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LOWER-LIMB ORTHOTICS

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The practice of lower-limb orthotics varies considerably throughout North America. However, there are three basic types of orthoses available: conventional metal-and-leather, molded plastic, and electrical stimulation devices.

The design of conventional metal-and-leather systems has not changed much over the past several years. The use of aluminum and preformed component parts probably represents the most significant improvement achieved in this approach to orthotics. Conventional metal-and-leather orthoses still enjoy widespread usage throughout North America, but plastics have begun to attain popularity in the fabrication of many types of lower-limb orthoses, particularly for correction of ankle and foot problems.

The *Orthopedic Appliance Atlas* (6) published in 1952, refers to over a dozen different types of plastics for use in orthotics, but most of these materials proved not to be very useful in orthotics and prosthetics, and plastics did not find mush usage in the field until 1968, when Gordon Yates published a paper in *Orthopaedics: Oxford* (13) in which he discussed the use of polypropylene and ABS in orthotics. Following Dr. Yates' visit to the United States in 1969, the use of thermoplastics began to increase, slowly at first, but by the mid-70's, some form of plastics could be found in most orthotic facilities in North America.

Thermosetting resins such as the polyesters, acrylics, and epoxies were applied with considerable success in prosthetics, and were carried over naturally into orthotics. However, thermosets could not withstand the continued high impact and flexion stresses that occur in an orthosis during ambulation and, thus, considerable breakage occurred.

When thermoplastics such as polypropylene, polyethylene, ABS, etc. were first used in orthotics, manufacturers were as unfamiliar with their application as were orthotists. Research workers found that thermoplastics had varying degrees of flexibility, impact strength, color, and formability. Selection of the appropriate material was difficult. Today, we have over 100 different usable materials to choose from, and numerous variations of each.

Polymers, both thermosetting and thermoplastic, are now used widely in the field of orthotics.

Dr. Richard Lehneis and his staff at the Institute of Rehabilitation Medicine (5) have contributed much to the advancement of the use of thermosets in orthotics. Dr. Lehneis did not simply substitute plastics for metals, but he used a concept of total contact to improve function by applying pressure directly. The solid-ankle orthosis (Fig. 1), the supracondylar knee-ankle-foot orthosis (Fig. 2), the supracondylar knee orthosis, and the laminated above-knee orthosis are but a few examples.

Fig. 1. Laminated solid ankle-foot orthosis

The solid-ankle orthosis is designed to immobilize the ankle-foot complex and is indicated in cases where ankle motion produces pain or to control or reduce severe spasticity. It was found that the total contact, and the fact that pressure is distributed over a large area, cause the patient to gain better position sense through sensory feedback.

The supracondylar knee-ankle-foot orthosis (SKA) can be used as a substitute for the conventional knee-ankle-foot orthosis (KAFO). It permits free knee flexion, provides a knee extension moment in the stance phase, provides rigid ankle control in both the medio-lateral and the anterior-posterior planes; the extension above the knee provides M-L control, and pressure in the popliteal area prevents excessive recurvatum. An additional advantage is that various types of shoes can be worn with this system without modification of the shoes.

The supracondylar knee orthosis (SKO) is a spin-off from the SKA. By virtue of its design, the knee is controlled in the M-L plane, and by application of a three-point-pressure system, genu recurvatum is controlled.

