Fiberglass Reinforced Plastic Orthotic Appliances

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Orthotic technology has developed rapidly in recent decades in western countries. Korea has been confronted with the problems of purchasing the appropriate orthotic materials, training of orthotists and financial expense. The introduction of new materials and lamination technology for orthotic appliances will enable such problems to be solved. Fiberglass reinforced plastic (FRP), which was laminated with Korean made plastic resins and fiberglass, was superior to the mechanical properties of other plastic materials, such as acrylic, polypropylene and thermoplast. Lamination of the orthotic devices with FRP was introduced and it should be technically possible for an orthotist in a small workshop or a member of the house staff of a hospital to make an appliance on the premises.

Key Words: Fiberglass reinforced plastic, mechanical properties of plastic

Rapid development of industrial orthotic technology has provided for the restoration of the lost functions that are required for the support, realignment and control of the body segments.

Over the past several decades, the choice of material for orthotic devices has grown extensively with a wide variety of many kinds of metal, leather, fabric, rubber, wood and composite materials. More recently, there have been remarkable developments in the fabrication of plastic appliances.

Indications for the application of orthosis include conditions such as slow healing fractures of the long bones, and joint instability or pain resulting from trauma or disease. Besides supporting, realigning and controlling body segments, plastic appliances can help reduce burn scar contractures by compression of the scars, thus preventing and/or minimizing disfigurement of the area (Robitaille et al. 1973; Rivers et al. 1979). While the primary objective of a device is to relieve skeletal weight bearing, some designs also incorporate the means to maintain structural alignment of the skeletal system (Nickel and Mooney).

The plastic appliance can be named according to the part of the body to which it is applied: facial mask or splint (Paterson 1977; Rivers et al. 1979; O'Shaughnessy and Heimbach 1982), body jacket (Yates et al. 1974; Counts 1987), and cervical collar (Steven 1982). Splints for the upper and lower extremities are named differently (Bender 1982; Lehmann 1982; O'Shaughnessy and Heimbach 1982), such a brace, below knee orthosis, short leg brace, ankle-foot orthosis, or knee-ankle orthosis (Jebsen 1968; Lehmann et al. 1970; Lenmann et al. 1979; Lehmann et al. 1983; Bronkhorst et al. 1987), shoe insert or sandal (Campbell and Inman 1974; Hampton 1979), heel-cup or heel-seat (Helfet 1956; Bistevins 1982) and in part of the quadrilateral socket and patellar tendon bearing socket (Lehmann 1982).

Recently in Korea, plastic materials, such as polypropylene, have been imported and introduced for orthotic devices. Many patients prefer to wear the plastic appliances rather than the conventional orthosis which are heavy, unsightly and fit poorly from a biomechanical point of view.

Orthotists who would like to provide plastic appliances, but who have a very small workshop, face a considerable disadvantage because of the high cost of installing an electric oven which is necessary to soften the polypropylene prior to molding. If the shop owners were to become equipped with all the necessary tools, these expenses would fall heavily on the patients and their families.

The history of the use of glass fibers is nearly as old as glass itself. In Egyptian times glass vessels were made by winding fibers onto a suitable core. The in-
vention of glass blowing began at the beginning of the Christian era (Loewenstein 1966). In the 1920's, the necessity of electrical insulating tape capable of withstanding high temperatures led to the development of a special glass composition. Continuous fibers of uniform diameter were drawn by mechanical attenuation into yarn and woven into suitable tapes. In 1935 thermosetting resins were polymerized. These were polyesters which, if combined with glass fibers, could produce material with a high strength-to-weight ratio. Thus, glass fibers and polyester resins became the basis of a new material (Loewenstein 1966).

In medical fields, a study was conducted on synthetic plastics for use as plastigut (Bellas 1940) and fiberglass suture material (Scholz 1942). The glass plastic bandage, a waterproof, non-absorbable, strong mesh, proved to be successful when applied under tension and conformed to any contour (Anderson 1945).

It was the primary purpose of this study to provide inexpensive plastic appliances by the clinical application of many layers of fiberglass reinforced plastic (FRP), by laminating fiberglass cloth with two kinds of unsaturated polyester resins which are korean products and which set easily at room temperature. A study has been conducted to compare the mechanical properties of FRP with those of other materials to determine FRP's usefulness in terms of longevity and convenience.

LAMINATION OF APPLIANCES

First, a negative plastic cast (negative mold) is made on the part of the patient where the appliance will be worn. A lubricant such as vaseline is applied over the skin to grease the inside of the cast in order to allow easy removal (Fig. 1). Indelible pencil marks are made over the bony prominence, around pressure sensitive areas and along the planned margins of the appliance. These marks will later be visible on the inside of the negative plastic cast.

