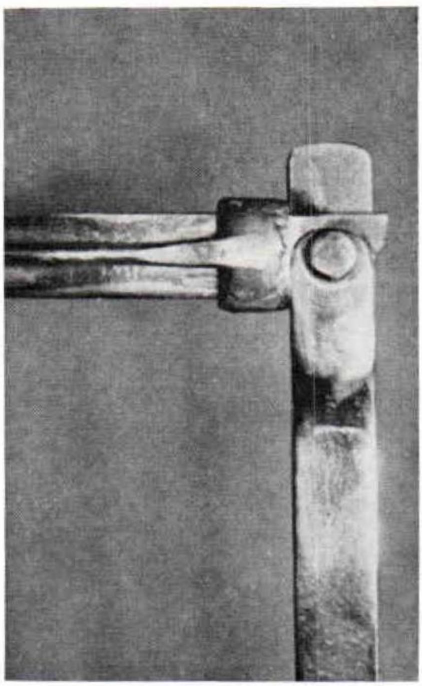

Figure 11. Ring lock on knee hinge.

In most neuromuscular disorders characterized by muscle weakness or paralysis there is a minimal degree of torsion of the brace; therefore single locks are used because patients can manage them more easily, especially if they have to use bilateral braces and crutches. Such patients may have difficulty in maintaining balance, and certainly the unlocking of four locks while holding on to two crutches is a difficult and almost impossible procedure. These patients usually weigh below average, therefore single locks are usually sufficient to provide a soundly locked and stable knee.

There are four basic types of locks used: 1) the ring lock (slip or drop lock); 2) the slot lock (tongue and groove or plunger lock); 3) the pin lock; 4) the bail lock. The first three locks are usually only on one upright; however, they may be used on both. The bail lock always locks both uprights. As a general rule, the single locks are put on the lateral uprights, although this placement depends on the muscle involvement of the upper extremities. It is obvious that it would be easier for a hemiplegic patient to manage a knee lock, if this was necessary, placed on the medial band than on the lateral band.

The ring lock is the most popular lock because it is easily made and is quite sturdy (fig. 11). It is also called a drop lock or slip lock. The lock is composed of a simple ring which rides freely along the upper bar and slips or drops over a projection of the lower upright. This projection is an objectionable feature of this lock because it causes damage to the clothing. This is especially true when the projections are sharp and pointed. Such a projection can cause severe injury to the wearer. This objection has been remedied in England by their ring lock box hinge made so that it has the pivot screw fitted eccentrically. This keeps the sharp projection of the lower upright below the brim of the rounded part of the upper part of the box hinge (15).

The slot lock has been known, also, as the tongue and groove or plunger type. The one that we use (3) has been modified by Witt (fig. 12) and is far superior to the others in its locking ability. The lower upright has a slot in the upper part and a ring is dropped into this to lock it. The ring has one wedge-shaped side which secures the lock tightly. This wedging of one side is most important in providing good stability to this lock. This is one of the best locks available at the present time, and it appears to be quite secure.

The pin lock or McCrae lock (fig. 13) basically consists of a pin which inserts through an opening in both lower and upper uprights, thus engaging them and locking the brace at the knee. For convenience, the pin is attached to an extension arm activated by a spring, thus causing the lock to become automatically fixed on extension. Manipulation of this lever unlocks the brace. This lock should be used only for patients of less than 130 pounds in weight. It should not be used for patients who are heavy or are too active, because the pin which forms the lock may shear off. This lock is not very destructive to the clothing.

Spring Extension Handles for Locks

The three knee locks described above can be made to close automatically on extension by adding to them spring extension handles. In addition, these handles facilitate the opening of these locks in patients who do not have too good balance awareness or have their hands occupied by crutches or canes. These patients cannot bend forward to accomplish the unlocking of braces easily. With the extension handle, they do not have to bend and usually can open the lock more easily. The locking force is provided by a helical compression spring which exerts a constant load force on the

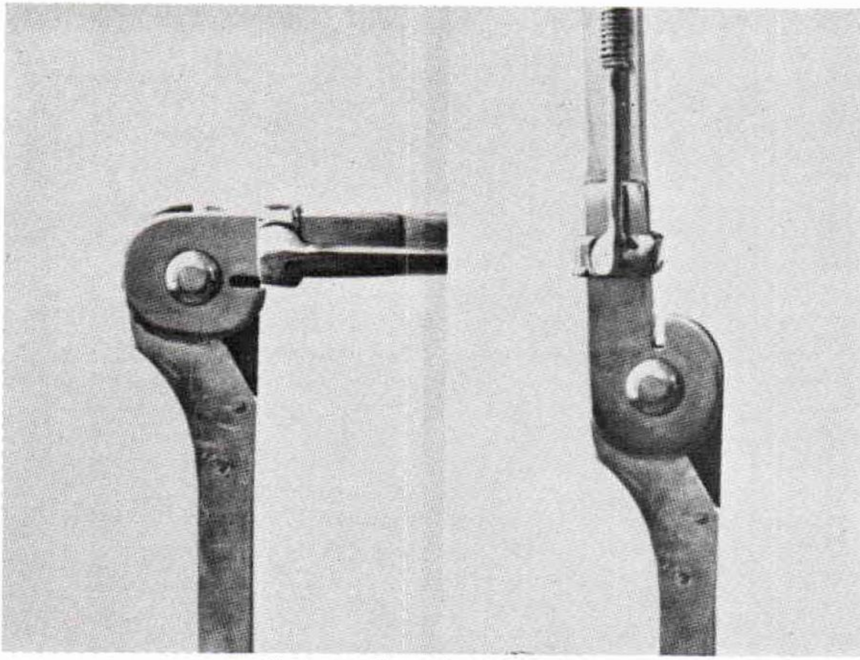

Figure 12. Slot lock on knee hinge.

locking device, forcing it to be constantly engaged when in appropriate position, that is, when the brace is in extension. The lock is released by means of a steel rod or a cable which passes axially through the spring from the locking device to the release extension handle located on the upright at a convenient level for the given patient.

