

PLASTIC SPIRAL ANKLE-FOOT ORTHOSES¹

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Two configurations of plastic spiral ankle-foot orthoses (AFO) have been developed at the Institute of Rehabilitation Medicine (IRM), New York University Medical Center, to provide control of the ankle-foot complex in many neuromuscular conditions that result in weakness or paralysis of the ankle and foot. They are the spiral AFO and the hemispiral AFO.

These spiral configurations in their present form are the result of work over the past approximately seven years (1) (3). The stages of design and development and detailed rationale of design are not elaborated upon in this paper. Rather, indications, contraindications, description of design and fabrication procedures are summarized here (5) (6) (7). The fabrication procedures described are not intended by any means as a substitute for formal courses of instruction in this technique.

THE SPIRAL AFO

The spiral AFO (Fig. 1) is believed to provide controlled motions in all planes; that is, adaptation to transverse rotation, as well as motions in the frontal and sagittal planes. The spiral portion of the orthosis originates from the medial side of the footplate, passes around the leg posteriorly, and terminates at the level of the medial tibial condyle. A horizontal band is attached to the spiral at the level of the calf. The thermoplastic used in the construction of the orthosis is SADUR³, an amber-colored,

acrylic-nylon material. The spiral configuration represents a new and unique concept which obviates the need for metallic joints, yet permits controlled plantar flexion and dorsiflexion. The spiral unwinds on weight-bearing to permit plantar flexion. Removal of body weight results in rewinding of the spiral, thus dorsiflexing the foot. Following the midstance phase, the spiral is stressed progressively, increasing resistance toward dorsiflexion. Thus, the spiral orthosis assists push-off following heel-off, as the stressed spiral returns to its original configuration.

Adaptation of the orthosis to transverse rotation is based on the principle of the spiral helix—that is, unwinding and rewinding of the spiral produces transverse rotation. In addition, controlled eversion and inversion of the ankle is provided by the application of the three-point pressure system inherent in the spiral configuration. The performance of the orthosis described so far is possible not only due to the design configuration but also because of the properties of the plastic used. SADUR possesses excellent memory; that is, instantaneous return to the molded, unstressed position. It is, therefore, not necessary during casting to predorsiflex the foot. Alignment of the major joints in the lower limb in the sagittal plane is thus maintained in the normal relationship; that is, the long axis of the leg should be at 90 deg. with respect to the floor, with the shoe on. This alignment, together with the dorsiflexion resistance provided by the spiral, accounts for the ability of this orthosis to influence anteroposterior control of the knee.

Indications for use of the spiral AFO are:

1. Motor weakness affecting all compartments of the ankle-foot complex which may be flaccid or mild to moderately spastic.
2. Medial-lateral instability during stance or swing phase of walking.
3. Slightly diminished motor power at the knee in addition to motor weakness at the ankle.

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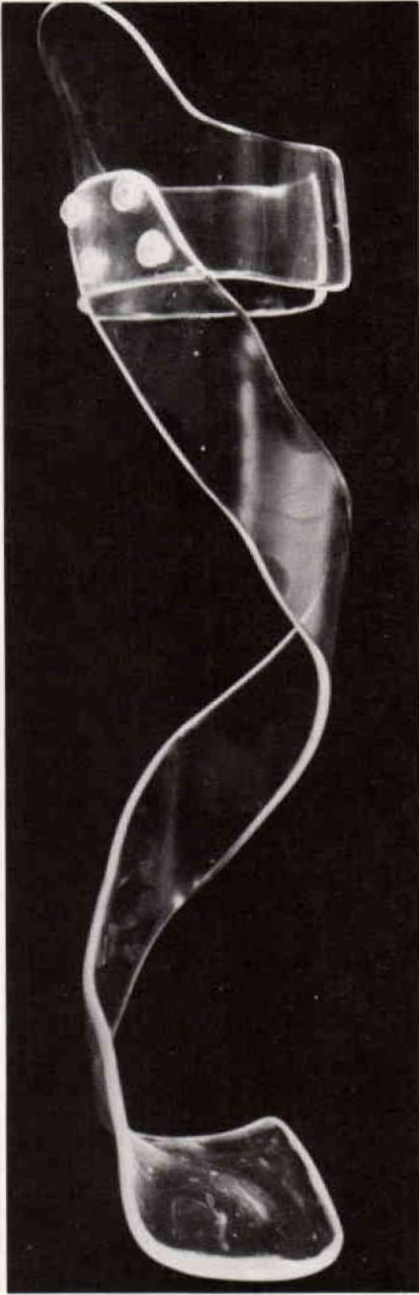


Fig. 1. Anterior view of spiral AFO.

