A Fiberglas-Epoxy Drop-Foot Brace

by

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INTRODUCTION

It is generally believed that an appliance for the correction of drop-foot deformities should substitute for specific weakness only, and leave all other muscles free to act normally (1). A flexible appliance is preferred to a fixed or rigid device to allow as much freedom of motion of the forefoot and ankle as possible to enhance comfort, endurance and gait.

In this paper, the design and fabrication of a flexible plastic drop-foot brace which meet these criteria are described, and patient reactions are presented.

BRACE DESIGN

In the plastics drop-foot brace design, fiberglas-epoxy composites in rod form are used to duplicate the function of the metallic uprights and ankle joint in the conventional brace, thereby eliminating the need for a spring-loaded joint. By varying the diameter of these plastic rods, the degree of medial-lateral stability required may be accomplished with the accompanying change of force required for dorsiplantar flexion.

Toe lift is controlled by interchangeable shoe adaptors available with precut angles as required. The adaptors are coupled either to a shoe plate or a bar that fits into a conventional shoe channel.

The rods are connected at their proximal ends to a leather calf-cuff by insertion into sewn pockets. When maximum medial-lateral stability is required, a molded fiberglas-epoxy calf band is attached to the rods and covered

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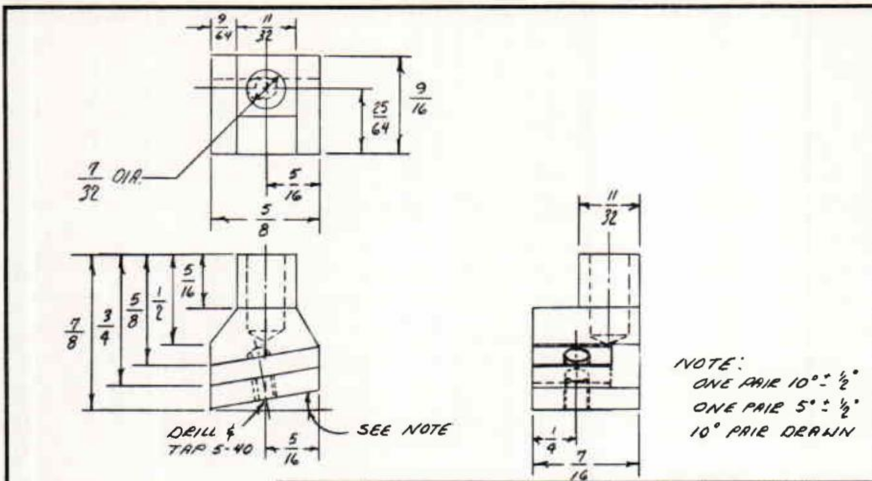

PART NO.	PART NAME	NO. REQ.	MATERIAL	REMARKS
	SHOE ADAPTOR	AS NOTED	AL.	

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DRAWN RON	DATE 3-12-68		NEXT ASSEMBLY
CHECKED JTH	DATE 3-12-68	TITLE	DRAWING NO.
APPROVED JTH	DATE 3-12-68	BRACE SHOE ADAPTOR	FIG. #1

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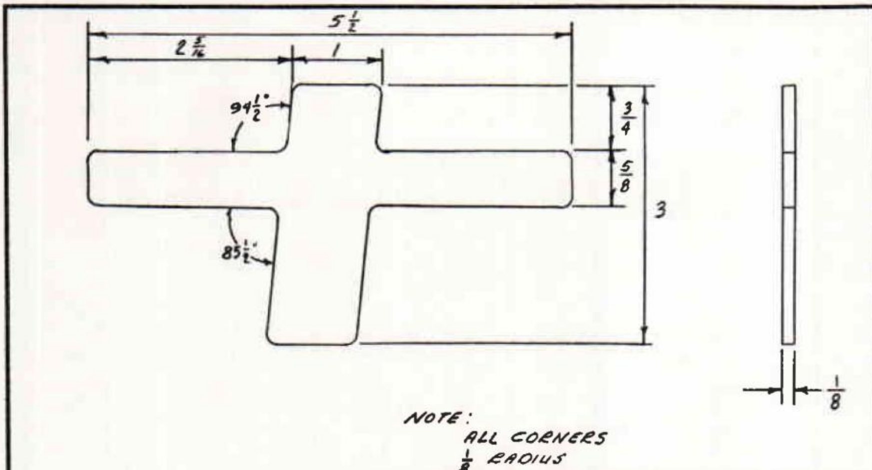

PART NO.	PART NAME	NO. REQ.	MATERIAL	REMARKS
	SHOE PLATE	ONE	AL.	

