

SOME BIOMECHANICAL CONSIDERATIONS IN THE DESIGN OF ANKLE-FOOT ORTHOSES

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The proliferation of new designs for ankle-foot orthoses fabricated with thermoplastic materials presents a bewildering picture for the clinician faced with the prescribing of a particular device for an individual patient. Indeed, the orthotics specialist with his special knowledge may require to adopt a trial and error policy extending over a considerable number of patients before the advantages of the various designs become apparent and a practical prescription philosophy can be formulated.

Two important factors that appear to govern the success or failure of a fitting with a particular device are the accuracy with which the patient's requirements have been assessed and the ability of the device to fulfill these requirements. A successful orthotic prescription may thus be considered as a process of patient-orthosis matching involving measurement of the patient's functional deficit and selection of an orthosis whose characteristics, also determined by measurement, are such as to reduce the patient's deficit to the minimum.

Characteristics of the Jointed Orthoses

It is possible to illustrate the meaning of the term "characteristic" of the device by reference to the conventionally constructed

ankle-foot orthosis (AFO) fitted with a fulcrum lever and toe-raising spring.

The effect of the spring is such that as the foot is pushed into an attitude of plantarflexion the spring will tend to create an opposing dorsiflexing effect or "moment," which will increase as the deflection of the foot is increased. This characteristic of the orthosis may be measured accurately and recorded in the form of a graph, and in this case will result in an approximately straight line (Fig. 1). The stronger the spring stiffness, the greater will be the moment it develops for a particular deflection and hence the steeper will be the slope of the line on the graph. Thus the orthosis with a free joint has a characteristic of zero slope as illustrated by the horizontal line on the graph and a joint which is locked has as a characteristic an infinite slope as illustrated by the vertical line.

Obviously it is possible to apply this system to define the behavior of an orthosis in other planes of deflection such as inversion or eversion, and, as in the case under examination, this would result in a straight vertical line since the conventionally constructed AFO may be considered to be virtually rigid in this plane when subjected to the loads encountered in walking.

BELOW KNEE DOUBLE IRONS

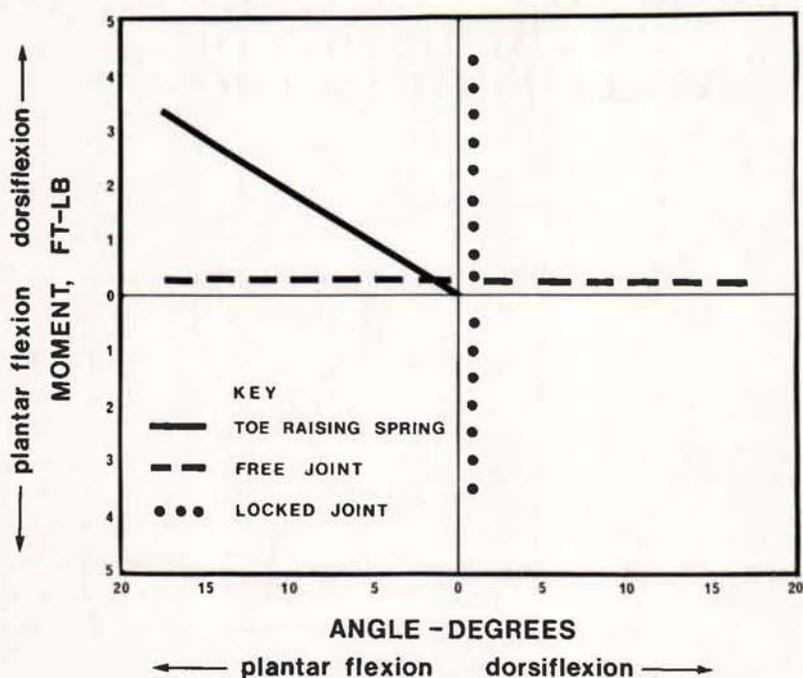


Fig. 1. Plot of moment about the ankle vs. ankle flexion for three types of ankle-foot orthoses.