4. Loss of proprioception at the ankle.

Contraindications for use of the spiral AFO are:

1. Pronounced imbalance of forces acting on

- the ankle-foot complex.
2. Greater than moderate spasticity.
3. Fluctuating edema.
4. Fixed deformities.

CASTING PROCEDURES

For casting, foot-casting boards which correspond to the heel heights of the shoe to be worn are required (Fig. 2). The head of the fibula and the medial malleolus and any bony prominences on the foot, such as the base of the fifth metatarsal, are marked on the tube gauze stocking with indelible pencil (Fig. 3).

The limb is wrapped with plaster bandages in two stages. First, the foot and ankle are wrapped to midshank; the foot is then placed on the appropriate foot board and manipulated in such a way as to provide the proper toe-out, eversion-inversion control and forefoot alignment. The foot is held in this position until the plaster hardens. At the same time the shank should be aligned so that a vertical line connects the medial condyle of the knee with the medial malleolus. An alignment reference rod inserted in the casting board will assist in this procedure (Fig. 4).

In the sagittal plane the shank should be held vertically. After the plaster hardens place both hands around the proximal portion of the shank with both thumbs pointing toward the patella (Fig. 5). The purpose of this maneuver is to shape the calf triangularly through displacement of the underlying tissue. The index finger of one hand must be at the level of the neck of the fibula, while the thenar eminence of the same hand identifies

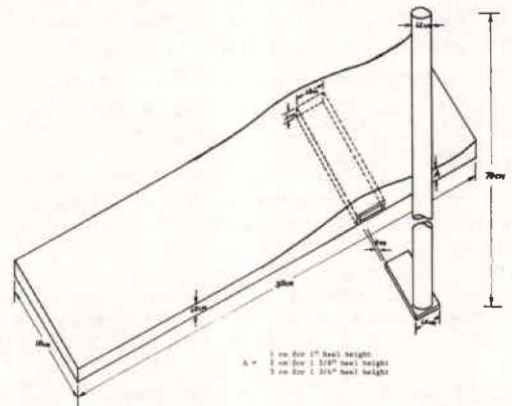


Fig. 2. Casting board with reference rod.

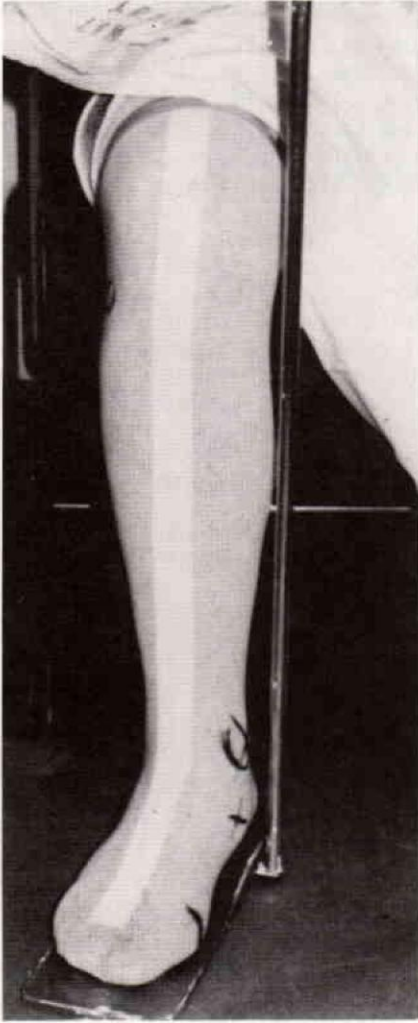


Fig. 3. The leg, with tube gauze in place, ready for casting.