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with a leather cuff. Figs. 1–4 illustrate the brace and shoe attachment.

DESIGN MATERIALS

Since it is desirable to fabricate the strongest, lightest, and most durable brace possible, strength-to-weight ratio and flexural fatigue strength are the most important materials and design considerations.

Fiberglas-epoxy composites offer great flexibility of design due to their extremely high strength-to-weight ratio. The specific compressive strength of these composites is 2.8 times that of steel and 3.7 times that of aluminum (2). From a practical standpoint, this allows the brace designer a wide latitude for application. In a case where strength is of prime importance, a brace could be constructed almost three times the strength of steel with the same weight. At the other extreme, when reduction of weight is critical, a brace can be constructed as strong as aluminum but weighing only one-fourth as much. These comparisons show that braces may be designed both stronger and lighter than either steel or aluminum.

FIGURE 3—Lateral view of plastics brace at heel contact.

The superior fatigue performance of fiberglas-epoxy composites can best be illustrated by a comparison with the fatigue and flexural properties of steel and aluminum.

The fatigue strength of fiberglas-epoxy composites (unidirectional filaments) is 36,000 psi at 10 million cycles, while spring steel and aluminum are 33,000 psi

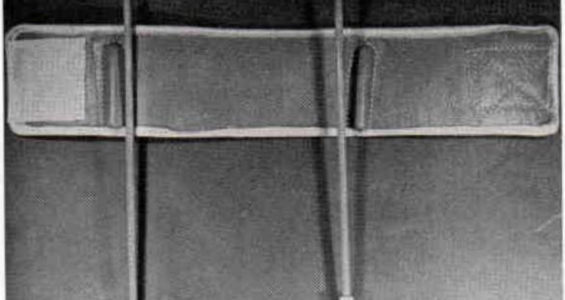

FIGURE 4—Individual plastics brace components. Top to bottom: 1) Calf cuff; 2) Fiberglass rods with adaptors; 3) Channel bar.

and 27,000 psi, respectively, at 10 million cycles. The specific fatigue of the fiberglas-epoxy composite is almost five times that of steel and over twice that of aluminum (3).

Notch sensitivity can be very important in fatigue applications, particularly with springs subjected to scratches and nicks which occur in brace application. These lead to premature fatigue failures. Reinforced plastics are far less notch sensitive than most metals. Aluminum retains only 37% of its original fatigue strength, steel 43–47% of its original strength, while fiberglas-epoxy composites retain 80–90% of their original fatigue strength.

The properties of fiberglas-epoxy composites compared to those of aluminum and steel make them an obvious choice for brace fabrication.

BRACE FABRICATION

Fiberglas-Epoxy Rods

The fiberglas-epoxy rods are fabricated from Scotchply* Reinforced Plastic, Type 1008. This is an epoxy-fiberglas preimpregnated material that comes in rolls up to 48″ wide.

The rods are fabricated as follows:

Cut strips of prepreg tape 1 to 2 inches longer than desired length of rod. (19-inch rods would be long enough to fit 97.5% of the adult male population) (5). The number of strips of tape required is dependent on the desired diameter of the rods. Below are tabulated the strips of tape required per rod for a given diameter.

Desired Diameter	*Prepreg Required*
$^5/_{32}$ inch	1 strip—1½″ width
$^3/_{16}$ inch	1 strip—1½″ width plus 1 strip—¾″ width
¼ inch	2 strips—1½″ width plus 1 strip—¾″ width

Take a strip of 1½″ tape, remove the release paper and lay on a flat surface. Roll the tape longitudinally as tightly as possible (there should be no visible hollow core in the center) until a round rod is obtained. If necessary, roll additional pieces of tape around this rod until the desired diameter is obtained.