Characteristics of Thermoformed Orthoses

Clearly, it is relatively simple to predict the characteristics of conventional orthoses with their readily identifiable joints and controls. The plastic AFO's however which have no discrete joints are not so readily open to predictions regarding their behavior.

Because of this difficulty equipment has been developed at the Dundee Limb Fitting Centre to measure the characteristics of an orthosis (Fig. 2). The AFO is clamped in the machine at the cuff and foot piece and deflected throughout its normal range of motion. The stiffness/deflection characteristic developed in this fashion is plotted directly on a graph plotter. It is thus possible to compare the characteristics of differing types of orthoses (Fig. 3), and to examine also the al-

tered behavior of an individual orthosis achieved by varying its trimline (Fig. 4).

The Teufel AFO

The first design of an AFO fabricated from a thermoplastic material to achieve significant acceptance was the Teufel posterior leaf-spring orthosis (4) made of Ortholen, a high density polyethylene. The Teufel orthosis was described as being appropriate for "flaccid conditions of the foot."

The Hartshill AFO

In 1968, Yates (5) published his description of the use of polypropylene in the construction of ankle-foot orthoses. The method of construction adopted required no cast rectification and resulted in a rather rigid de-

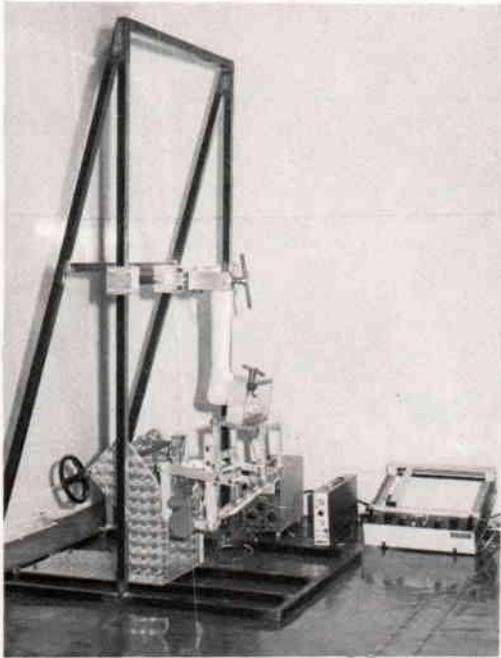


Fig. 2. AFO machine for measuring properties of ankle-foot orthoses.

vice extending forward to the medial malleoli. At fitting, the orthosis was normally flexed vigorously into extreme dorsiflexion to reduce significantly the resistance which the device would afford to movement in that direction while retaining the high resistance to plantarflexion inherent in the geometry of the device. In the United Kingdom this device is customarily referred to as a "Hartshill" AFO. According to the developer, this orthosis is intended for use primarily in cases of flaccid "drop foot" or where there is minimal spastic muscle behavior.

The TIRR AFO

The potential of this new material was recognized immediately by many other developers, notably in North America, and further variations emerged, one of the best known of which was the polypropylene AFO with corrugations, developed at the Texas Institute for Rehabilitation and Research (1). The developers of this device sug-

gested that it was indicated for "a lack of dorsiflexion."

Prescription

Thus it seems at least three different new AFO's are available which appear to be appropriate for the same group of patients. These claims will now be investigated by examining the "characteristic" of the orthoses.

Simple Drop Foot

If the patient's disability may be truly described as a drop foot, that is to say, isolated weakness of the dorsiflexor muscles, the requirements of the matching orthosis should be rather simply specified. Firstly, the orthosis should replace the action of the dorsiflexors following heel contact, thus avoiding a foot slap, and secondly, by raising the foot at toe-off to ensure foot clearance during the swing phase. For this comparatively simple requirement there appears to be no doubt that the TIRR and the Ortholen devices with their comparatively low plantar/dorsiflexion stiffness characteristics are a much more appropriate prescription than the more rigid Hartshill device. Similarly, both of these alternative devices provide the least unnecessary resistance to the movements controlled by the unaffected musculature of the ankle.