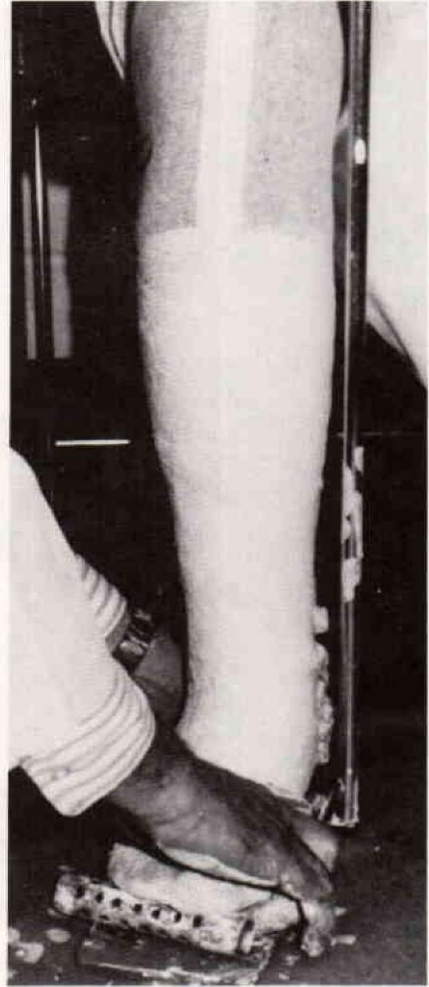


Fig. 4. Positioning the foot during casting.

the soft tissue area between the crest of the tibia and the shaft of the fibula. The thenar eminence of the opposite hand must be firmly pressed against the medial portion of the shaft of the tibia. Posteriorly, the fingers of both hands opposing the thenar eminences must exert firm forward pressure to provide a triangular cross section of the cast in that area with the posterior portion flattened along with relief for the crest of the tibia. Hand pressure must be maintained until plaster hardens. The resulting negative cast is thus functionally shaped and a minimum of modifications of the positive model are needed.

MODIFICATION OF THE POSITIVE MODEL

The longitudinal arches are shaped by removing 6 mm of plaster under the area of the sustentaculum tali and continuing toward the lateral longitudinal arch, tapering toward 3 mm plaster removal in the lateral longitudinal arch across from the sustentaculum tali (Fig. 6). The metatarsal arch is then shaped by removing at least 15 mm of plaster at the apex of the metatarsal arch, i.e., under the second metatarsal ray and about 20 mm proximal to the metatarsal heads (Fig. 6). A well-shaped metatarsal support is very



Fig. 5. Shaping the plaster bandage at the proximal portion during casting.



Fig. 6. Sketch indicating areas on the plantar surface of the male model that require modification.

important since the reaction point of the dorsiflexion-assist force is at the distal termination of the orthosis.

In the soft tissue area between the crest of the tibia and the shank of the fibula, 6 mm of plaster are removed starting 15 mm distal to the head of the fibula and extending to a point halfway between the neck of the fibula and the lateral malleolus. At the level of the medial tibial flare 4 mm of plaster are removed (Fig. 7). No further plaster removal is required except smoothing of the popliteal area. A flat if not a concave popliteal area is maintained. Six mm buildups are required in bony areas previously marked on the foot. After the entire cast has been smoothed, one or two coats of parting lacquer are applied.

MOLDING PROCEDURE

The calf band of the precut spiral kit⁴ (Fig. 8) is placed in a preheated oven for a few minutes

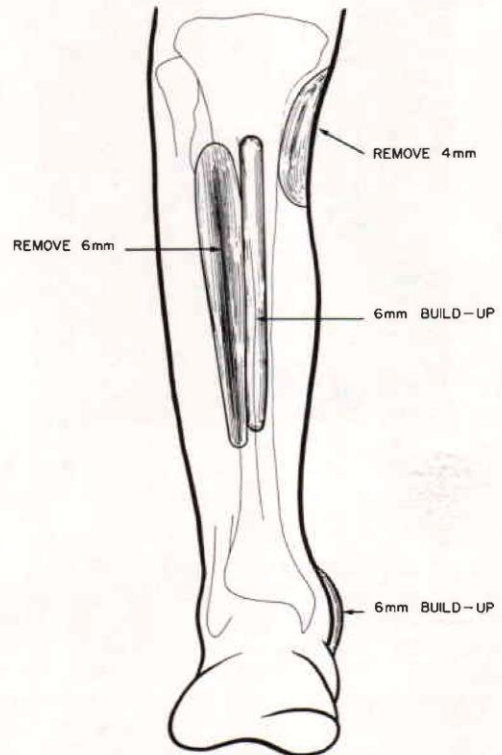


Fig. 7. Sketch indicating areas on the leg part of the male model that require modification.

