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AN EXTERNAL-CRUCIATE-LIGAMENT ORTHOSIS[1]

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Orthopaedic surgeons assigned to our regional health care center observed that many patients with internally deranged knees were unable to participate in strenuous athletic activities. We, as orthotists, recognized the validity of their observation and furthermore recognized that bracing knees in the traditional manner is not satisfactory for patients who wish to engage in contact sports. Both the leather, polycentric-knee orthosis and the rotational-control orthosis (Fig. 1) are inadequate to control fore-and-aft displacement of the joint components because the axis or axes of the mechanical knee joints are confined to a single plane. We were challenged to design and construct an orthosis that would guide the knee through a helical arc. We believe we have been successful in fabricating with plastic materials an effective orthosis for the knee which enables patients to engage in athletics. In this paper, the external-cruciate-ligament orthosis (Fig. 2) is described.

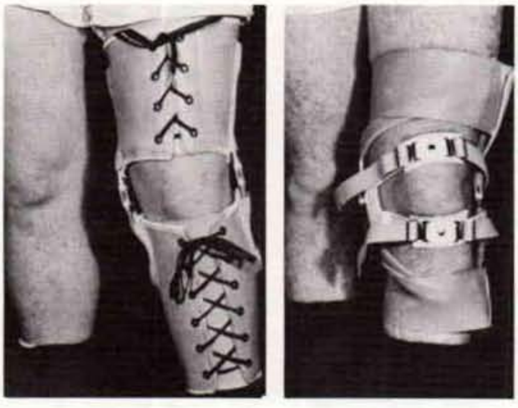

Fig. 1. Contemporary approaches to providing anteroposterior stability to the knee joint. *Left*, knee orthosis with leather cuffs and polycentric joints. *Right*, the "derotation" orthosis.

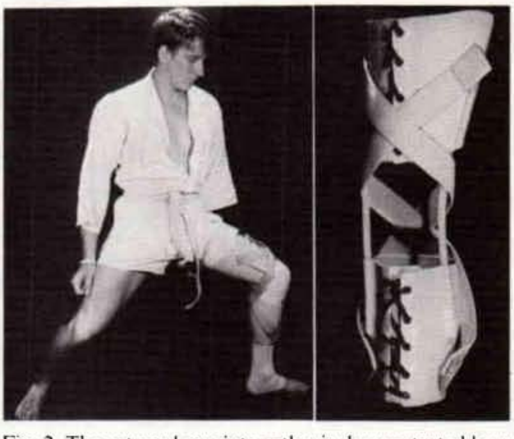

Fig. 2. The external cruciate orthosis demonstrated by a patient who is a student of karate.

ANATOMICAL CONSIDERATIONS

The femoral condyles slide and roll on the tibial condyles as the knee joint is flexed. The amount of sliding and rolling determines the axis of rotation at any given instant. Excessive sliding results in displacement or subluxation fore and aft (Fig. 3). The quadriceps, hamstrings, and the gastrocnemius assist in controlling fore-and-aft displacement, but sound ligaments are essential for absolute control. Fore-and-aft displacement between the condyles imposes tremendous strains upon sound ligaments, tendons, and cartilage. Normally, subluxation is prevented by the anterior and posterior cruciate ligaments and the posterior capsules.

Orthopaedic surgeons at Letterman Army Medical Center (LAMC, 1972–74) are convinced that many severely internally deranged knees are really the result of a two-stage insult. The initial

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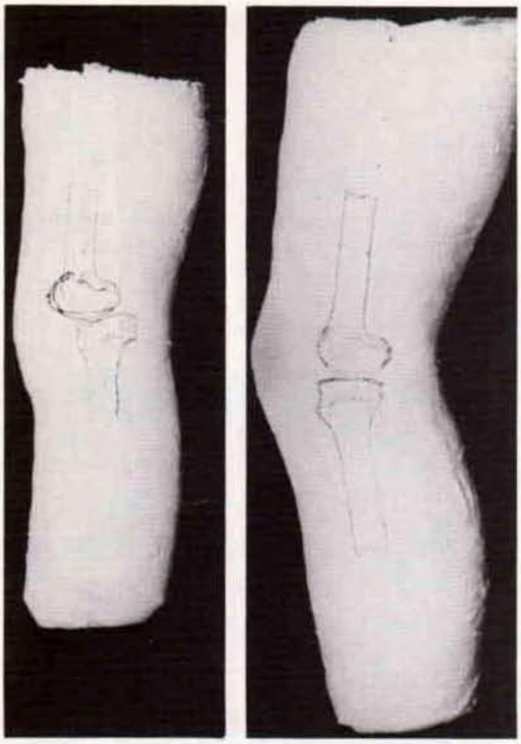

Fig. 3. The cast on the left reflects subluxation of the knee joint, probably resulting from a severed or otherwise damaged posterior cruciate ligament. The cast on the right reflects correct alignment of the tibia and femur.

injury may be a tear of one or both cruciates, followed by a progressive laxity of stabilizing ligaments on the posterior aspects of the knee joint. Continuous or strenuous activities after injury to a cruciate ligament contribute further to laxity of the ligamentous structures surrounding the joint, a condition which contributes to a change in the glidepath of the joint, and compromises the meniscii.

SELECTION OF MATERIALS FOR ORTHOSIS

We proposed that an all-plastic knee orthosis would be desirable and possible. Polypropylene can assume high compressive and tensile loads, and we selected polypropylene rod for use as "knee joints." Polypropylene has been used for fracture bracing, and has been used effectively for a below-knee orthosis; therefore we had good reason to believe that it could lend, in the form of an orthosis, excellent stability to the knee.

