Principles of Design For Lower Limb Orthotics

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INTRODUCTION

When designing an orthosis, care should be given to the principle that the still existing motions must not be restricted more than is necessary and that the patient is secure. The position of the orthotic joint axes will have to be chosen in such a way that they match the body axes as perfectly as possible. At each joint which does not coincide with the natural joint, new "shear stresses" will appear which are contrary to the natural motion and therefore limit it.

FRONTAL PLANE CONSIDERATIONS

The cornerstone of every lower limb orthosis is, of course, the foot section; when designing this part it is of vital importance that the basic static laws are respected and to make full use of all available possibilities. A house cannot be built on an unstable foundation. The foot section alone, through its shape and through its structure greatly determines the statics. In Anglo-Saxon countries the foot part is often attached onto the outside of the shoe. In Central Europe it is customary to integrate the foot part in the shoe. Both solutions present advantages and disadvantages.

When the orthosis is attached to the shoe the effective positioning of the stop is especially difficult and cosmesis is compromised. The built-in sandal requires space-causing problems with the shoe size. In general, the foot part which is independent of the shoe has the advantage of offering more possibilities and clearer proportions in regards to the entire orthosis.

Basically, the same fabrication principles apply to both designs of foot sections. The point of reference for the fabrication of an orthosis is a level flat surface. The shoe and the foot support have to form a unity with the level floor, i.e. the support in the shoe and the shoe on the floor have to have a solid base, so the patient gains a feeling of stability. It is of secondary importance whether the foot is in pronation, supination or a neutral position. The necessary balance, whatever its extent, can be adjusted. In the end, the support and the shoe have to conform to the floor.

The length and cut of the support are very important. A low lateral trim gives less hold on the outside. Depending on the status, the tip of the support will be trimmed straight or, in order to avoid an outside tilt, a slight detorsion cut may be used.

CONTROL OF THE HEEL

The positive model should be of the natural heel when the weight of the body is on it. Because the foot of a patient is usually molded with the weight off of it, the heel must be slightly flattened on the plaster positive model. The plaster is added to the side to give the calcaneus enough room. In the case of a correcting heel wedge, it is important that this should be in the shape of a flat surface and must not be left round. To leave a roundness would mean to invalidate the correction, because the heel would be left unstable and could slide back into the original position.

below the ankle. Should the support be kept too medially the patient will always tilt towards the outside.

This correctional position is a great help in holding the foot. The displacement of the support toward the outside will have a greater correctional effect than any pronation wedge can. If these rules are applied carefully when aligning pronation and supination, pressure symptoms will be