⁴ Manufactured by the Teufel Co., Stuttgart, Germany. Available through distributors also.

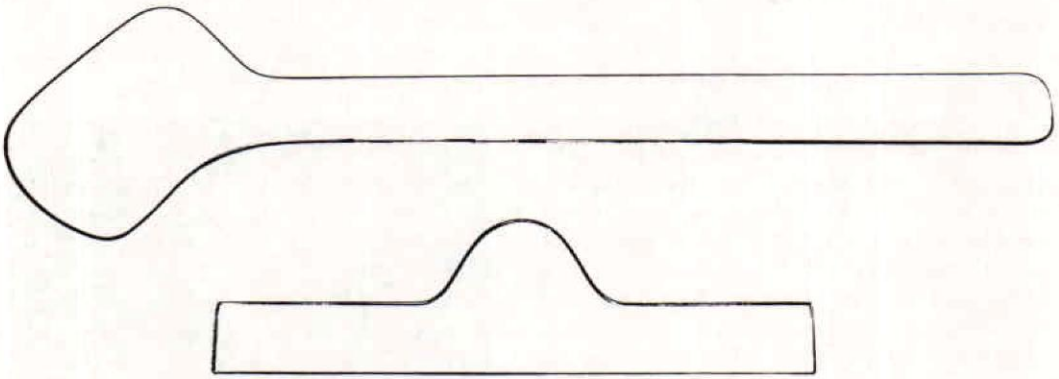


Fig. 8. Shape of SADUR parts needed for the spiral AFO.

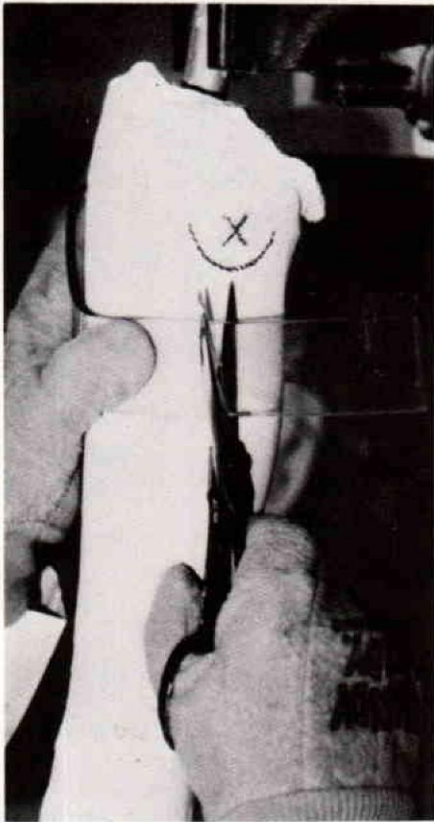


Fig. 9. Trimming the SADUR calf band.

20 mm distal to the neck of the fibula. Any overlap in this area is cut off with a pair of scissors (Fig. 9). The medial upper projection of the calf band should cover the medial tibial flare. A felt pad is placed over the area of the concavity between the shaft of the fibula and the crest of the tibia and the entire calf area is wrapped with an Ace bandage. When calf area is cooled, the Ace bandage is removed and the heated spiral blank with the footplate is placed on the cast so that the spiral portion extends from the medial longitudinal arch with the anterior border coinciding with the apex of the medial malleolus (Fig. 10). An extra large metatarsal pad is positioned on the footplate over the area of the metatarsal arch and held in place with an Ace bandage that is wrapped from the metatarsal area up to the ankle area. Once the footplate is held in place properly, the spiral portion is wrapped around the leg overlapping it with the medial portion of the calf band. A felt pad over the concavity in the mid-shank area is placed between the crest of the tibia and the shaft of the fibula to provide a "locking



Fig. 10. Applying the SADUR spiral piece.

at 140 deg. C until the calf band is limp. It is then placed on the cast with the lateral opening

channel," and the entire leg cast is wrapped with additional Ace bandages.