To insure maximum strength of the attachment of the rod to the shoe adaptor, the diameter of the rod is increased over the last 4½″ to a maximum of ¼″. This is accomplished by wrapping triangular pieces of prepreg around the ends of the rods.

For a $^5/_{32}$″ rod, cut a triangle 4½″ long × 2¼″ high.

For a $^3/_{16}$″ rod, cut a triangle 4½″ long × 1½″ high.

Remove the release paper and wrap the triangular prepreg around the end of the rod in such a manner that the 4½″ side runs along the rod when you start to roll this piece around the rod. Roll the piece around the rod. Next, spirally wrap the rod with 1″ wide release tape applying slight,

* Minnesota Mining & Manufacturing Co., St. Paul, Minn.

but uniform, tension during the winding. Tedlar,* polyvinyl alcohol and Scotchply† XP-242 release films have been successfully used.

After the rod has been wound, seal both ends to prevent leakage of the epoxy. Transparent adhesive-backed tape is excellent for this purpose. Lay the rods on a flat surface and cure for 2 hours at 160° ± 10° C. (320° ± 18° F).

Calf-Cuff

For those patients who don't require a rigid calf band, only a leather cuff is necessary. A 3" wide cuff should be adequate. It is made in the usual manner utilizing either straps or Velcro fasteners. Leather pockets are sewn on the medial and lateral aspects of the cuff to accommodate the rods.

Rigid Calf-Band

In those cases where a rigid calf band is required, the following procedure should be followed:

1. Determine the diameter of the patient's leg 1½" below the head of the fibula.

2. Using this diameter, draw a half circle on a 1⅝" to 2" thick piece of wood.

3. Draw a line parallel and equal in length to the diameter ¾" away from the diameter on the outside of the half circle. Connect the ends of this new line with ends of the diameter. Cut out the entire enclosed area. This will provide a form for the calf band.

4. Tape a strip of 1/16" thick, 40–70 durometer silicone sheeting over the perimeter of this form. Cover this sheeting with release film.

5. Stand the form on its flat edge. Cut a strip 1½" wide of prepreg tape to fit around the exposed perimeter of the form. Remove the release paper and lay onto the form. Next, cut pieces of 1½" prepreg 1½" long and lay the fibers 90° (perpendicular) to the fibers of first prepreg and fill in all around the band. Continue the buildup, alternating the fibers, until there are 9 layers.

6. Put a piece of release film over the final layer of prepreg tape.

7. Cover the release film with 1/32", 70 durometer silicone sheeting and place the entire layup into a polyvinyl alcohol vacuum bag.

8. Cure the layup for 2 hours at 160° ± 10°C (320° ± 18°F) under 25–30" vacuum.

9. Remove cured calf band from the form and sand the edges smooth.

Attachment of Rods to Rigid Calf Band

In order to attach the rods to the calf band, the ends of the rods must be first built up as described below:

1. From 1½" wide prepreg tape, cut 4 pieces 1½" long and 7 pieces ¾" long.

2. Lay up these prepreg tapes around rod as shown in the diagram. The fibers in the 1½" × 1½" pieces run in the same direction as the rod. The ¾" × 1½" fibers run 90° to the rod.

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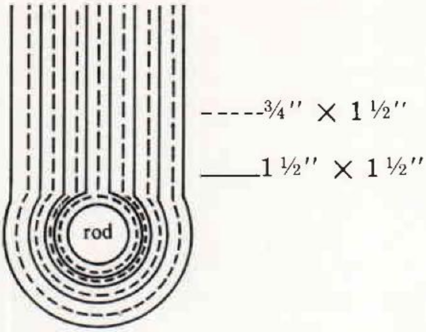
* E. I. duPont deNemours Co., Wilmington, Del. Film Dept.

† Minnesota Mining & Manufacturing Co., St. Paul, Minn.



3. After the prepreg tape is wrapped around both rods, lay the rods on a piece of wood that has been covered first with 1/16" silicone sheeting, then a piece of release film. The rods should be placed so the buildups are facing in opposite directions. This will insure proper alignment of the rods on the calf band.