There are several types of release mechanisms used to unlock the braces. The selection of the proper type is very important and depends on the muscular power, dexterity and ability of the hand and arm of the patient.

1. The pull method extension handle is used in the ring and slot type of knee lock. It is successful only when the patient has good power in flexion of the elbow, and a satisfactory grip.

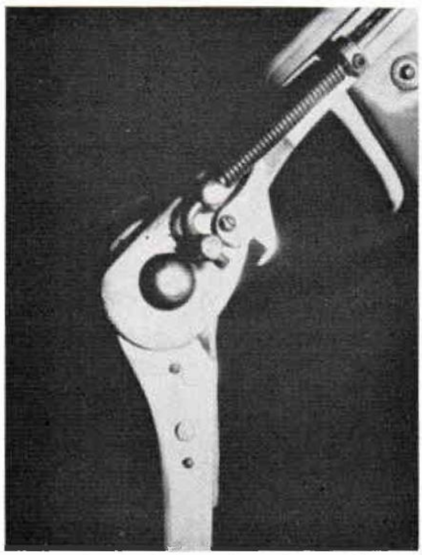

Figure 13. Pin lock on knee hinge. The one illustrated has a catch to permit free knee joint action when desired.

2. The rotation method is used primarily in the pin lock and is indicated when the patient lacks flexor power in the elbow but is able to internally rotate the shoulder. The pin lock is often used selectively for women because it is easier to operate through clothing and is less embarrassing than pulling upward on the dress.

3. The squeeze method (fig. 14) is a cable release method and is used

in some patients in whom the muscular power for elbow flexion or shoulder rotation is poor or non-existent. In such cases the squeeze method of lock opening may be tried if the patient has adequate power in his grasp. This method manages to open the ring and slot locks. This method is less secure than the others, especially for a patient walking on crutches, as the lock can be released accidentally by striking it against the crutches.

4. On the trip method the lock is released by a trip mechanism, so arranged that it will be functional for a severely handicapped patient. However, this type of closing is quite dangerous, as it may open the lock accidentally; therefore it is very seldom used.

Opening Catches on Locks

All three of these locks can be made free by adding catches to them to keep them unlocked. This is often a desirable feature because it permits the patient to walk part of the time with a free joint. If the patient becomes fatigued or has to walk on uneven ground or in a crowded area, he can easily release the catch, thus converting the brace into a stable support.

Double Locks

For patients who are heavy and have severe involvements, it may be necessary to lock both sides of the brace, that is, the medial and lateral uprights. Ring locks can be used for such a purpose; however, opening these may prove to be too difficult for patients with poor balance, who are using crutches for ambulation or who have involvement of the upper extremities. These patients can use the bail lock to advantage; this will depend upon the functional capacity and activity of the patient. The bail (fig. 15), which in bracing is a half ring connecting the lateral and medial double lock parts, provides a positive automatic lock on extension and can be locked and unlocked with minimal effort on the part of the patient without using his hands in this operation.

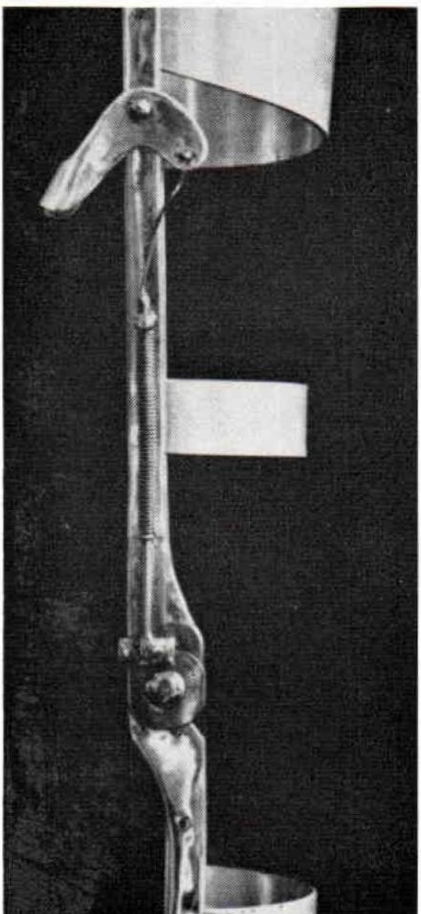

Figure 14. Squeeze method of cable release of a slot lock at the knee.