ASSEMBLY

After the spiral has cooled sufficiently, four holes are drilled in the area of the overlap of the spiral and the calf band. A China marker is used to indicate the proximal edge of the spiral, which should be 40 mm proximal to the distal edge of the calf band and parallel to it. A mark is made on the footplate 6 mm proximal to the heads of the metatarsals. The lateral trim line of the footplate is marked as well as a line indicating the posterior distal edge as a continuation across the footplate at a point 25 mm posterior to the apex of the medial longitudinal arch and perpendicular to the long axis of the foot (Fig. 11). The components are removed from the cast and the edges are finished with a sand cone, Tycro wheel and fine sandpaper, and then buffed. The four holes previously drilled are countersunk on the inside of the calf band, and shrink-expansion rivets are introduced with the shank protruding into the

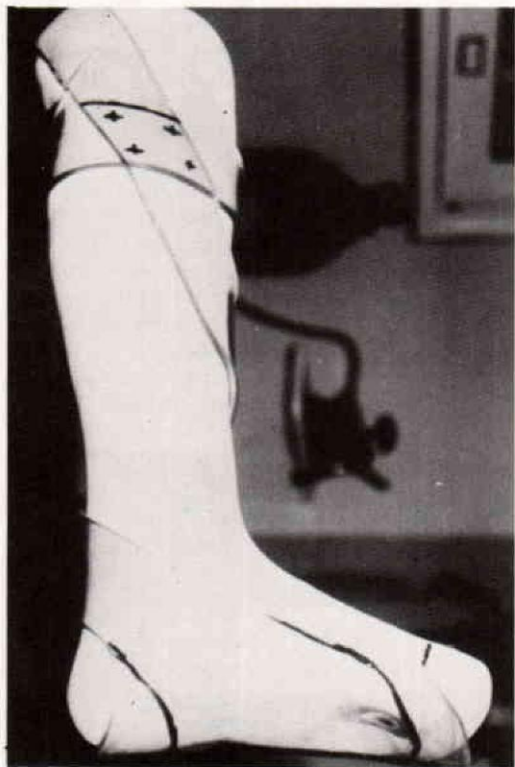


Fig. 11. View showing typical trim lines.

countersink. Each rivet is heated with a heat gun with funnel attachment to expand the shank and thus fasten the spiral to the calf band securely (Fig. 12).



Fig. 12. Heating the shrink-expansion rivets with heat gun with funnel attachment.

FITTING PROCEDURE

1. The lateral opening of the calf band is increased to the point that it will pass the mediolateral width of the narrowest part of the ankle.
2. The orthosis is applied by placing the lateral opening of the calf band over the posterior portion of the narrowest part of the ankle, then twisting the orthosis onto the leg as it is pushed proximally.
3. Trim lines of the footplate as described above are checked.
4. The orthosis is then removed from the leg,

and the fit in patient's shoe is checked. Material is trimmed as necessary.

5. The orthosis and shoe are reapplied and a check is made for any areas of discomfort.
6. Necessary adjustments are made by spot-heating with a heat gun. All edges are smoothed with a Tycro wheel, sanded, and then polished on a clean buffing wheel.
7. The orthosis and shoe are applied (Fig. 13). The Bulcher-type shoe with either a tie or buckle closure over the instep is preferred. For women, modern-style shoes may be used as long as the counter is adequately stiff and high and there is an adjustable, nonelastic closure over the instep. Regular sized, lightweight, nonorthopaedic shoes may be worn since the footplate incorporates any necessary foot corrections and support without taking up an appreciable amount of room in the shoe. It is necessary to have a firm fit of the shoe for proper function of the orthosis. A knee-length sock for males or hose for ladies is recommended for comfort and ease of donning and removal of the orthosis.



Fig. 13. Completed spiral AFO on patient.