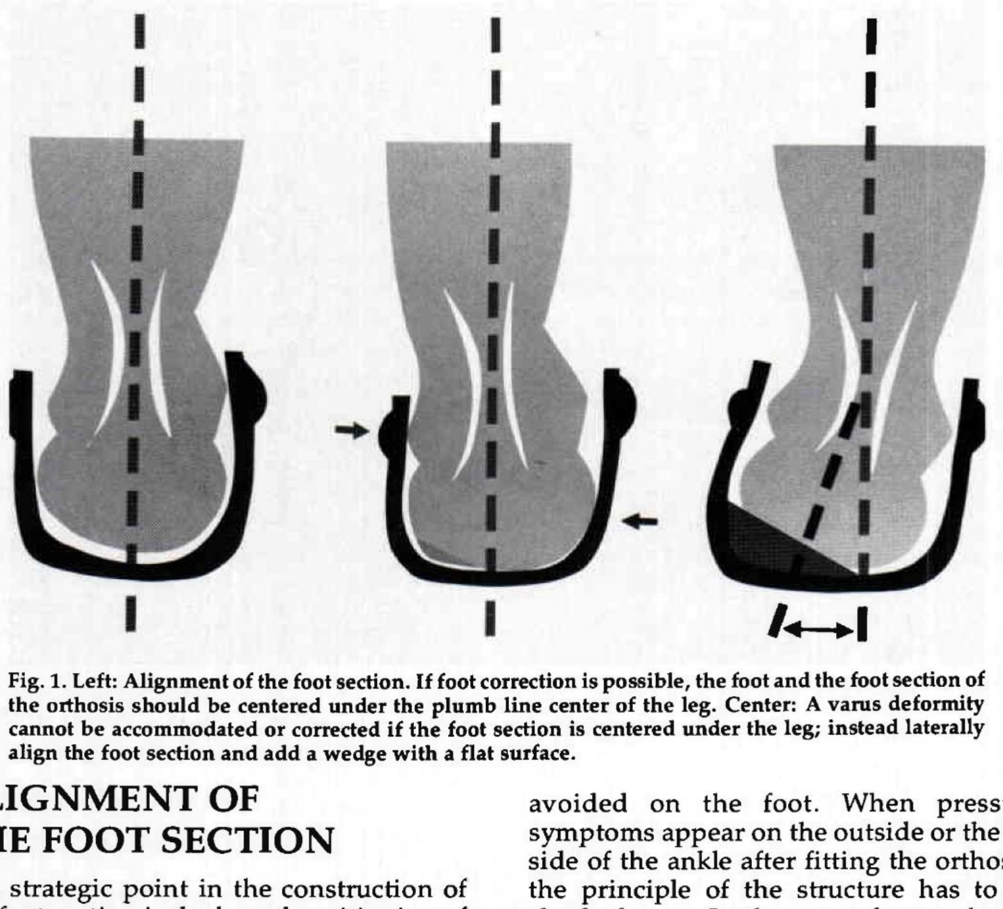

Fig. 1. Left: Alignment of the foot section. If foot correction is possible, the foot and the foot section of the orthosis should be centered under the plumb line center of the leg. Center: A varus deformity cannot be accommodated or corrected if the foot section is centered under the leg; instead laterally align the foot section and add a wedge with a flat surface.

avoided on the foot. When pressure symptoms appear on the outside or the inside of the ankle after fitting the orthosis, the principle of the structure has to be checked over. In the case of pes valgus a support having been set too much on the outside leads to an unintentional bend which invalidates every internal correction.

ALIGNMENT OF THE FOOT SECTION

A strategic point in the construction of the foot section is the lateral positioning of the support in relationship to the ankle. If it is possible to correct the foot actively or passively and to set it back into the neutral position then it is indispensable that the plumb line of the leg and of the orthosis coincide with the plumb line of the foot part (Fig.1). Since this is not always possible when dealing with a pes varus, laterally align the support. In the case of a pes valgus the support remains straight and

The angle of the toe out depends on standing and walking alignment of the patient. The joints should, if at all possible, lie on the sagittal plane; no matter what the outward turning of the foot is, this contributes to a lessening of the energy con-

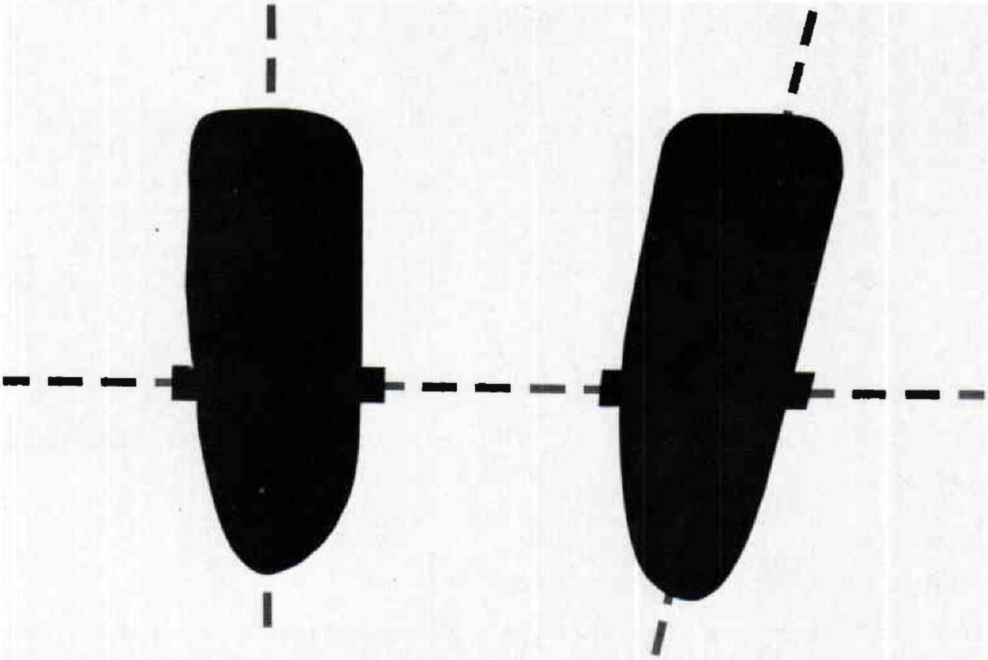

Fig. 2. No matter what the amount of toe out is, the ankle joint should be aligned in the sagittal plane in order to decrease energy consumption and wear on the orthotic joints.

sumption during walking and the wear of the brace (Fig.2).