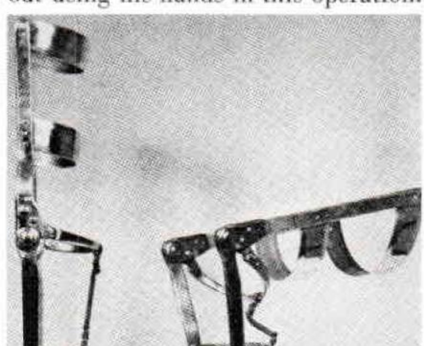

Figure 15. The bail lock on knee hinge. (From von Werssowetz (9), courtesy of Archives of Physical Medicine)

The bail can be used with any type of cam or plunger lock when double locks are indicated. A cam lock, in general, is activated by a spring, rubber or elastic which provides the locking force which acts on a short lever type of projection or a cam, usually on the thigh upright, to force it into the receiving slot on the posterior edge of the hinge box on the lower upright. The patient opens it by tripping the lock hinges, either by lifting the bail with one hand or by pressing the bail on the edge of a chair when sitting down. There is a great variety of cam locks used with automatic locking properties, such as the Schweizer or Swiss lock, the Baeyer lock, the French lock, the bow lock and other types. The principle of action of these various locks is essentially the same.

The most commonly used joints with bail usually have short bars used for locking on each side. These bars are connected by the steel bail posteriorly at the level of the popliteal region, but mostly depending on the type of chair the patient will use. The bail should be placed about 17 to 18 inches above the floor when the patient is to use an ordinary chair. If he is to use a wheelchair, the height should be greater, about 20 to 21 inches. This will improve the patient's ability to manipulate his brace more adequately. The bail is usually connected by a rubber or an elastic webbing with the calf band, or a spring is used on one side of each hinge to keep the brace locked in extension.

It has been said that the bail lock is unsafe and that it will open when the patient backs up against a wall. This will happen only when the semicircular lever or bail is not aligned properly, that is, if it is not pointing slightly downward, but is horizontal or tilted upward. In such a case, any pressure on the lever will open the lock. A patient with severe adductor spasm and scissoring should use bail locks with caution, because sudden spasm may trip the knee and open the lock. Occasionally, the bail lock has a tendency to open during certain functional activities, such as getting out of a wheelchair. If this occurs, the bail lock can be easily transferred into a single lock with spring extension arm.

HINGES AT THE HIP

There is still great controversy regarding the use of trochanteric hinges (20, 21). Some clinicians vehemently opposed to their use, whereas others may use them too much. There is always a happy medium in which a pelvic band or a spinal brace and a trochanteric hinge have a necessary and important place. They are used to prevent abnormal motion at the hip, especially external or internal rotation. It should also provide stability when necessary (3, 18, 22, 23). It has been said that there are very few poliomyelitis patients with hypermobile hips, yet our experience has been that these cases are not too infrequent, and for these patients trochanteric joints may be indicated. Certain other neuromuscular disorders also require the provision of more stability (some paraplegics) or control of involuntary movements (some cerebral palsies) at the hip which can be accomplished by trochanteric hinges.

The trochanteric hinge is placed at the level of the tip of the greater trochanter and slightly anterior to it. If it is not placed properly it will distort the alignment of the entire brace, because on changing position from standing to sitting, the upper trochanteric hinge arm will tend to push or pull on the lateral upright of the long leg brace to which the whole trochanteric hinge ensemble is attached, thus causing a rotation of the long leg brace on the thigh. Trochanteric hinges can be free, limited or locked.

Free Trochanteric Hinge

A simple or double free hinge (fig. 16) corrects abnormal rotation of the extremity but does not provide too great stability. It can be used successfully in cases with weakness of the pelvic girdle, but especially of gluteus medius muscle when it is attached to a well fitted spinal support or a pelvic band. This arrangement may prevent further damage to the muscles. It is especially valuable in children who will not use their crutches. In patients who have involuntary movements and over-activity of muscles, a ball-bearing hinge may be used to provide greater torsional strength and prevent shearing. Also, the ball-bearing joints provide more normal motion with less effort in these patients, although they are heavier.

Limited or Off-set Trochanteric Hinges

Off-set trochanteric hinges are constructed similarly to the off-set hinges at the knees (fig. 17). They can be used with excellent results, especially in children who have hypermobility in the hips, poor balance, and a tendency to dislocation in one or both hips. Off-set hinges provide free range of forward (flexion) motion, but provide limited and secured movement on slight hyperextension, which can be controlled as desired. On flexion the "off-set" unfolds and actually increases the length of the upright, thus compensating for the increased length of the surface of the extremity which occurs on sitting. These facts accomplish two major objectives which are: a) providing better posture, and b) preventing excessive strain on the anterior pelvic and femoral ligaments which tend to stretch under prolonged pressure.

Locked Trochanteric Hinge

A locked trochanteric hinge makes locomotion impossible except when using a swing-to or a swing-through gait with crutches. It also interferes greatly with functional activities of the patient. However, it provides excellent stability which may be needed by some patients who are engaged in certain occupational or vocational pursuits requiring them to stand.

Trochanteric joints are not prescribed routinely. The patient always is tried first on long leg braces with crutches and is instructed in a proper gait. He is then observed and evaluated. If it becomes apparent that he is not going to ambulate correctly, he may be given a trochanteric hinge if it is thought it will help him. Later, he is evaluated again and if the trochanteric hinge accomplishes some correction, it is left on, but if it does not improve the gait or posture, it is removed. It is necessary to re-check a patient with trochanteric hinges very carefully. If it becomes evident that the trochanteric hinges have performed their function and are no longer necessary, they are removed.

The pelvic band is placed in the hollow below the crest of the ilium and above the tip of the greater trochanter. It should be molded to conform to the contour of the pelvis. It should be made of sturdy metal which will maintain its contour. Pelvic bands usually extend from one anterior superior spine of the pelvis around to the other side. Such a solid pelvic band provides the best stability. In some cases, especially those in which rotation is the only problem, a half pelvic band can be used.