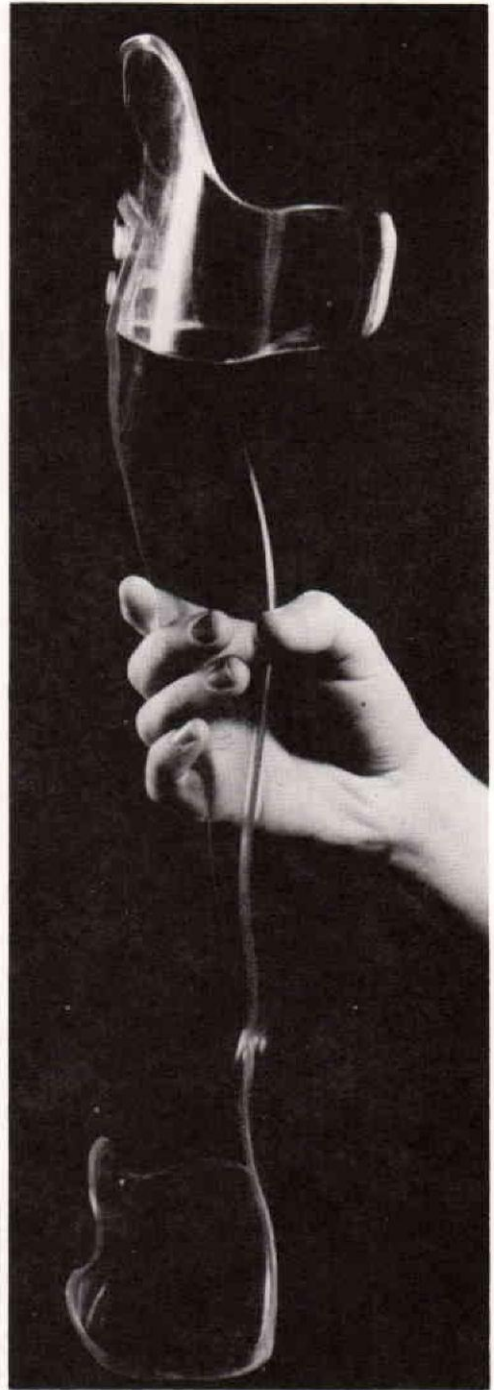


Fig. 14. The hemispiral AFO.

HEMISPIRAL AFO

In contrast to the full spiral AFO which originates on the medial side of the foot and describes a complete turn of 360 deg. around the leg, the hemispiral AFO originates from the lateral portion of the footplate, passing around the leg in a direction opposite from that of the full spiral AFO and covering only half a turn of 180 deg. (Fig. 14). Thus, the reduction of the helical turn in the hemispiral results in greater stiffness with improved resistance against the equinus tendency. At heel strike, external torque of the foot is induced by the unwinding of the spiral which, as mentioned above, is in the direction opposite from that of the full spiral AFO.

Indications for use of the hemispiral AFO are:

1. Motor weakness of the evertors and dorsiflexion of the foot with resultant imbalance of forces in the direction of equinovarus.
2. Moderate spasticity when present with condition described in "1" above.
3. Mediolateral instability during stance or swing.

Contraindications for use of the hemispiral AFO are:

1. Severe spasticity with sustained clonus.
2. Fluctuating edema.
3. Fixed deformities.

CASTING PROCEDURES

Casting procedures for the hemispiral AFO are similar in all respects to those described for the full spiral AFO with the exception that the

lateral rather than the medial malleolus is marked.

CAST MODIFICATIONS

Cast modifications are also similar to those described for the spiral AFO with the following exceptions:

1. Plaster removal in the soft tissue area between the crest of the tibia and the shaft of the fibula is necessary only on the proximal shank area because the spiral portion will not cross the tibia anteriorly.
2. Plaster is removed in an area extending proximally 8 cm above the lateral malleolus.
3. The lateral malleolus is built up 6 mm while no additional plaster is necessary on the medial malleolus.

MOLDING PROCEDURES

For molding the hemispiral AFO, a precut kit is available (Fig. 15). Molding of the calf band is identical to that described for the full spiral AFO, but the hemispiral is placed on the cast so that the spiral upright extends from the footplate to cover the lateral malleolus. After the footplate has been wrapped and held in place with an Ace bandage, the spiral upright is then wrapped posteriorly around the leg, terminating over the medial tibial flare area of the calf band. This position is maintained with Ace bandages until the plastic has cooled sufficiently.