THE KNEE

To correct a valgus knee or a varus knee, correctional forces above and below the knee must be applied. The positioning of the counter pressures on the hip and below the knee is also very important (Fig.3). Overcorrection of a valgus knee or a varus knee *limits* the extension of the leg. In the case of valgus knee, an over-correction results in flexion; a decision must be made between a full correction and the freedom of movement. The following could be used as a rule of thumb: if the patient is a child, choose correction; if he is an adult, choose movement.

THE HIP AND THIGH

The main principle to be retained for the hip and thigh is: avoid any free-play between the orthosis and the leg. In other words, do not allow the leg to move inside the orthosis. This is absolutely detrimental to the security and the sure footing of the patient.

The weaker the muscles of the hip joint, the tighter the orthosis must be fitted above the knee. With a weak gluteus medius, the use of an above-knee encasing is recommended. The result will be immediate in that the patient will walk with a surer step. If pistoning is allowed, at each movement it will cause great discomfort and possibly result in an open sore. Girdles may be of varied shape and construction. Each girdle will have to be made individually to suit the patient and the treatment.

SAGITTAL PLANE CONSIDERATIONS

The above-knee prosthesis is a mechanical substitute for the leg and the same mechanical principles apply for knee ankle foot orthoses. When in a free erect position, the torso is upheld by the legs in such a way that the body's center of gravity is in a stable balance. A healthy person does this

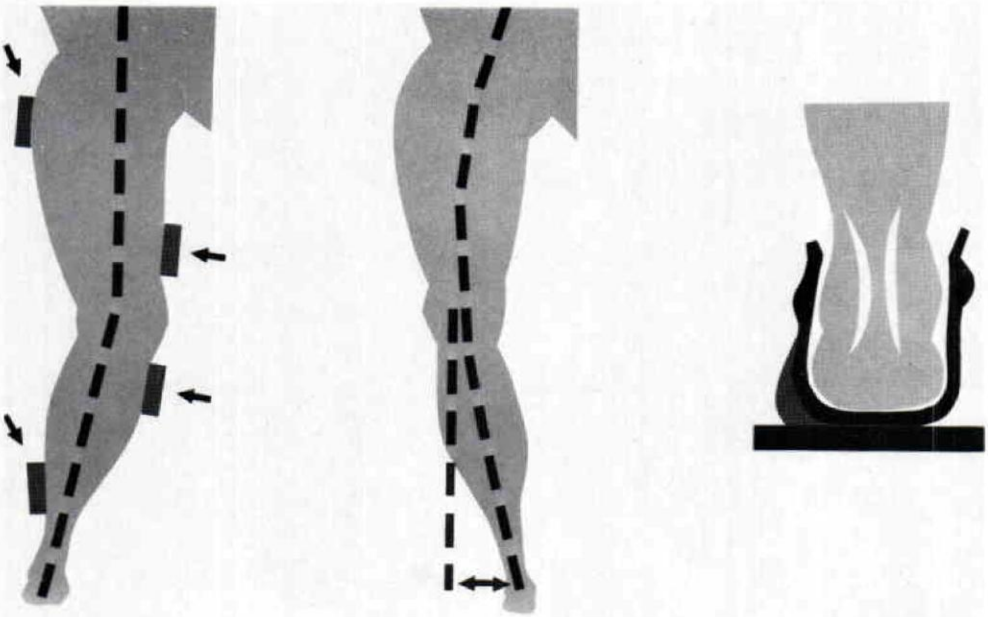

Fig. 3. Left: Correctional forces applied for valgus knee correction. Center: Forces emanating from the foot section should be placed as laterally as possible to control Genu Varum. Right: A lateral flare added to the foot section will help to diminish varus forces at the knee.