CHAPTER III. UPRIGHT BARS, BANDS AND CUFFS

UPRIGHT BARS

The upright bars should conform to the contour of the leg and thigh and should clear the ankle and the knee. They should not touch the skin, and the clearance should be about $\frac{1}{8}$ to $\frac{3}{8}$ inch except when the construction of the hinges does not permit this fitting, or when proper alignment of the orthesis demands otherwise, as it usually does on the thigh. Usually two uprights, that is, a medial and a lateral bar, are used because it is difficult to hold an extremity securely with only one upright, no matter how strong this bar

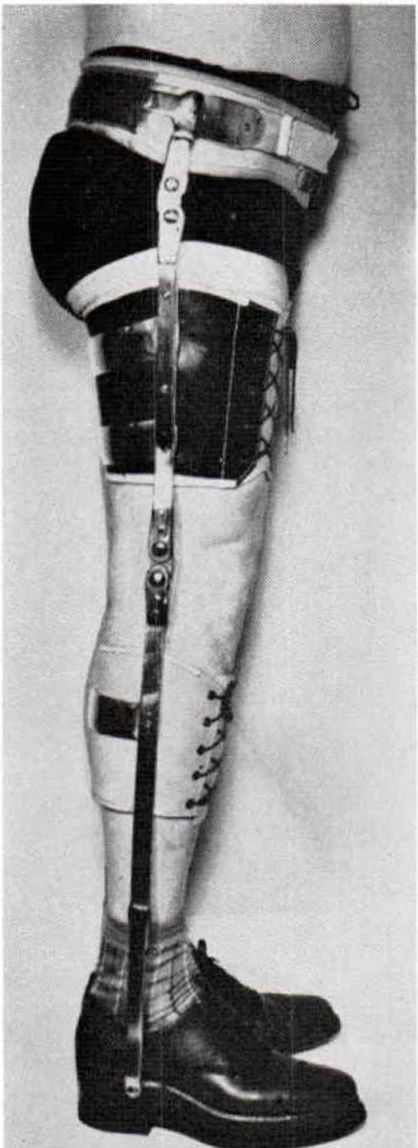

Figure 16. Double free hinges at the hip and knee used in post-traumatic condition.

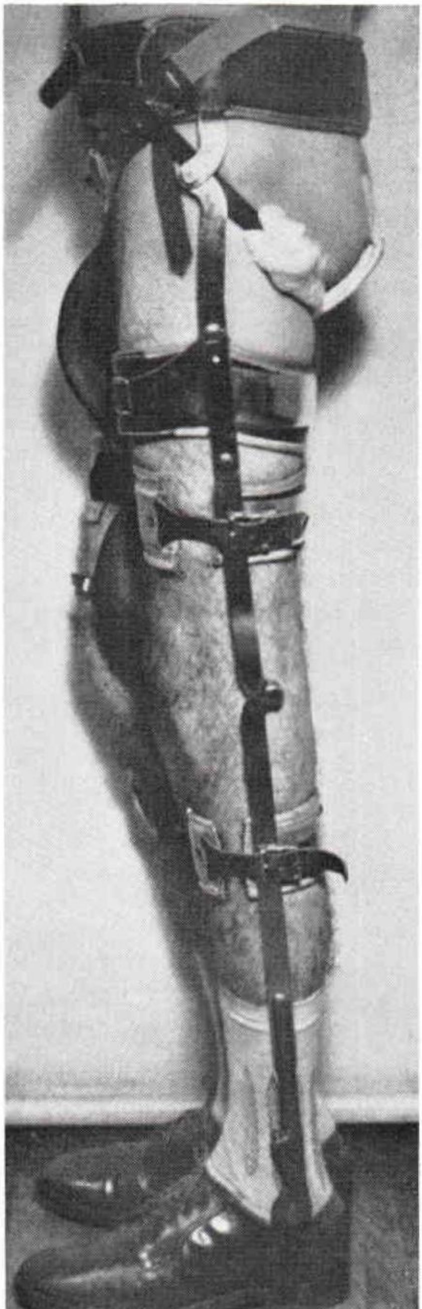

Figure 17. Off-set trochanteric and knee hinges used in a paraplegic patient who had exceedingly good balance awareness. The patient is wearing urinary collecting device.

may be. A single bar may be used to advantage in some hemiplegic patients who have minor muscle imbalance. Hessing and Hasslauder (24) and after them, Jordan (5) and lately Schillinger (25) suggested the use of one spiral bar in certain specific neuromuscular conditions for special reasons. However, as a general rule, bilateral bars are preferred.

Flat solid bars of steel or hard aluminum are the best. Cylindrical or tubular uprights, though offering relatively more lightness in relation to strength and rigidity, are not used much because mechanically they are hard to fit and adjust, especially in a growing child. It does little good, for example, to make a brace from a light weight alloy which provides adequate strength only at the cost of greatly increased bulk. Such a procedure defeats its own end. The upright bars should be attached to the shoe so that the foot will be held in a neutral alignment. They should help in preventing any tendencies to eversion or inversion. The uprights are like columns which transmit eccentric load forces. The lower part of the upright should be as vertical as possible to the point where it is bent to join the basic metal plate of the shoe where it is fastened. If the uprights flare out wide at the heel, the eccentric force is exaggerated and a greater stress is put on the uprights. Therefore, the uprights should be fitted close to the shoe. This also improves stability.