The patient is positioned appropriately and a cotton stockinet is pulled on until it is above the planned trim line of the cast. The lead strip is placed along the cast where it will be cut to open it.

Application of the plaster-of-paris bandages is simple and, in general, can be easily done by anyone familiar with the universally used plaster technique. Only four to six layers of bandages are needed for the negative mold. The negative plaster cast is cut open with a sharp knife or cast saw over the lead strip. The cast is spread open and removed from the body part. The cut edges are then drawn together and fastened with masking tape. The open end of the cast is covered with plaster-of-paris bandages to form a bowl shape or bulkhead, thus closing it, a mandrel is placed in the middle of the negative cast, then the impression plaster is poured into the lubricated negative cast and it will not leak.

When the impression plaster has set, the negative plaster cast is removed. The mandrel is firmly clamped in a vise and the surface of the positive mold is carefully smoothed with a rasp, a file and sandpaper (Fig. 2). Build-ups of three mm. are made over the bony prominences and any other area where sensitivity is expected. The positive mold is coated with wax. The wax is then wiped off with a dry cloth, followed by application of a liquid form of polyvinyl alcohol using a brush and it is left to dry.

Resins are chosen according to the body segment function and/or the specific purpose of the appliance. The choices are: No. N-350L polyester resin and flexible polyester resin No. F-275A.
If a rigid component is desired, No. N-350L should be the first choice but this sometimes breaks with the application of a very strong external force. Therefore, a larger percentage of No. N-350L and a smaller percentage of No. F-275A, which is the soft component of resin should be used. For example, for a posterior leaf solid ankle-foot orthosis, 60 per cent No. N-350L and 40 per cent No. F-275A are recommended. Sometimes even for a single appliance, such as a posterior leaf spring ankle-foot orthosis, the combination of resins could be varied depending on the function of the orthotic part. In the ankle area, the percentage of No. F-275A flexible resin should be higher than No. N-350L but in the calf area, the percentages will be reversed. The desired magnitude of spring function at the ankle could be adjusted by trimming the anterior edges of the ankle.

With each new item, the resin formula should be modified for the specific purpose of each appliance.

A paper cup or a small can will be sufficient for mixing the resins. Catalizer, Cobalt octoate, in the amount of 0.6 per cent of the resin's weight is added into the resin mixture and blended with a tongue depressor or a spatula. This is followed with drops of promotor, methyl ethyl ketone peroxide in the amount of 1.0 per cent of resin's weight, and stirred thoroughly.

Then, lamination of the appliance will begin in the following order: 1) The mixture is applied over the mold by the hand lap-up method using a brush, 2) The fiberglass, which is a two-dimensional directional fiber orientation woven cloth, is cut into the appropriate size and shape and is palced over the resin mixture, 3) This lay-up process is repeated until a desired thickness is achieved. A small rolling pin is useful to distribute the resin evenly, to expel all the air bubbles and to impregnate the fiberglass in the resin. The working time before the resin mixture sets (gel form) is about 20 to 25 minutes at 25°C after the promotor is added. Since the working time should not exceed 25 minutes, the amount of mixture should be prepared according to working time and the same process is repeated for the remainder of the appliance.

The resin will cure in 12 hours at room temperature. The longer the better. After the resin has cured, the plastic appliance is removed from the positive mold. The excess material is removed and the edges are smoothed off. The surfaces are smoothed with sandpaper and cloths.

The straps and buckles or velcro are attached for fastening the appliance to the body (Fig. 3 and Fig. 4). If porosity is desirable, ventilation is ensured by making small drill-holes, as many as desired.

**COMPARISON OF MECHANICAL PROPERTIES OF APPLIANCE MATERIALS**

The composite system of fiberglass-resin, is very useful in areas where high strength is required. The properties of the resulting materials are a function of the relative quantities of fiberglass and resin, orientation of the fiber reinforcement in the resin matrix and technique, etc.

In this study, the mechanical properties are determined on standard test pieces (Fig. 5). Samples were made from FRP sheeting by the same technique as the plastic appliances and other materials for comparison with FRP.
A test was employed to measure the tensile and flexural strength. These were determined by a short-time laboratory test and were measured in Kgf/mm². The testing instrument was the Instron Model 1123 (Fig. 6).

**RESULTS**

The tensile strength of the FRP with resin No. N-350L and fiberglass is higher than that of aluminum (Table 1).

Both tensile and flexural strength are somewhat lower in FRP which contains flexible resin No. F-275A. But these are still higher than those of polycoat with one ply fiberglass, and acrylic, polypropylene and thermoplast.

FRP which has been laminated with many layers of fiberglass is superior to the mechanical properties of other plastic materials and is much the same as aluminum.
Kyoung-Ja Cho

DISCUSSION

When managing a patient who requires an orthotic appliance to increase his or her function, it is essential to adapt the device to maintain the progress made. An appliance which will substitute for a specific weakness only and leave all other muscles free to act normally and in comfort, a flexible or semiflexible appliance is preferred to a rigid device (Hill and Fenwick 1968).