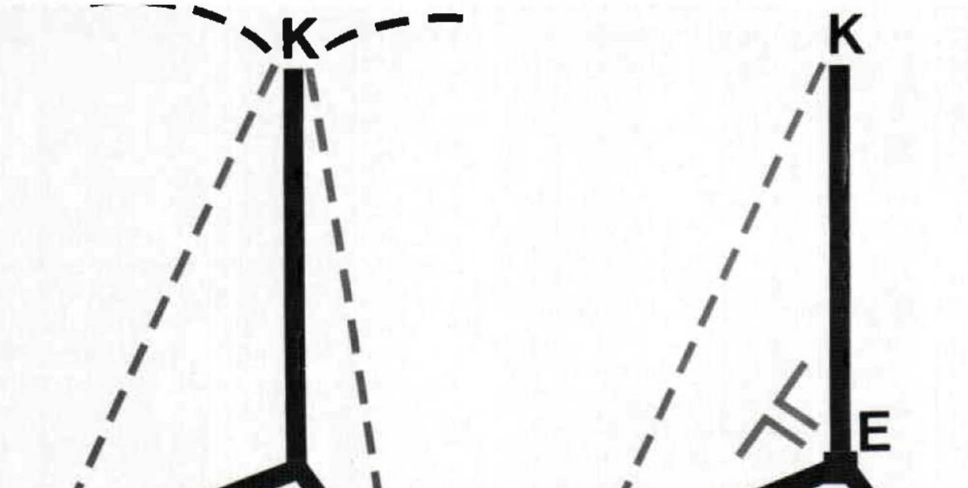

Fig. 4. Statics of the standing position. Left: If the ankle is locked completely, there are essentially two physical bars present, designated by the dotted lines K-D and K-F. The center of gravity must rise if bar K is moved in either direction. Left: If only one direction of fall is blocked there are again two physical bars, K-D and K-E Bar K-E is unstable if a clockwise rotation occurs. This simulates the mechanics of a dorsiflexion stop ankle foot orthosis, which is adequate for knee stabilization with patients having slight to medium quadriceps paralysis and an intact iliopsoas and gluteus maximus.

both actively and passively. Active stabilizing is caused by the muscles; the paralyzed patient either cannot perform or can partially perform this stabilization. The ligaments take care of the passive stabilization by preventing a bending of the joint in certain directions which limits the keeping of a firm stance to only one position, but saves energy. Of all true mammals, man is the only one to possess such a safety device and he is therefore the only one to be able to stand erect such a long time.

Only the passive stabilization functions can be reinforced by orthoses because the muscular system is not intact; this is where the hinge-joints with their stopping mechanism come into play.

THE STATICS OF THE STANDING POSITION

A body is in equilibrium when the plumb line emerging from the center of gravity of the body runs through the base of support. The equilibrium remains if the center of gravity raises when the body changes position; it is unsteady if the center remains in place, or lowers.

If a bar is balanced vertically it is unstable and will remain so if weight is applied to it. If an angular lever is added in the shape of a foot then the bar is stabilized. Physically speaking, there is not a branching bar but two straight ones, the mechanical axes, running from K to D and from K to F, respectively. Now if a hinge is placed on E, then there is again one single bar, K-E, which is in an unsteady equilibrum. But if one direction of fall is blocked there is again in the presence of two physical bars, one in the blocked direction K-D, the other in the unblocked direction K-E. This leads us to the following conclusions:

1. If one joint is blocked then the two adjacent limbs can be considered as one unity. The limbs form a rigid lever whose mechanical importance lies in the line connecting the two free ends. This line corresponds to the shared mechanical longitudinal axis of both limbs which incidentally does not match the anatomical longitudinal axis.