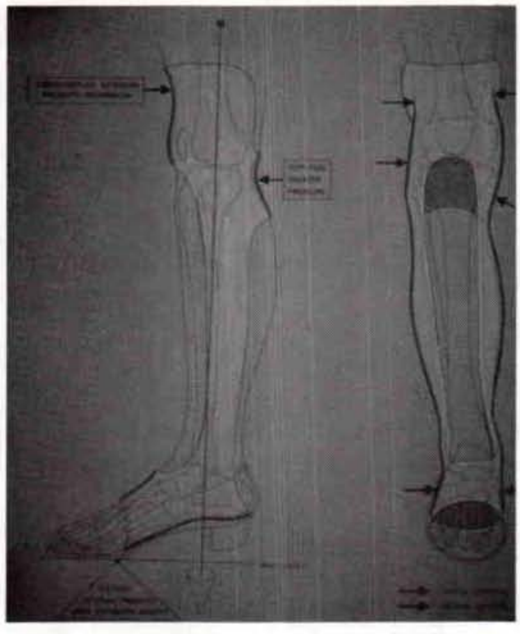

Fig. 2. The supracondylar knee-ankle-foot orthosis laminated

With the addition of conventional metal knee joints, the laminated single-bar orthosis (Fig. 3) and the laminated double-bar above-knee orthosis (Fig. 4) were developed. The single bar is applied in cases of severe genu valgus or varus, and recurvatum is easily controlled. The plastic-laminate knee-ankle-foot orthosis can be substituted for the con-

Fig. 3. Laminated single-bar knee-ankle-foot orthosis.

Fig. 4. Laminated double-bar above-knee orthosis

ventional metal-and-leather orthosis, and the laminated quadriceps section provides greatly improved function through more comfortable weight-bearing, better control of the hip, improved cosmesis, and the ability to interchange a wide variety of shoes.

Two methods have been devised for the handling of thermoplastics: hand-forming or vacuum-forming techniques. Hand-forming is commonly used when working with acrylic nylons such as Plexidur because of difficulties that occur in vacuum-forming.

The IRM spiral AFO (Fig. 5) is one example of a hand-formed thermoplastic device. This system is intended for the totally flail ankle-foot complex. The orthosis completes a 360 deg. turn around the extremity and provides controlled plantarflexion, dorsiflexion, eversion, and inversion of the foot. The hemispiral is a modification in that it makes a 180 deg. turn around the limb and is designed to provide control against equino varus.

Polyolefins, such as polypropylene and polyethylene, are easily adapted to orthotics and can be molded either by hand or by vacuum forming techniques.

Fig. 5. The spiral ankle-foot-orthosis developed at the Institute for Rehabilitation Medicine, New York University. This particular unit was formed from polypropylene. The original design used the clear acrylic nylon thermoplastic known as Plexidur.

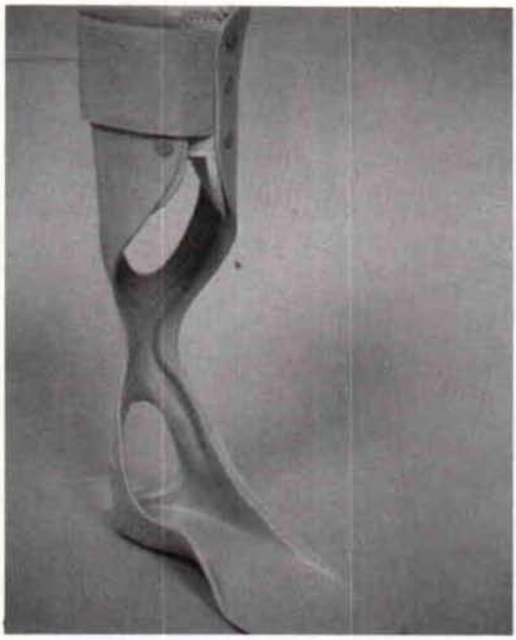

Fig. 6. The molded polypropylene ankle-foot-orthosis developed at the Texas Institute for Rehabilitation and Research.

The polypropylene corrugated dorsiflexion assist, or TIRR AFO (3) (Fig. 6) as it is popularly referred to, was developed about 1968 by Thorkild Engen at the Texas Institute for Rehabilitation and Research. The present day TIRR ankle-foot orthosis evolved from several different designs over a period of time. Mr. Engen used total contact and the ability to control rigidity in the orthosis to effect control of the ankle-foot and to improve ambulation. The TIRR device provides dorsiflexion assist and added mediolateral control of the ankle. The system weighs approximately 4 oz. and permits a large selection of shoes as long as heel height is maintained. Mr. Engen has carried the concept of the polypropylene corrugated dorsiflexion assist to include other designs such as knee-ankle-foot orthoses having either standard metal knee joints or plastic joints.