As a general rule, the upright bars should be so aligned that on weight bearing they will enable the sole and heel to assume a parallel relation to the walking surface. Bennett (26), in certain special conditions as in the deviation of the heel due to muscle imbalance in poliomyelitis, uses a lateral bar which is slightly longer at the distal end than the medial upright. This increase in length should not exceed 3/16 inch for the adult or $\frac{1}{8}$ inch for children. If the outside bar is too long, the shoe will be held in a varus position. If the patient's foot does not conform to this position of the shoe, it will result in a misfit about the heel.

A longer lateral upright will have a tendency to correct some external rotation, and shift the brace medially on weight bearing, permitting the body load to come more directly over the hip. This enables the patient to get over the hip more smoothly, thus facilitating locomotion. If the lateral upright is too short, it will cause the foot to go into a valgus deformity and tend to produce an abducted gait. The upright bars in the long leg brace should extend on the lateral side to the base of the greater trochanter and on the medical side to about $\frac{1}{2}$ to $\frac{3}{4}$ inch below the perineum. If the lateral bar is placed too low, it will interfere with proper placement of the upper thigh band. Also, the brace will have a tendency to rotate more frequently. The fitting of the medial upright should take into consideration the width of the crotch, the bulk of the adductor muscles and the skin sensitivity of the region. It is obvious that in a stout or obese individual or in one who has a narrow crotch, medial bars may have to be lowered or placed at an angle posteriorly, especially if the patient has to use long leg braces on both extremities; otherwise these high bars, in addition to pinching, will cause the patient to walk with a wide base in an effort to clear them from being tangled. This will tend to produce a valgus of the ankle and a forefoot varus.

For children, the upright bars should be adjustable in the leg and the thigh so they can be extended with their growth. In the short leg brace, the bars should extend to just about the prominent part of the calf but must be approximately $\frac{1}{2}$ to $\frac{3}{4}$ inch below the head of the fibula to avoid pressure on the peroneal nerve as it comes around and below the head of this bone. As a general rule, a short leg brace should not be used for a long time in a growing child because it has a tendency to create and increase the torsion of the tibia. This is a mechanical factor brought about by the necessity of the lower extremity to rotate during weight-bearing phase of locomotion (27). During locomotion the foot usually has a good purchase on the walking surface and as the body is carried over this support, it rotates from an extremely external position into internal rotation in relation to the body. Saunders *et al.* (28) have shown that most of this occurs in the ankle. When the ankle is stabilized by a brace and the foot by its purchase on the ground, the lower extremity has to find another point for rotation. Often this may occur in the epiphysis of the proximal end of the tibia which has inadequate lateral protection. When this occurs the result is external torsion of the tibia.

A certain amount of torsion can be compensated by rotating or twisting the upright bars below the knee or calf band of a long leg brace (fig. 18). This modification is in addition to that obtained by attaching the basic metal plate at 15 to 25 degrees of external rotation. Attempts to fit a straight brace on an extremity with excessive tibial torsion will result in a varus of the foot unless the entire brace is rotated externally to a degree equal to the amount of torsion. This will allow the foot to maintain its normal relationship with the ankle, but the knee and the hip will be internally rotated. A small degree of torsion can be corrected to some extent by a long leg brace. A short leg brace will not have any significant influence on torsion because this brace does not have enough purchase to hold it securely in place and it will tend to twist on the calf. A brace cannot correct fixed deformities; it can prevent their occurrence. Tendencies toward rotational deformities are hard to prevent and correct. If there is a struc-

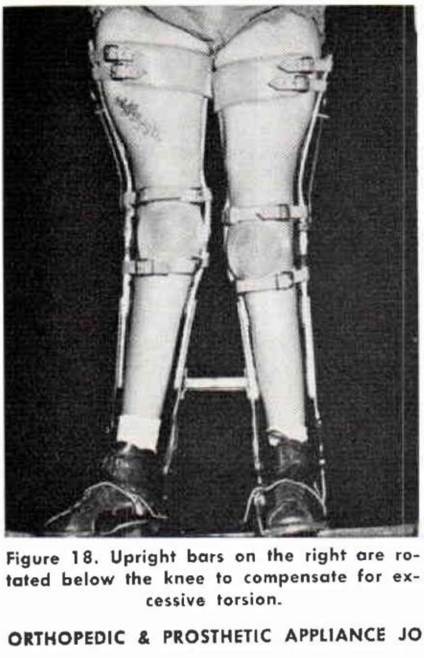

Figure 18. Upright bars on the right are rotated below the knee to compensate for excessive torsion.

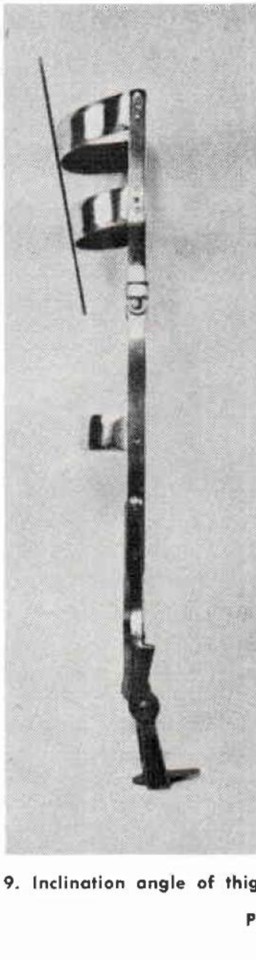

Figure 19. Inclination angle of thigh bands.

tural varus deformity associated with severe tibial torsion, these deformities should be corrected surgically; otherwise, a brace cannot be fitted adequately.