Drop Foot With Other Weaknesses

The choice of an ankle-foot orthosis becomes more complex when one considers cases of more generalized ankle-foot functional deficit including weakness of the muscles controlling plantarflexion and the movements at the subtalar joint. A further important consideration will be the presence of spasticity in the affected musculature.

In 1972 Lehneis (2, 3) presented his design of a spiral brace fabricated in Plexidur which was intended for use with these kinds of patients. Regretably experience with this device has been marred by repeated fracture problems and many prescribers have been forced to consider alternative solutions. The policy adopted at the Dundee Limb Fitting

COMPARISON OF PLANTAR/DORSIFLEXION CHARACTERISTICS

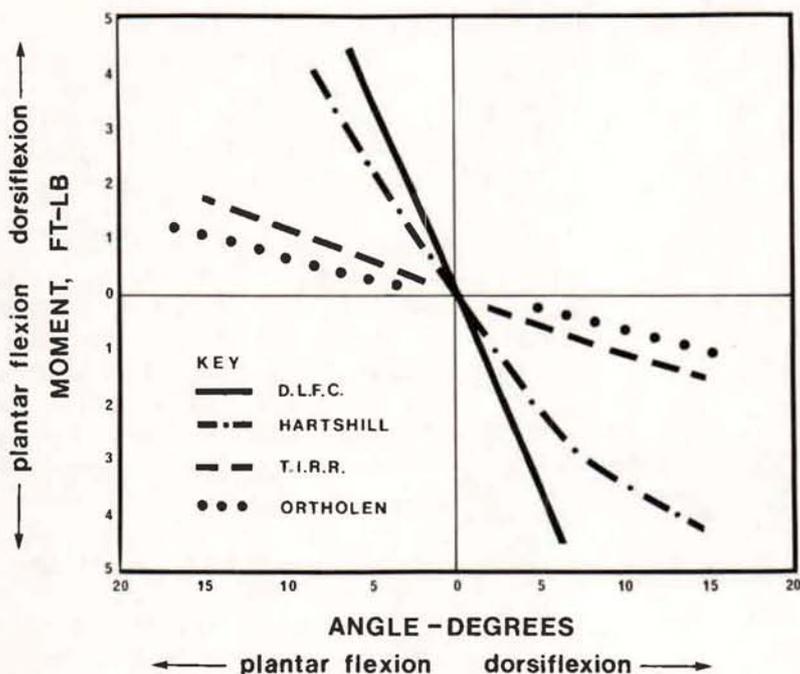


Fig. 3. Plot of moment about the ankle vs. ankle flexion for four types of plastic ankle-foot orthoses.

Centre has been to adapt the basic Hartshill design of AFO to produce an orthosis capable of providing the greater degree of control required for this group of patients. This effect is achieved principally by selecting a trimline which leaves slightly more material around the ankle joint (Fig. 5).

The increase in the stiffness characteristics which are achieved by this simple measure may be demonstrated easily by reference to the graph lines obtained from the testing equipment, which show an increased slope. An example, in this case the plantar/dorsiflexion characteristic, is illustrated in Figure 3.

Foot Length Discrepancy

Complicating disabilities such as limb or foot length discrepancy may be treated si-

multaneously by adopting a particular foot attitude and using a plastic foam build-up on the sole piece. Similarly, a foam plastic calf restoration may be built into the shank section of the orthosis for cosmetic reasons (Fig. 6).

More Severe Cases

There are however some patients for whom the orthotic prescriptions already considered would appear to be still inadequate. These patients may be considered in two categories: those patients where more severe spasticity will require larger forces to achieve full correction; and those patients where the joint deformities are not fully correctable and may indeed become increased when the patient attempts to bear weight upon the foot.