Various vacuum forming techniques have been utilized in the development of orthotic systems. One method allows for the hand draping of the material over the model and the application of a vacuum through the model.

Numerous orthoses of varying designs have been developed using these two techniques. The molded ankle-foot orthosis (Fig. 7) is in total contact with the posterior and plantar surface of the foot and is an effective means of controlling the ankle, subtalar, and forefoot. Rigidity is controlled by geometric shape, cross-sectional area, and selection of materials. The use of thermoplastics and vacuum forming techniques permits the fabrication of orthoses with varying amounts of rigidity about the ankle (Fig. 8). In addition, ankle positioning can be used effectively to produce either a knee flexion or extension moment during the stance phase of gait (Fig. 9). Total contact improves cosmesis in that the orthosis can be covered with a stocking or a boot, or it may be painted (10).

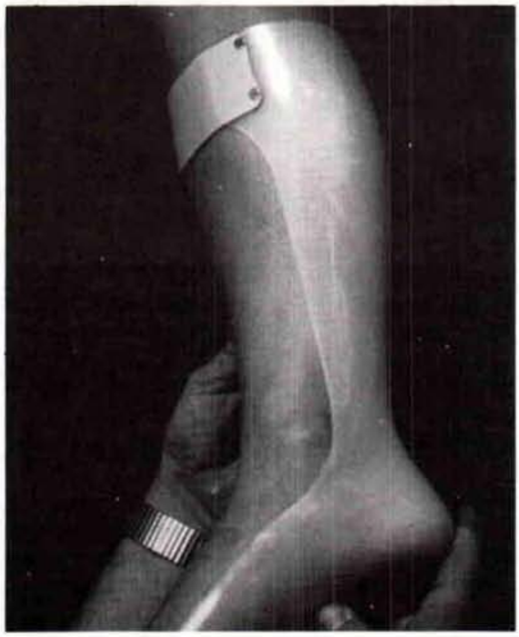

Fig. 7. Molded polypropylene ankle-foot orthosis.

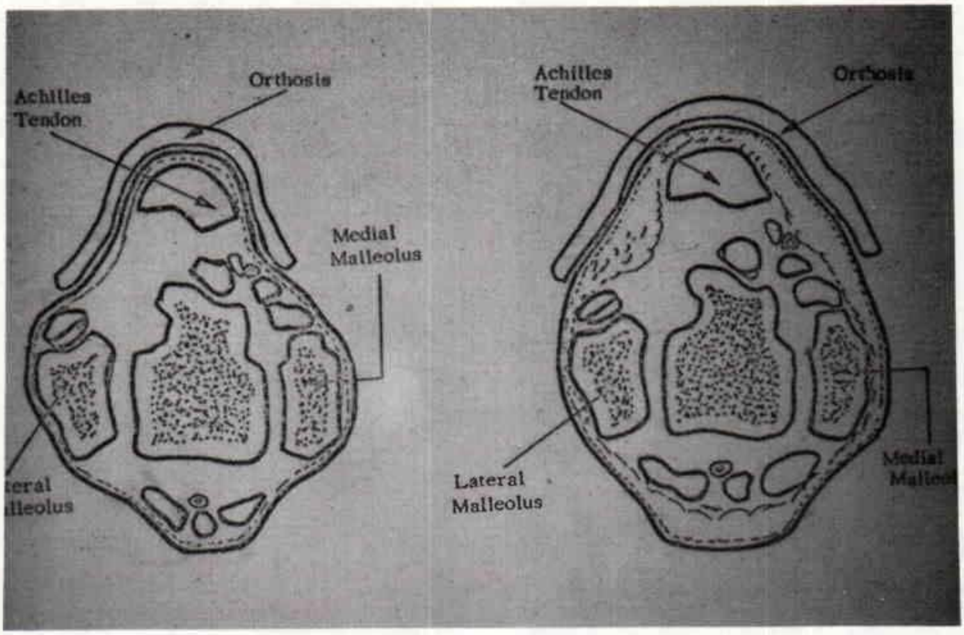

Fig. 8. Rigidity about the ankle of a molded AFO is controlled by geometric shape, thickness, and properties of the material used.