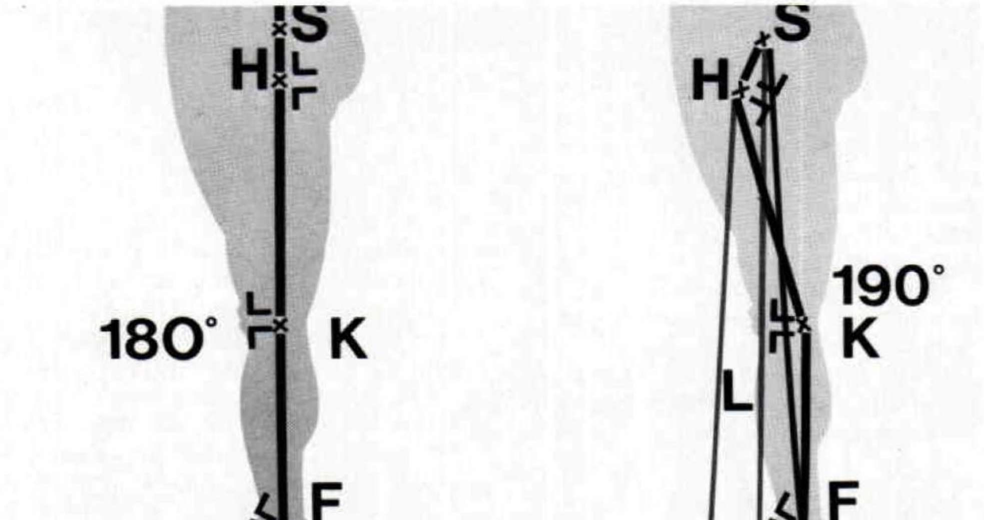

Fig. 5. Mechanics of a KAFO with a dorsiflexion stop and different knee joints. Left: Conventional KAFO knee alignment. This alignment should be used when little or no iliopsoas and gluteus maximus are present. The orthotic knee joint can be used when good hip control is present. The posterior position of the orthotic knee joint, combined with a lengthened foot support, can stabilize the knee without a lock.

2. For all static and dynamic studies only the mechanical axes are of importance.

Applying these conclusions to orthotics allows the use of a light ankle foot orthosis with a blocked dorsiflexion stop on patients having only slight to medium paralysis of the quadriceps and an intact iliopsoas and gluteus maximus. If a locked knee joint becomes necessary because of the degree of paralysis, the dorsiflexion stop must be reduced considerably because the knee and foot movements should not be blocked at the same time.

The mechanics of a KAFO with dorsiflexion stop and offset knee joints will now be described. The further back the knee joint is placed, the greater the stability (Fig. 5). In order for the altered position of the knee joint of the orthosis to show any results, the orthosis has to be fitted perfectly; if this is not the case, the upward sliding of the orthosis will cause friction and render the effect negative.

The angle of the dorsiflexion stop has a very important stretching function; experience has shown that the angle, making allowance for the heel height, should never exceed 90 degrees. Should the angle of the dorsiflexion stop be more than 90 degrees, the knee will be hyperextended and the patient will have trouble rolling his foot properly.

In order to increase stabilization of the knee, do not extend the angle of the dorsiflexion stop but *lengthen* the foot support. The exact structure and the choice of a dorsiflexion stop have to be determined and mounted on the patient while he is standing. He should stand as straight as possible, wearing the orthosis and shoes, keeping his feet parallel and the toes aligned; in this position the stop should be fixed without play and pressure.

PREREQUISITES FOR THE APPROPRIATENESS OF SUCH AN ORTHOSIS

- The affected leg should show no contractures at the hip and the knee-joint. The patient should be able to stretch the knee-joint passively without problems.

Fig. 6. Knee joint used in Switzerland extends the knee and provides stability by using an offset alignment. A spring extension mechanism and optional knee lock are incorporated into the design.

- The iiopsoas and the gluteus maximus should not be too weak. In any case, the patient must be able to move the knee joint back and forth actively and easily while in a standing position.
- The patient, especially children, must be willing to get used to the orthosis and practice a certain walking discipline.

The remaining muscle tone of the quadriceps does not play an important role, while a well-calculated dorsiflexion stop and the length of the foot support are of decisive importance. Assuming that the adjustment of the plantarflexion stop is common knowledge, it should be remembered that the stop, in the case of a drop foot, hinders the stretching of the knee and may even have a knee-bending effect when the heel is ready to strike the floor. For this reason one should opt for a soft plantarflexion stop, although this is not a very esthetic solution, since a bulkier ankle joint is required.

Since the patient wearing an orthosis with an offset knee joint has some trouble moving his lower leg forward, it is often necessary to insert a spring extension mechanism into the knee joint which may also be hade to serve to stabilize the knee.

For about twenty years a knee-lock has been used in Switzerland which both stretches the knee and may be locked (Fig. 6). The patient feels more secure and the joint facilitates the forward motion of the lower leg. No system, even under the most favorable conditions, can replace the quadriceps. Although by making small improvements here and there, the patient's comfort and appearance can be improved.

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