TYPICAL PLASTIC AFO showing effect of trimming

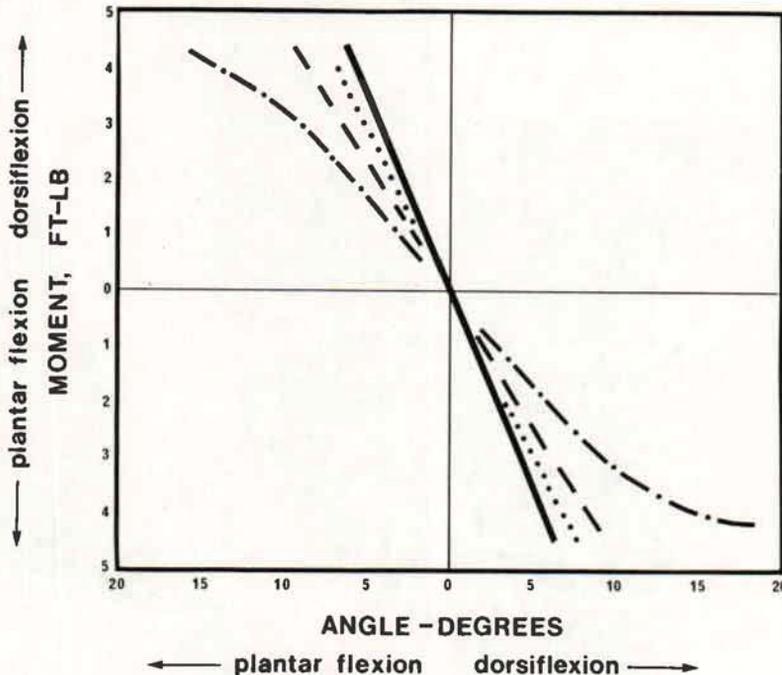


Fig. 4. Plot of knee moment of a plastic orthosis vs. ankle flexion for various trim-line configurations.

Severe Spasticity

Severe spasticity is commonly encountered with the more severely involved hemiplegic patient. Experience has demonstrated to us that even the modified polypropylene ankle-foot orthosis is unable to control adequately the typical equino-varus deformity.

A careful study of this problem suggested that a further increase in the stiffness of the device would be unlikely to improve its effect upon the patient unless the fit were modified to apply the corrective forces in a much more specific manner than is customarily achieved by standard casting and fabrication procedures.

It was this consideration in mind that the hemispiral orthosis was developed at the New York University Institute for Re-

habilitation Medicine (3). This orthosis, made also from Plexidur, is designed to impose a three point system of corrective forces upon the patient's leg and foot to control an equino-varus deformity, and, when correctly fitted, can be very effective. It does unfortunately have several disadvantages. It is difficult and time-consuming to produce and therefore relatively expensive. It can also be awkward for the patient to apply, especially when many of the potential patients have the effective use of only one hand. Consequently, in Dundee it was decided to attempt to produce a further modification of the polypropylene AFO which would utilize a similar three-point force system to control this type of deformity.

The extent of the correction which can be achieved is assessed by manually applying



Fig. 5. Polypropylene, Ankle-Foot Orthosis as used at the Dundee Fitting Centre.

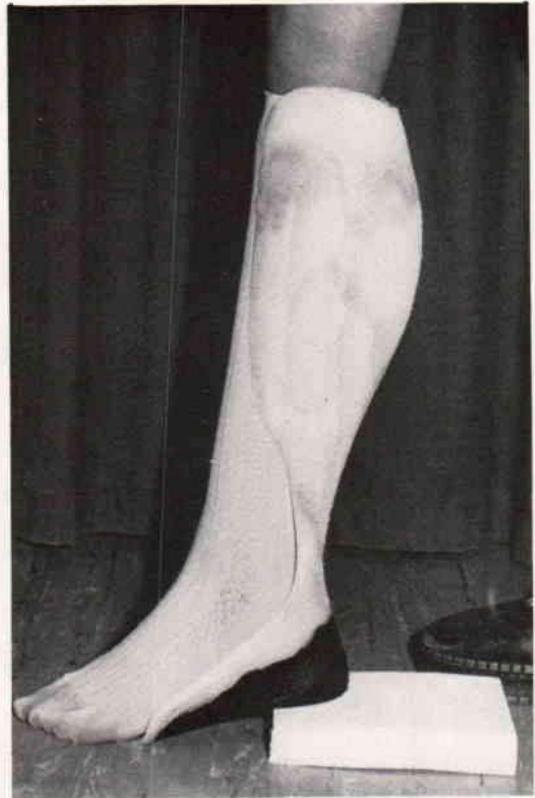


Fig. 6. Polypropylene AFO with compensations for length discrepancy and calf restoration.

the necessary three-point force system. Obviously, where fixed deformity exists, this position may be short of plantigrade. Additionally in cases of severe muscle spasm the force required to maintain a fully corrected position may not be tolerable.