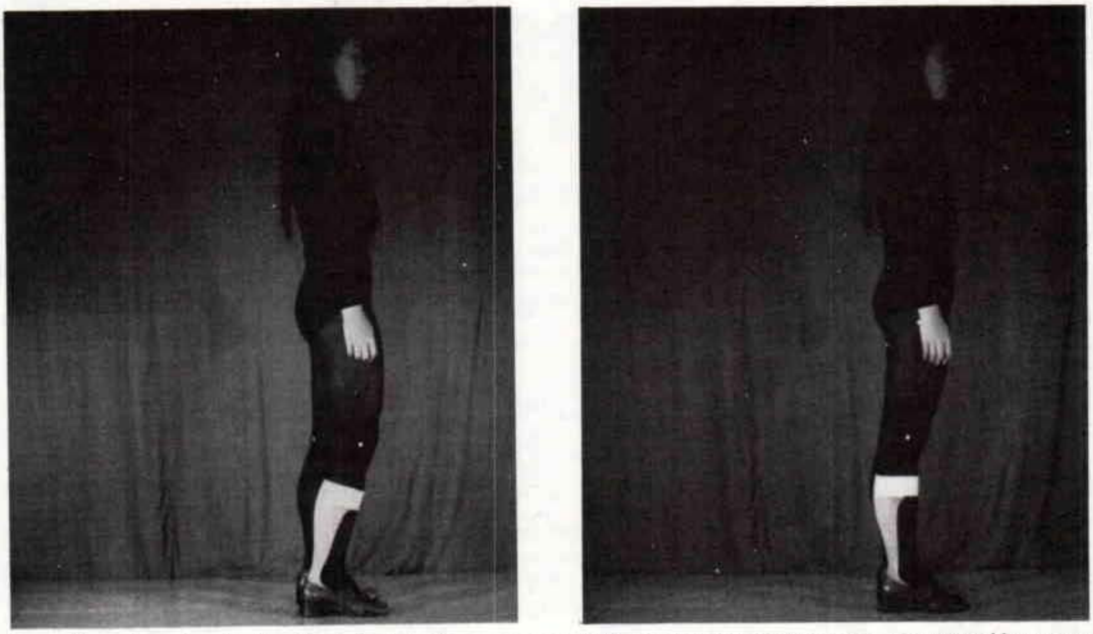

Fig. 9. Two views showing the effect of ankle alignment of an AFO on control of the knee joint. The vertical line represents the actual weightline of the subject.

The staff at Rancho Los Amigos Hospital has developed an adjustable ankle-foot orthosis (Fig. 10) which enables the evaluation of the effectiveness of ankle positioning during ambulation, and at the same time, maintains the advantage of light weight.

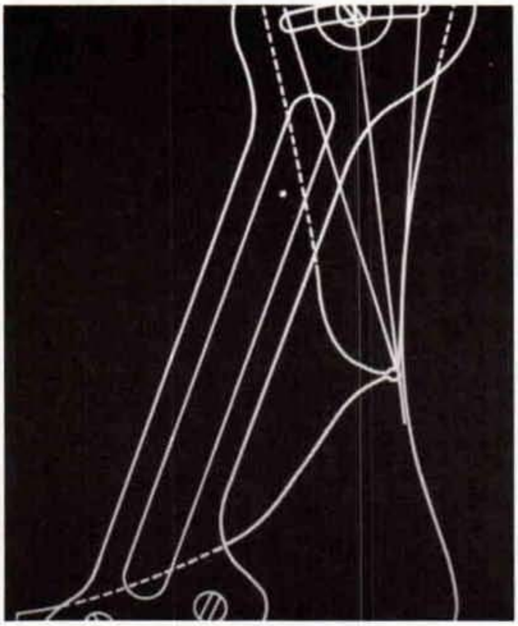

Fig. 10. Adjustable ankle-foot orthosis developed at Rancho Los Amigos Hospital.