Knock-knee deformity can be prevented and sometimes corrected by proper alignment of the uprights. Knock-knee is usually associated with some degree of recurvatum. The attempt to prevent knock-knee is made in constructing the brace with uprights as straight as the patient can comfortably tolerate. A small medial knee pad is given for pressure. This type of fitting tends to distribute the corrective pressure over a wider surface and permits the use of greater force with lesser discomfort to the patient than if a large pad at the knee were used for this purpose. In addition, this method permits better and closer fitting of the entire brace. Sometimes it is necessary to use a T-strap on the lateral side of the ankle to compensate for the force exerted to bring the leg in proper position and to keep it in proper alignment.

The upright bars must be rigidly connected with metal bands. Usually two thigh bands and one calf band are used. The thigh bands should follow the contour of the thigh. The inclination angle of these bands should be the same and should correspond to that of the thigh (fig. 19). If one band is changed in its alignment, the other has to be changed and realigned in order to obtain the same inclination plane. Otherwise, one of the edges of either band or both, will cut and dig into the thigh because the distribution of pressure is not equal along the upper and lower border of the band. The metal bands should extend half way around the thigh and should be fitted to the contour of the soft parts.

The lower or mid-thigh band should be placed high enough above the knee to permit free motion of the hamstrings. The relative position of this band to the calf band is very important because if the adjacent edges of these bands are too close, the knee cannot be flexed to 90 degrees. If the mechanical knee hinge is offset posteriorly, the bands can be closer together.

The upper thigh band is placed obliquely, curving upward and outward (fig. 20). Its upper edge should be approximately parallel to the inguinal ligament. It should be placed ½ to ¾ inch below the ischial tuberosity and fitted well into the gluteal fold (fig. 26). This will minimize and control the rotation of the brace and not pinch the patient. If it is too high, it will have a tendency to throw the patient forward, and the patient will be unable to stand or walk satisfactorily. The band should be placed low enough to cause no undue pressure in this area but not too low because then the brace is too short, and the patient will have a tendency to sit back on the brace (fig. 21). This position on top of the brace causes flexed knees and predisposes to flexion-abduction contractures at the hip and knee which may result in severe disabilities. This is one reason why it is important to check braces after they have been fitted and why it is of equal importance to re-check the patient at frequent intervals.

The band should be made of very good metal to preserve its shape. If an inferior metal is used, the bands will flatten out during sitting, causing malalignment, torsion and spreading of the brace. The best metal for these bands is good surgical steel or 24 ST 0.102 aluminum, because these materials will retain their shape under stress. It is important that the depth of these bands be accurately calculated, because the proper relationship of the depth between the upper and lower thigh bands will control the position of the knee in the standing or weight-bearing position and will determine the fit of the brace. If the lower thigh band is too shallow, it will cause buckling of the knee or at least a tendency to flexion, with decreased stability around this joint. If the lower thigh band is too deep as compared with the upper thigh band (which is usually shallow), it will cause a back knee or recurvatum in spite of a strong 180-degree stop on the knee hinges. Therefore, it is essential that the depth of the thigh bands be individually evaluated and fitted so that proper alignment at the knees is obtained. A shallow lower thigh band may have to be used to correct or prevent tendencies to genu recurvatum.

The calf band is used only to provide stability to the uprights below the knee. It should not press against the calf muscles, especially in early phases after poliomyelitis or other neuromuscular disorders, as this may interfere with the functional recovery of the triceps surae muscles. As a general rule, the calf band should be fitted so loosely that daylight shows through it when the patient is standing. In very unusual cases, the calf band can be used to help to realign the knee, that is, when there is so much relaxation around the knee capsule and ligaments that there is a tendency to posterior dislocation of the tibia. A shallow calf band will have a tendency to control this condition.

CUFFS

The metal bands may have individual leather cuffs, or they may be incorporated in a corset or lacer, or have no anterior attachment. In the treatment of patients with poliomyelitis or other neuromuscular disorders, where special emphasis is placed on the lightness of braces, corsets or lacers generally are not used. Another objection to the use of corsets or lacers is that they require considerable functional ability in the hands to put them on, which is lacking in these patients. Simple straps with buckles are easily managed by most patients. If the brace has been aligned properly, they provide sufficient counter-force to give the brace desired stability. For those patients who have difficulty, even with simple straps and buckles, Rudolph (29) suggested the use of the overshoe buckle. This buckle requires very little dexterity, therefore it can be used by patients with considerable disabilities of the hands. This type of fastening is especially recommended for hemiplegic patients.

Figure 20. Alignment of bands. The upper thigh band follows the gluteal fold.

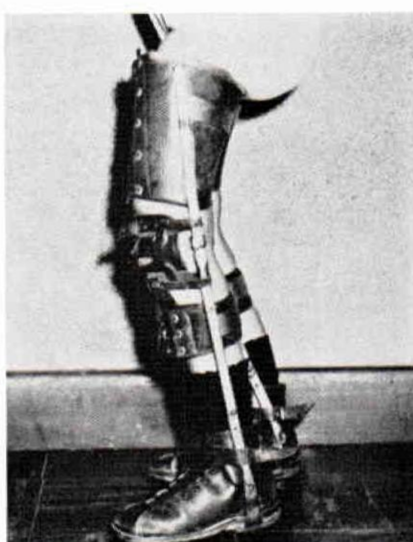

Figure 21. Too short brace; thigh band too low. Patient is sitting on the brace.