4. Cover the buildup with release film, then 1/32", 70 durometer silicone sheeting, place in a vacuum bag and cure for 2 hours at 160° ± 10°C (320° ± 18°F) and 25–29" Hg vacuum. Sand the edges of the cured buildup.

5. Place the plastic calf band on the patient's leg and align the rods. Mark the location of the rods on the band.

6. Rivet or cement the rods to the calf band. If cement is used, the following formulation is very satisfactory:

Epon*815 . . .	4 parts
Curing Agent T-1	1 part
Filler	As required to make a paste

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* Shell Chemical Co., New York, N.Y.

Shoe Adaptors and Shoe Plate

The design of the shoe adaptors is shown in Figure 1. Although this design is for a 5° or 10° lift, slots may be made for any angle of lift required. The shoe plate is shown in Figure 2.

Brace Assembly

The patient's shoe may have either a conventional flat channel attached, or a shoe plate similar to the one shown in Figure 2. The plate or channel may be attached with rivets or the cement formulation given above.

If the channel is used, cut a flat bar of aluminum to fit the channel and extend 7/16" beyond the channel on each side. If the shoe plate is used, cut the extending medial and lateral pieces 7/16" beyond the edge of the heel. Drill 1/8" holes 3/8" from the ends of the channel bar or shoe plate. Next, determine the proper rod length by actual measurement on the patient. Cut off 1/2" from the tapered end of the rod. Cement the tapered end into the shoe adaptor using Epon 815, 4 parts and curing agent T1, 1 part. Allow the cement to cure for 1 hour at room temperature plus 30 minutes at 50°–65°C (120°–150°F) or overnight at room temperature.

Attach the shoe adaptors to the shoe and have the patient put on the shoe. Determine the length of rods necessary (3/4"–1" below head of fibula) and cut off the excess with a hacksaw.

If the flexible calf-cuff is used,

you need only insert the rods into the cuff, and the brace is ready for use. If the rigid band is being used, sew a leather cuff to slip over this plastic band.

EVALUATION

Plastic drop-foot braces have undergone an 8-month trial evaluation by two bilateral brace wearers. During this period, the following observations were noted (7, 8).

1. The plastic braces are lighter and more cosmetically attractive than metal braces.

2. There is little danger of the plastic braces interlocking and thereby creating a tripping hazard. The contouring of the metal brace away from the ankle presents this interlocking hazard with its potential of causing a serious fall.

3. Plastic braces are so light and flexible, one forgets he is wearing them. Metal braces cause fatigue when walking.

4. Plastic braces do not damage clothing, while metal braces cause damage to the trousers through tears and grease spots.

5. Plastic braces allow one to cross his legs comfortably, while metal braces do not.

6. Plastic braces require no upkeep, while the springs in the metal brace require occasional oiling and replacement.

7. Driving with plastic braces is almost as easy as it was without braces. Although metal braces are adequate for driving, they are heavy and clumsy to move from the accelerator to the brake pedal.

8. Plastic braces provide adequate medial-lateral stability yet are flexible enough to allow walking on uneven terrain.

9. Plastic braces are easier to put on than metal braces.

10. When one is inactive for an appreciable length of time, such as sitting at an office desk, the rigidity of metal braces prevents adequate flexing of ankle muscles causing severe aching in the calf and ankle regions. The flexibility of the plastic brace allows sufficient ankle motion to minimize this effect.

11. There is no noticeable numbness of feet since abandoning the rigid metal braces.

12. If it were a choice between metal braces and plastic braces, plastic would be preferred.

SUMMARY

A plastic drop-foot brace of simple design has been developed which provides toe lift and concomitantly insures comfortable and effective performance. To allow as much natural action of the foot and ankle as permissible and provide good gait and enhanced standing balance, it was found desirable to employ the dual spring action of flexible fiberglas rods to counterbalance dorsiflexion and plantar flexion (6).

The brace is easily removed, prevents clothing damage, and provides for an interchange of shoes. The plastic brace is lightweight, durable, cosmetically attractive, and corrosion resistant. Provisions have been made for

altering the degree of lift as necessary to compensate for progressive maladies.

Although the results discussed were obtained in a limited number of test cases, application of this appliance to a wide range of brace wearers appears warranted.

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