Thermoplastics have also been used effectively in the treatment of fractures of the long bones of the lower limb. Dr. Augusto Sarmiento, University of Miami, is using Orthoplast, a synthetic balata, to provide circumferential control of a fracture site (Fig. 11). He has found that it is not necessary to unload totally an extremity in order to provide good management of fractures (1). The staff of the Krusen Center for Research and Engineering, has found that the addition of an anterior section to the molded ankle-foot orthosis (Fig. 12) achieves circumferential control, as well. Both of these management techniques permit the patient to assume more normal activity inasmuch as conventional footwear may be worn, the patient can bathe regularly, the systems are light in weight, and open wound areas are easily cared for while bony alignment is maintained (11).

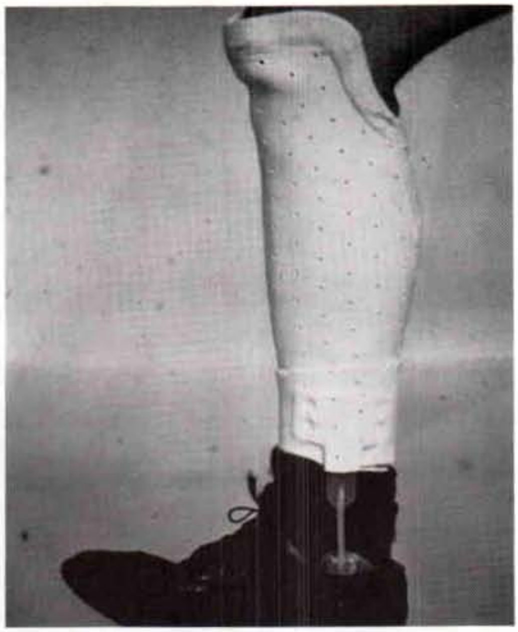

Fig. 11. Ankle-foot orthosis custom molded in place with synthetic balata used for management of tibial fractures.

Fig. 12. Ankle-foot orthosis custom molded of polypropylene for management of tibial fractures.

Thermoplastics are especially useful in the orthotic management of the knee. The use of materials such as polypropylene and low

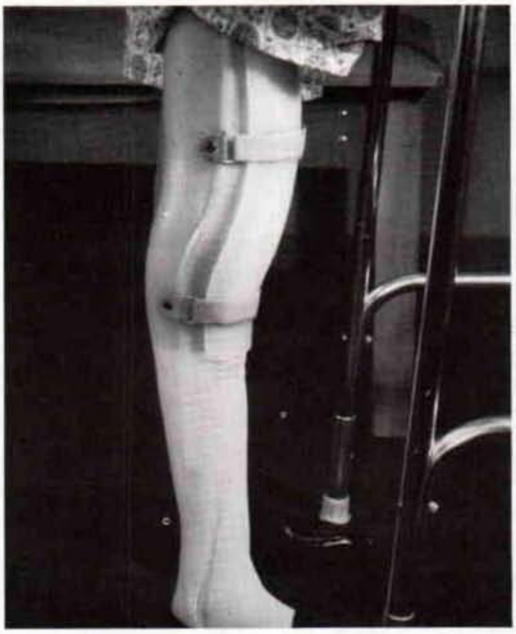

Fig. 13. Molded low density polyethylene KAFO for total immobilization of the knee joint.

density polyethylene permit the development of systems that can totally immobilize the knee joint against flexion, extension, valgus, and varus (Fig. 13). Low-density polyethylene is very useful when rigidity and flexibiltiy are desired in the same orthosis. Geometric shape, due to contouring of the limb and the addition of corrugation, causes the orthosis to be rigid in both planes, but circumference can be increased or decreased to accomodate swelling that might occur as a result of quadriceps rupture or joint bleeding secondary to hemophilia. Lightweight systems of this same design have been used in the orthotic management of patients with muscular dystrophy and arthrogryposis.