Usually straps are used on both thigh bands and usually none are used with the calf band. Often the lower thigh strap is eliminated in favor of a knee pad which constitutes the active kinetic force in the three-point system of bracing. Theoretically, this type of support is not adequate because when the pad is tight and the knee is secured, as it should be when the brace is extended, it will not allow the knee to bend during flexion. If there is a slack in the pad, or if it is not tightly secured, it does not afford sufficient stability. The pad is used, however, because it has been found from practical experience that a little motion in the knee evokes proprioceptive and other reflexes which have a tendency to stimulate the anti-gravity muscle and increase their tone.

CHAPTER IV. WEIGHT-BEARING BRACES

There are two types of weight-bearing braces, the ischial weight-bearing brace and the tibial weight-bearing brace.

ISCHIAL WEIGHT-BEARING BRACES

The ischial weight-bearing brace is so constructed that it permits the superincumbent load to be taken on the ischial tuberosity or the adjacent gluteal muscles or both. Actually the body weight is most often taken by the fibro-fatty fold of the buttock around the ischial tuberosity. This brace is used when it is necessary:

1. To protect a diseased, injured or post-operative hip joint, as found in Legg-Perthes disease, in dislocation of the hip, in osteoarthritis and post-operative cup arthroplasty and femoral head prosthesis. The brace in such cases must be abutted against the ischial tuberosity.

2. To immobilize the extremity to provide healing of a fractured femur.

3. To prevent abnormal movements at the hip caused by muscle imbalance such as occurs in gluteus medius or gluteus maximus limp, or both. A gluteal bearing brace may be used. This brace tends to minimize both the limp and the resultant strain of muscles and ligaments on the affected side. It should not be used in early convalescent poliomyelitis, as the pressure on the extensor muscles of the hip may interfere with recovery and cause greater atrophy.

The brace must be made of rigid material so that there is no give when weight is borne on it. When it is fitted properly, no weight should be borne on the patient's heel, which should lie at least $\frac{1}{4}$ to $\frac{1}{2}$ inch above the inner sole of the shoe. Exception to this rule is made for weight-bearing braces used for control of gluteus medius or maximus limps. In such cases the sole of the foot can be in contact with the inner sole of the shoe (fig. 22).

The Thomas leg splint is the basic model for these braces. It consists of two lateral upright rods and an ischial ring. The ischial ring is objectionable because it interferes with comfortable sitting and often shows through clothing as a bulge. A flat ischial support has been used successfully (fig. 23). Also, ischial seats can be constructed by extending the upper thigh band to fit the tuberosity. The leather covering of this band can be molded to make the seat. A more lasting seat is made by reinforcing this molded covering with several layers of plastic. Other types of ischial seats have been used (30, 31). The most comfortable seat is one which provides a slight slope to its bearing surface. It must be remembered that the ischial tuberosity normally shows a 23-degree slope.

Originally the ischial weight-bearing brace was made of round uprights and did not have knee joints. This lack of joints made the brace unyielding and difficult to manage during sitting. At the present time most of these braces have flat uprights and are equipped with knee locks, which permit easier sitting (32). Great care should be taken about the fitting of the ischial seat so that there is no possibility of its slipping from the ischial tuberosity. Therefore it is necessary to ascertain that:

1. The ischial tuberosity does not ride high above the ischial seat. This indicates a fit that is too tight.

2. The ischial tuberosity does not slip into the band. This means that the outlet of the brace is too large and the ischial tuberosity will have a tendency to gravitate to the lowest level of the expansion. In such cases the extremity will tend to rotate internally, causing toeing-in, because the patient finds this position most comfortable on weigh bearing.

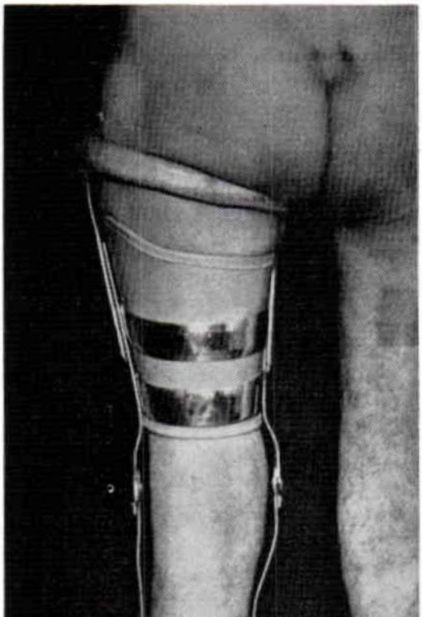

Figure 22. Ischial weight-bearing brace.

Figure 23. Flat ischial weight-bearing brace.

Figure 24. Weight-bearing brace with suspended foot. The weight-bearing surface is a re-inforced upper thigh band properly fitted.

3. The ischial seat expansion does not crowd or fit too tightly in the adductor region, especially at the junction of the band and the medial upright bar. If this happens, the patient may have pain and discomfort. He will tend to rotate the foot outward at the heel strike and carry the extremity in abduction. In addition, tightness in this area may produce severe skin irritation.

The gait of a patient with an ischial bearing brace will be altered because the weight-bearing line is shifted about 7 to 8 degrees posteriorly to pass through the ischial tuberosity instead of the head of the femur.

Occasionally the upper part of the thigh is used for weight bearing. In such a case, a long molded leather cuff or lacer is provided. Experience has shown that this type of bracing is satisfactory only for very short lengths of time. The thigh, except for its cone shape contour, does not provide adequate foundation for purchase of such a brace. Also, the shape of the thigh changes with movement and position, thus making it difficult to obtain a satisfactory fit. Excessive pressure on the thigh muscles even for a short time always leads to atrophy, which causes malalignment of the brace. A brace using only the thigh for weight bearing, that is, one that does not use the ischial tuberosity or the gluteal fold area, will not be a satisfactory weight-bearing brace.