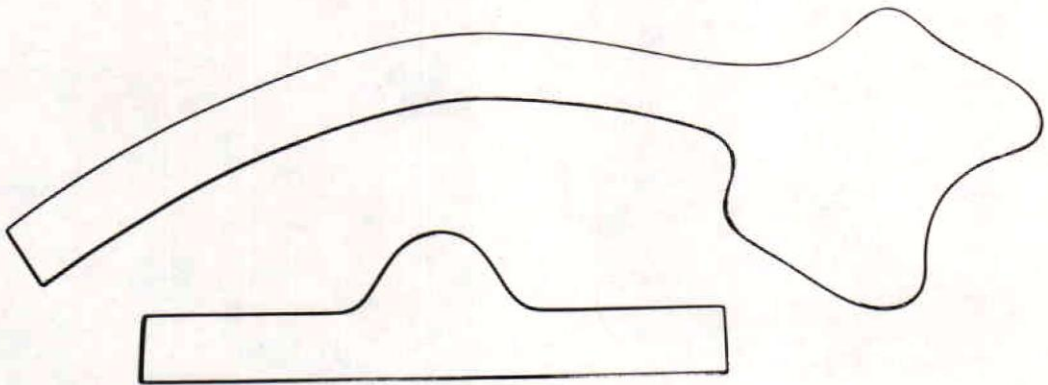


Fig. 15. Shape of SADUR parts needed for the hemispiral AFO.

ASSEMBLY

Assembly of the hemispiral is similar to the full spiral AFO with the following exceptions:

1. The medial trim line of the footplate is such that a flange of the footplate covers the area immediately behind the first metatarsal head and another flange covers the medial portion of the calcaneus. The purpose of the flanges is to prevent forefoot adduction and hind-foot inversion, respectively.
2. Normally the distal trim line of the footplate should be such that the lateral border extends distal to the fifth metatarsal head, i.e., covering the metatarsal head, while the medial aspect terminates 6 mm proximal to the head of the first metatarsal. The purpose of this trim line is to provide an increased lateral base (Fig. 16).
3. The heel section of the footplate is not removed but rather is maintained for the purpose of effectively inducing an external torque on the spiral at heel strike, thus compensating for the varus tendency in this type of patient.

FITTING PROCEDURES

Fitting procedures are again similar to those for the full spiral AFO, except for the trim line

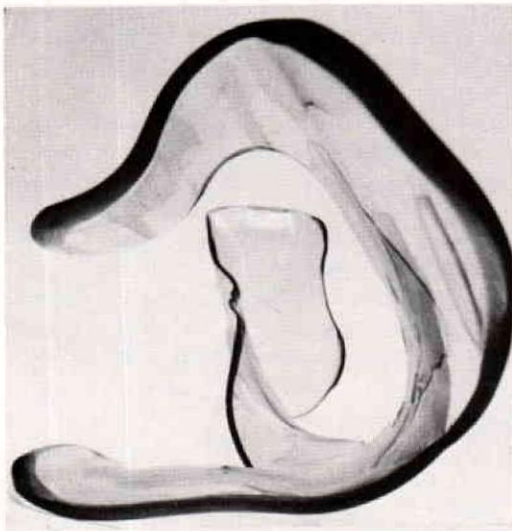


Fig. 16. View of hemispiral AFO from the proximal end.

of the footplate as described above. The shoe type to be used with the hemispiral AFO is the same as for the full spiral AFO. However, a shoe 1/2 to 1 size larger and 1 to 2 sizes wider is usually required. Figure 17 shows the hemispiral on a patient.