Molded knee-ankle-foot orthoses (KAFO's) with mechanical knee joints (Fig. 14) have found widespread usage because total contact provides better control of the ankle and knee. They are light in weight, approximately 960 grams or just over 2 lbs., depending upon the size and weight of the patient. Bilateral molded KAFO's improve and increase mobility, and better limb control and increased endurance are facilitated by their use.

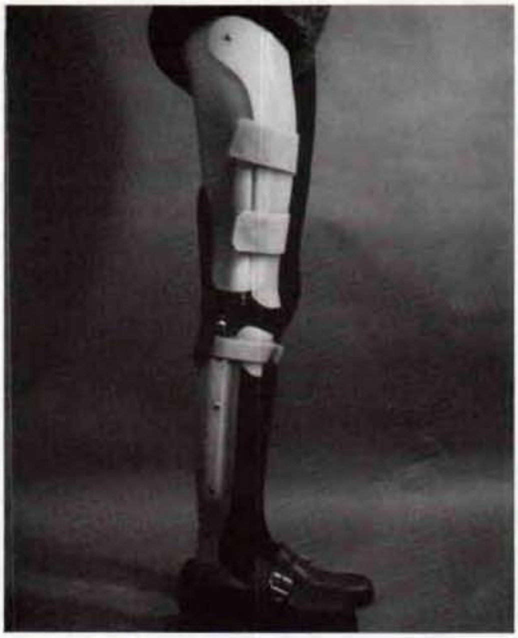

Fig. 14. Molded polypropylene-polyethylene KAFO.

Fractures of the femur have also been managed by the use of the molded KAFO, but the staff at Rancho Los Amigos Hospital (9) has taken a rather unique and somewhat different approach in that they permit full knee and hip flexion while providing full circumferential control (Fig. 15). Total hip control has been provided with thermoplastic pelvic hip femoral devices. Extensive bracing, such as thoracic-hip-knee-ankle-foot orthosis can provide almost complete immobilization of the long bone without adding excessive weight or bulk.

Unique systems are also available for orthotic management of children, by simply modifying the systems developed for adults.

Fig. 15. KAFO used in management of femoral fractures. Pelvic hip femoral orthosis for proximal femoral fracture immobilization.

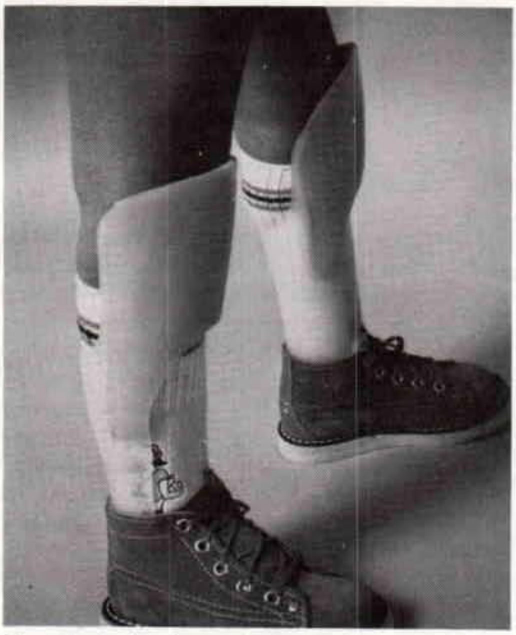

Fig. 16. Ankle-foot orthosis with anterior support used for patients with myodysplasia.