Traditional braces have been found wanting because of their undesirable appearance, excessive weight, clinical inflexibility and unsound biomechanical design (Samo and Lehneis 1971). Of particular concern is their weight and the additional energy cost caused by a heavier device (Coracoran 1971). The plastic appliance weighs approximately a quarter to a half of that of the conventional device (Simon et al. 1967; Jebsen et al. 1968; Jebsen et al. 1970). Another advantage seems to be primarily that of cosmesis, especially considering the reduced bulk of the device.

The advent of plastic materials and the development of plastic technology have served as a stimulus to the orthotic appliance industry. The motion that occurs between the conventional orthosis and the skin is an insufficient arrangement, therefore this motion should be reduced, necessitating a contour-molded total contact plastic appliance that can be highly recommended.

Acrylic devices have been studied by many authors (Campbell 1944; Cholmeley 1945). Their advantages are elegance of appearance, low specific gravity, cleanliness in use and radiolucency. However, they are much less durable than laminated plastics (Table 1). In another study, Herschell (1948) pointed out that acrylics have neither elasticity nor durability.

Orthotic devices have been developed over many decades for restoration of functions lost mainly from neuromuscular skeletal disorders. The plastic appliance is known to also be useful in the care of the burned patient (Rivers et al. 1979; O'Shaughnessy and Heimbach 1982). Hypertrophic scarring is the consequence of a deep burn injury of the skin and/or underlying soft tissues. Matured scars are characterized by a consistent pattern of dermal collagen fibers which are highly compact, often with capsule-like bands or tracts about their periphery. When it occurs in the extremities it can cause loss of function, and in the face, it leads to disfigurement (Linares et al. 1972). The burned tissue will continue to form hypertrophic scars until the elasticity of the surrounding tissue has been exhausted. Therefore early intervention by the application of pressure can greatly modify this natural process and will reduce the thickness of the scar already present. To reduce the formation of the contractures, various appliances, including pressure garments, were utilized but often without success. This failure was due to the inability of the device to maintain its position or to compress the scar in as narrow a depressed area as required.

Fitting the patient with a transparent mask for facial burns was introduced by Rivers et al. in 1979. However this is very difficult in Korea, because of the necessity of importing expensive transparent plastic material (cellulose acetate butyrate) and obtaining the use of an electric oven to generate dry heat above 204°C.

Application for the contoured parts, such as the face, neck, elbow or ankle, could not be made by hand pressure with heated pieces of plastic sheet pressed into the negative plaster cast or over the mold. This was because of the difficulty of securing sufficient pressure by the hand for anchoring or pressing to reach the deep narrow curves in two planes. The non-laminated thermoplastic materials lack a high tensile strength and there have been instances of breakage (Herschell and Scales 1948).

The laminated plastic short leg brace has been developed by many authors (Simons et al. 1967; Jebsen et al. 1968). Their work has spurred the development of industrial orthotic technology. But there is a problem with the lack of different degrees of hardness in different parts of the same orthotic device in order to accommodate its specific function.

Because fiberglass is inert, insoluble and reacts least in human tissue, it does not cause tissue swelling, exudation or cell proliferation (Scholz and Mount 1942). Fiberglass both stretches and shrinks the least and has great tensile strength. It is not affected by the action of chemicals and it does not absorb tissue fluids (Miwon Co, Ltd. 1984). Under load conditions, in FRP, 95 per cent of the stress is taken by the fiberglass and five per cent by the resin (Miwon Co. Ltd. 1984).

It must be noted that if great strength is needed, a laminated plastic, particularly resin-embedded fiberglass, is essential. In this study the mechanical properties of FRP were superior to those of acrylic, polypropylene, thermoplast and polycoat with one ply of fiberglass and nylon.

With the use of lamination, either a small or a very large sized appliance can be made where indicated for use over most body segments, around the trunk or near the body (trunk adapter in the chair or
wheelchair.

My interest in this study was to devise inexpensive light-weight, sturdy, cosmetically acceptable appliances which can be effectively applied wherever required and can be laminated in only one or two days by an orthotist who has a small workshop facility. Moreover, it has become evident that to achieve any measure of success it should be possible for a member of the house staff of a hospital to make and fit an appliance on the premises.

SUMMARY

Management of the patient with functional disability requires a combined approach including physiotherapy, occupational therapy, psychological counselling and the provision of appliances to promote his or her functional level and prevent any progressive deformity.

Effective methods, such as laminating the appliance with FRP, are described and their superior mechanical properties have been presented in a study comparing them with other materials.

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Kyoung-Ja Cho