The wrap cast is taken in the usual manner in the position thus determined and the required force system applied by hand as the cast sets. The orthosis is formed on the resulting positive cast which may have been further rectified to achieve the desired pressure distribution (Figs. 7 & 8).

In those cases where the final attitude is not plantigrade the sole of the orthosis is wedged with high density foam plastic to ensure correct shoe contact with the ground.

This modified AFO is only marginally



Fig. 7. Three-point-pressure polypropylene AFO.

more difficult for the patient to don than the standard polypropylene AFO, and the production techniques are only a little more demanding.

Joint Deformity

The three-point pressure technique may also be adopted "in reverse" to treat those patients with uncorrectable valgus deformities of the foot which are otherwise difficult to control, and cases of this type successfully treated include both children with spina bifida and cerebral palsy. In these cases an identical production technique is adopted

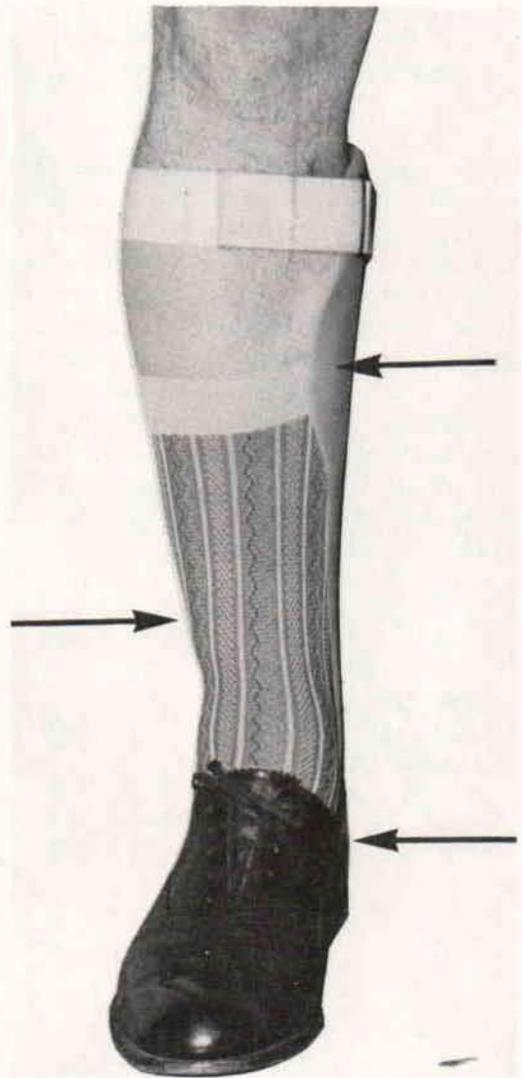


Fig. 8. Three-point-pressure system to control a varus deformity.

with the pressure points positioned to achieve the required control.

Conclusion

The range of modern thermoplastic AFO's exhibit a wide spectrum of functional characteristics. In spite of the apparent simplicity of the orthoses, the factors governing their functional characteristics are exceedingly complex. A deeper understanding of

the means of obtaining specific characteristics will permit more accurate matching to the patient's requirements.

Summary

This paper presents a biomechanical approach to development of prescription criteria for ankle-foot orthoses based on a system of measuring the "characteristics" of an orthosis. The result of applying this system to the existing range of AFO's of both conventional and molded plastic construction are described with the consequent prescription practices. Finally, some further development is described in the use of the molded polypropylene AFO to control severely deforming varus/valgus conditions of the ankle-foot complex.

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Footnotes

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