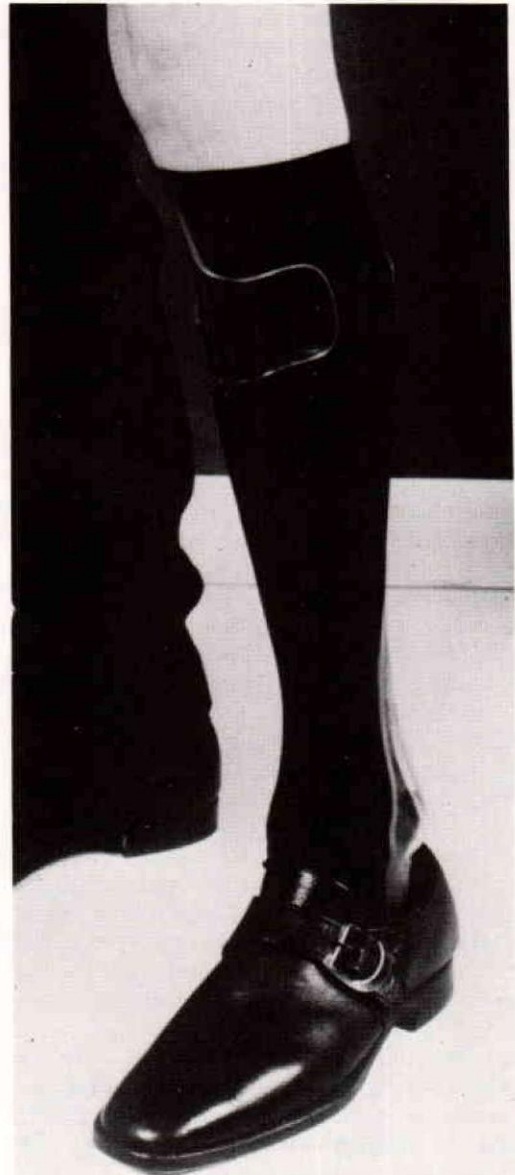


Fig. 17. Completed hemispiral AFO on patient.

CLINICAL EXPERIENCE

Both configurations of the spiral AFOs have been used extensively and almost exclusively employed in the orthotic management of patients with conditions described under the indications for each of the spiral AFOs at the Institute of Rehabilitation Medicine, New York University Medical Center, over the past five years. As compared to conventional means of bracing, patient performance with the spiral orthoses has been shown to be noticeably improved through conventional and photokinematic gait analyses (6). Substantial reduction in energy expenditures has been substantiated through measurement of oxygen consumption with these orthoses when compared with conventional braces (4). Beyond the physical effects produced by these lightweight orthotic designs (approximately 200 gm), which through a more intimate fit afford specific ankle control and better orthotic matching of the disabilities for which the orthoses are indicated than is possible with conventional braces, there has been enthusiastic acceptance by an overwhelming majority of the patients thus managed. It is believed that this not only relates to the rather readily measurable physical effects just described but to the psychosocial effects enhanced by improved cosmesis, cleanliness, and ability to interchange shoes. The results of psychosocial evaluations, as well as other biometric data relating to this research, are fully described in reference 6, to which the interested reader is referred for full details in these areas as well as statistical data on the numbers and types of patients fitted.

Breakage of the spiral AFO reported during the early stages of development has been greatly reduced in a number of ways, none of which are elaborated here. However, elimination of the heel section of the brace and the commercial availability of quality-controlled spiral and hemispiral blanks, have reduced breakage in the spiral AFO to 5-7 percent during the initial year of wear. This percentage is much higher in bilaterally involved patients, hence the orthosis is not recommended for this population. In those patients who have experienced breakage within a period of one year postfitting, it has become our practice to prelace the SADUR material with a spiral made from polypropylene. There has been no instance of breakage with polypropylene spirals which have been used for over two years,

although patients report a functional difference which relates to a reduction of springiness, i.e., rebound, as the plastic memory of polypropylene is less than that of SADUR. For functional reasons, therefore, SADUR is still the preferred material, but may be substituted with polypropylene when breakage occurs within a period of one year from the date of fitting as described above. There have been very few instances of breakage with the more recently developed hemispiral which has been applied for more than three years. It is not clear whether this reduction of breakage in the hemispiral is due to its design configuration making it considerably stiffer than the spiral AFO, reducing the excursion and, therefore, the demand on the orthosis, or whether the patient indications preclude extraordinary wear.

SUMMARY

The plastic spiral and hemispiral orthoses have been described in terms of indications, contraindications for each, their physical characteristics, as well as casting, fabrication and fitting procedures. Both orthoses have been used extensively and almost exclusively in the orthotic management of patients who fit the criteria for their indications in over one thousand patient applications at the Institute of Rehabilitation Medicine, New York University Medical Center, with favorable results and patient reactions. Similar results have been reported by other institutions and practitioners who have applied these orthoses.

It is believed that the technical problems of materials and fabrication methods which precluded more general application in the early phases of development have been sufficiently overcome to warrant introduction of this system into general orthotic practice as recommended by the Committee on Prosthetics Research and Development of the National Academy of Sciences—National Research Council (2).

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