Circumference can be increased easily to accommodate for growth, and if maximum length of the lever arm is provided at the initial fitting, growth of 2 to 3 inches can be accomodated.

The use of molded plastics with children requires close supervision to prevent the occurrence of pressure areas, and the development of deformity may be reduced.

The conventional method of bracing the child that has myelodysplasia is with metal-and-leather in the form of a hip-knee-ankle-foot orthosis (HKAFO). John Glancy (4) has described an alternate method using thermoplastics (Fig. 16). The "solid-ankle" orthosis uses the floor reaction principle to produce a knee extension moment during the stance phase of gait.

Mobility aids for children also fall under the heading of lower-limb orthoses; they are supportive, corrective, and assistive. The child with spina bifida must encounter the same daily life experiences as a normal child in order to have normal psychological growth, but the child with spina bifida requires special care from birth. Systems have been developed by Colin McLaurin, Douglas Hobson, Wally Motloch, and Dwight Driver, (8,12,7) to provide mobility to this class of patients. With these systems (Figs. 17 and 18), the child can be held safely, can sit and learn about his surroundings by use of head and eye movements, sit independently and use his arms and hands, move about and explore, then stand, and for the first time not be required to always look up.

The most recent new approach to bracing has been in the form of functional electrical stimulation (FES) for patients with upper motor neuron disorders (2). Two systems are available: surgically implanted and externally applied (Fig. 19). The fact that the patient's reflex arc is intact enables the peripheral nerves and muscles to receive stimulation. Stimulation is triggered by a foot switch as the heel leaves the ground. The anterior muscles are stimulated, causing dorsiflexion, until heel strike occurs again. Both external and internal systems require considerably more research and development before routine clinical application can be expected. Research is also being con-

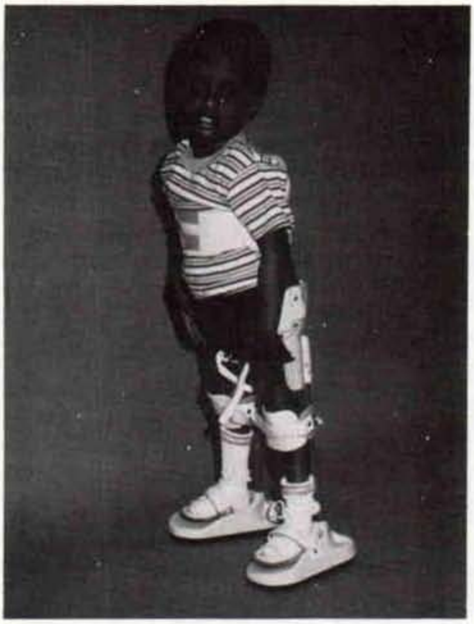

Fig. 17. Memphis Rehabilitation Engineering Center plastic upright positioner orthosis—(PUP).

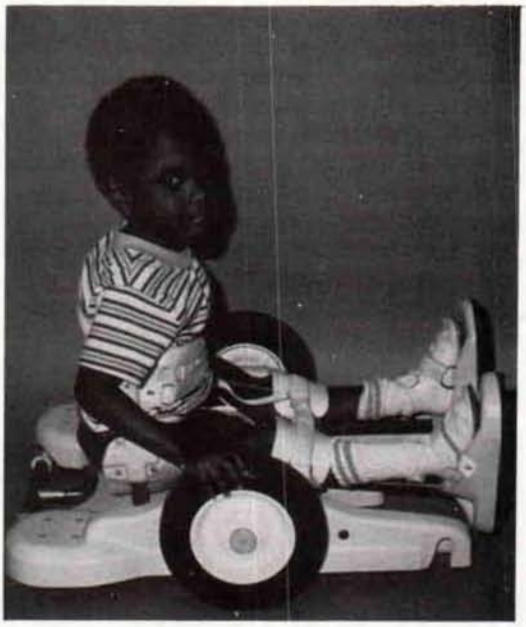

Fig. 18. PUP system with mobility cart.

ducted to assess the effects of FES in conjunction with external orthotic management. Muscle response varies among patients, but appears more effective in the proximal joints and seems to improve overall ambulatory function.