WEIGHT BEARING BRACES WITH A SUSPENDED FOOT

Ischial weight-bearing braces may be used for treatment of Legg-Perthes disease of the hip. However, in such a case it is necessary to prevent the child from putting the weight on the toes by rocking movements. Therefore, the affected leg should be suspended in the brace about 3 to 4 inches above the walking surface on a platform. This platform is so mounted that it slips up and down on the upright bars. This movable platform is necessary to be certain that no weight is taken by the diseased hip. When this type of brace is used, it is necessary to provide an appropriate lift on the other shoe to balance the patient (fig. 24).

WEIGHT-BEARING BRACES WITH SOCKET

Recently, a weight-bearing brace was developed in which the upper thigh band and the ischial expansion were replaced by a wooden socket-like ring which provided the weight-bearing surface. The wooden part is constructed and fitted exactly like the suction socket prosthesis. It provides an excellent weight-bearing surface.

TIBIAL WEIGHT-BEARING BRACES

The tibial weight-bearing brace is used seldom, and only when the lower extremity is normal, except for involvement below the knee requiring unweighting of the legs. It gives satisfactory results in decreasing the weight-bearing pressure on the ankle joint or the foot. It is also used to support convalescent fractures of the bones of the leg or to prevent fractures in a tibia after the removal of a bone graft. A long leg weight-bearing brace often produces, in such cases, discomfort and undue restriction of the free and normal knee. The basic principle of fitting of the tibial weight-bearing brace is to transfer the weight of the body on the out flaring tibial tuberosity and the patella. Frequently the tibia expands very little, and the side of its upper end is almost parallel. Even if it is possible to fit a tibial weight-bearing brace, precautions should be taken to prevent or eliminate excessive pressure on the head of the fibula and the vessels in the popliteal space.

Recently, McIlmurray (33) had used below the knee prosthetic sockets supported by conventional brace uprights and a stirrup to provide a below the knee weight-bearing brace. The socket permits bearing weight with comfort. The socket for this brace is fabricated in the standard manner from laminated plastic. In addition, it has incorporated two retaining rings and a stainless steel upright which articulates at the ankle hinge with a stirrup attached to a shoe. The ankle hinge is of limited motion, permitting 10 to 15 degrees of plantar flexion and no dorsiflexion. The socket may be split to facilitate its application. The use of heel caliper hinges is not recommended with this type of brace. The stirrup and the upright are fitted and aligned as in a convenional short leg brace (ankle brace).

CHAPTER V. EVALUATION OF PROPER FIT AND ALIGNMENT

When a lower extremity brace is being examined for alignment, the patient wearing this appliance should be stripped as much as possible. This is important because it is only in this way that the relationship of postural mechanics can be seen. At first, the brace should be inspected with the patient in a standing position. Then the gait should be analyzed. After this, the alignment is checked in a sitting position. Then the extremity is examined for evidence of pressure, and finally the brace itself is inspected for workmanship. During the examination of the brace for proper alignment and fit, it is essential to note the following points:

1. Is the brace, as a whole, and each essential part, smoothly fitted? Do the upright bars touch the skin? Is there sufficient, but not excessive clearance between the brace and the knee and the ankle joint? Does the clearance exceed $\frac{1}{8}$ to $\frac{3}{8}$ inch? Does it interfere with locomotion? Does the brace minimize the unbalanced action of muscles? Does it provide good stability?

2. Is the relative position of natural and artificial joints proper? Do the axes of artificial hinges correspond with the axes of natural joints? Do the various parts of the brace have the proper relation to each other, and to the weight-bearing line of gravity? Is there any motion between the extremity and the brace?

3. Is the foot in a good weight-bearing position? Is the motion permitted in the ankle hinge optimal for the patient? If used, is the T-strap in proper position?

4. Are the bands and cuffs properly fitted to the contour of the soft parts of that half of the limb contained within them? Are the bands smoothly lined?

5. If used, is the pelvic band around the pelvis horizontal? Is the trochanteric joint attached in the proper place to the pelvic band?

6. Are the pressure, and the counter-pressure equally distributed, or are they unequal, causing discomfort and pain? Are all bony prominences protected? Is there any pressure over the midtarsal region, at the insertion of the malleioli, at the crest of the tibia, at the head of the fibula or the patella? Are there any pressure sores in these areas? Has proper care been taken to avoid excessive pressure in cases in which the skin shows trophic changes, where there is atrophy of subcutaneous tissue or muscle, or where there is disturbance in the peripheral circulation?

7. Is the brace well, but simply constructed? Is it strong and sturdy? Is it easily applied? Are there any unduly sharp projections?

8. Is the brace designed for the patient's needs? Does it accomplish the task for which it was prescribed? Does it meet the demands of the patient's vocation or profession?

Functional braces for lower extremities should enable the patient to resume locomotion in general and if possible to return to gainful occupation. However, it is essential that such a patient receive adequate training in the proper use of his appliance. This has not been emphasized sufficiently. A brace which gives stability to the limb imposes certain limitation in the rotary components of motion during locomotion. This change causes altered motion of the individual body segments and disturbs dynamic balance. Furthermore, there are changes in inertia, speed, acceleration and the location of the center of gravity caused by added weight or mechanical limitations of the brace. To correct these factors, training is necessary for balance and musuclar coordination if effective ambulation and use of the appliance is to be expected.

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