The current decade has been one of tremendous change in the field of orthotics. Methods of patient evaluation have improved, resulting in more accurate detailed description and classification of patients' dysfunction. New materials are becoming available that lend themselves to unique orthotic management. Techniques of fabrication are changing, permitting custom designing of orthotic systems, which may appear simple and uncomplex, but actually require considerable knowledge for prescription development and fabrication. The orthotist of today cannot be just an artisan, skilled at fabrication, but he or she must be knowledgeable in the areas of anatomy physiology, materials, and engineering principles.

Fig. 19. Patient with peroneal functional electrical stimulation device in place. The electrodes in this case are external to the body.

In addition, there must be free and open communication among all members of the clinical team—physicians, surgeons, orthotists, nurses, therapists, engineers, and psychologists. Research dissemination and educational programs are mandatory in order to facilitate the utilization of orthotic systems and techniques. The American Academy of Orthotists and Prosthetists has assumed responsibility for content and administration of continuing education in the United States, not only for the orthotist, but for any member of the clinical team. Practitioners are kept up to date with new techniques, procedures, materials, and systems as they are developed.

The responsibility for education of those who are entering the field of orthotics is left to the universities. It is not the purpose of the university to teach fabrication of every device available, but to develop a basic knowledge of concepts and principles of orthotic management and, through good affiliation programs, round out the students' education. Like all other professions, the orthotist's experience really begins when he or she enters clinical practice and continues throughout the professional career.

Advancement in lower-limb orthotics is dependent not only upon our continuation of research but also on our ability to disseminate and transfer knowledge gained through research to the orthotic practitioner. Without the transfer of information, our research will be of little value.

REFERENCES

1. American Academy of Orthopaedic Surgeons. *Atlas of Orthotics*. St. Louis, The C.V. Mosby Co., 1975.

2. Committee on Prosthetics Research and Development, *Clinical evaluation of the Ljubljana functional electrical peroneal brace*. Report E-7, National Academy of Sciences 1973.

3. Engen, T.J. *Research developments of lower extremity systems for patients with various functional deficits*. Final Report, Project #23-P-55233/6-02. Texas Institute for Rehabilitation and Research, September 1971.

4. Glancy, J., and R.E. Lindseth. *The polypropylene solid-ankle orthosis*. Orthotics and Prosthetics 26(1), March 1972.

5. Lehneis, H.R., Frisina, W., Marx, H.W., and T. Sowell. *Bioengineering design and development of lower extremity orthotic devices*. Final Report, Project #23-P-55029/2-03. Institute of Rehabilitation Medicine, New York University Medical Center, October 1972.

6. Milton, C.L., Jr. *Plastic materials*, In: Orthopedic Appliance Atlas. Vol. 1. J.W. Edwards, Ann Arbor, 1952.

7. Motloch, W.M. *Human needs and orthotic goals for spina bifida patients*. Ortho-pros—. Summer 1975.

8. Ontario Crippled Children's Centre. *Annual report, Orthotic Research Project*. October 1968.

9. Rancho Los Amigos Hospital, Rehabilitation Engineering Center, *Annual report of progress*, December 1975-January 1977.

10. Stills, M. *Thermoformed ankle-foot orthoses*. Orthotics and Prosthetics 29(4):41-51, December 1975.

11. Stills, M. *Vacuum-formed orthoses for fracture of the tibia*. Orthotics and Prosthetics 30(2):43-55, June 1976.

12. University of Tennessee Crippled Children's Hospital School, Rehabilitation Engineering Program. *Activities Report*, September 1974-June 1976.

13. Yates, G. *A method for the provision of light weight aesthetic orthopedic appliances*. Orthopedics: Oxford 1(2): 153-162, 1968.