On a knee orthosis, the cuffs must be strong enough to carry the loads through to the polypropylene rod and elastic straps. The fit must be snug to ensure that no piston action occurs between the orthosis and the limb. A polyester-resin laminate was an obvious choice of material because it is impervious to water, perspiration, and radical temperature changes. The polyester resin can be mixed to provide a laminate as rigid or flexible as desired. An additional advantage of polyester resins is that they are incompatible with polypropylene, and should one of the rods break it can be replaced easily. Nylon stockinet and fine mesh fiberglass were chosen as the filler materials. Elastic webbing strap was used because it was cheap and available.

EVALUATION OF THE KNEE

Evaluation of the knee before making the plaster wrap is a prerequisite for a well-fitting useful orthosis. The evaluation must reveal: a) the cruciate ligament that is injured and needs support; b) the amount of pressure that is acceptable over the femoral condyles; and c) the activity in which the person expects to participate. Cast modification, the amount of flexibility of the cuffs, and placement of the rods and straps are determined using the results of this evaluation.

FABRICATION

A cotton stockinet is applied over the length of the limb, and a plaster wrap is taken with the patient sitting with the knee in 10 to 15 deg. of flexion. The outline of the patella, the apex of the fibular head, the prominence of the hamstring tendons, and the mediotibial plateau (MTP) are marked. Wrapping is begun from the lower third of the tibia, just superior to the malleolus, to the upper quarter of the thigh (Fig. 4). The first layer of elastic plaster-of-Paris bandage is molded closely to the limb. Two additional layers of standard plaster bandage provide the rigidity necessary. Certain precautions must be taken during wrapping to prevent tibial rotation and subluxation of the knee. When the patient keeps visual contact with the medial border of his foot while the wrap is being taken, excessive tibial rotation is avoided. To minimize subluxation, the knee must be supported during the entire wrapping and plaster-setting procedures. We contend that an accurate wrap, correctly molded, will limit the amount of positive mold modification needed later.

The positive mold is obtained in the traditional manner. We find that the lamination is easier when the pipe and long axis of the wrap are perpendicular to the floor. Preparation of the positive model consists only of removing and smoothing the plaster. Usually, plaster buildups are not

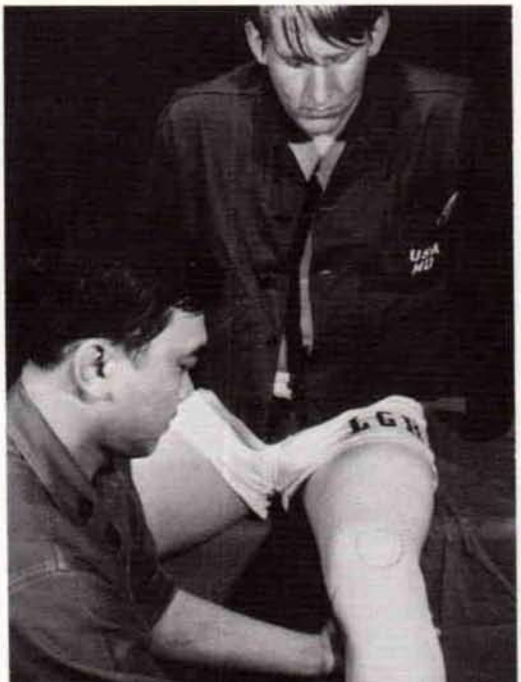

Fig. 4. In wrapping the cast the foot and ankle must be kept in alignment and subluxation must not be permitted to take place. The areas about the tibial flare, the shaft of the fibula, the distal femoral condyles, and the hamstring tendons must be molded closely.

necessary. Radical modifications include the removal of a predetermined amount of plaster above the femoral condyles. The tibial flare is blended to sustain load. The shaft of the fibula is loaded in a manner similar to the lateral stabilization provided in the below-knee prosthesis. The goal of this is not to provide lateral stability, but to provide rotary control of the orthosis against the leg. Posteriorly, the popliteal cavity is exaggerated and blended into the area of hamstring and gastrocnemius muscles. Care must be taken not to modify severely the impressions of the hamstring tendons. The MTP is measured and recorded from either end so it may be found later for definition of the trim line.

After radical modifications have taken place, the stockinet marks are removed from the entire surface of the mold with a Surform file, with the exception of the sensitive areas, i.e., crest of the tibia, tibial tubercle, fibular head, and patellar surface. After the mold has been prepared, its entire surface is then wet-sanded and all traces of stockinet marks are removed.

The materials needed for fabrication of the orthosis are:

1 layer 0.5 oz Dacron felt
5 layers nylon stockinet
2 layers tricot tube
2 strips (3 in.) fine mesh fiberglass
4 polypropylene rods 3/8 in. in diam.

A layer of Dacron felt is applied first, followed by two layers of nylon stockinet. Fiberglass strips are placed at the same location as metal bands would be on a conventional knee orthosis and serve the same purpose. The ends of these strips are rolled around to form "holsters" for the ends of the rods which are placed vertically.

Using the rationale offered by Radcliffe and Foort (*2*) for determination of the correct placement of the side joints on the conventional below-knee prosthesis, we concluded that the rods should be applied slightly posterior to the midaxial line of the knee if the anterior cruciate is to be supported; conversely, the rod is to be placed anterior to the midaxial line if the posterior cruciate ligament is to be supported. The rods and the fiberglass (holsters) are covered with one layer of stockinet (Fig. 5) and one layer of tricot. A separator is applied anteriorly to form a tongue. A second layer of tricot is pulled over the model, and the final two layers of stockinet are applied.

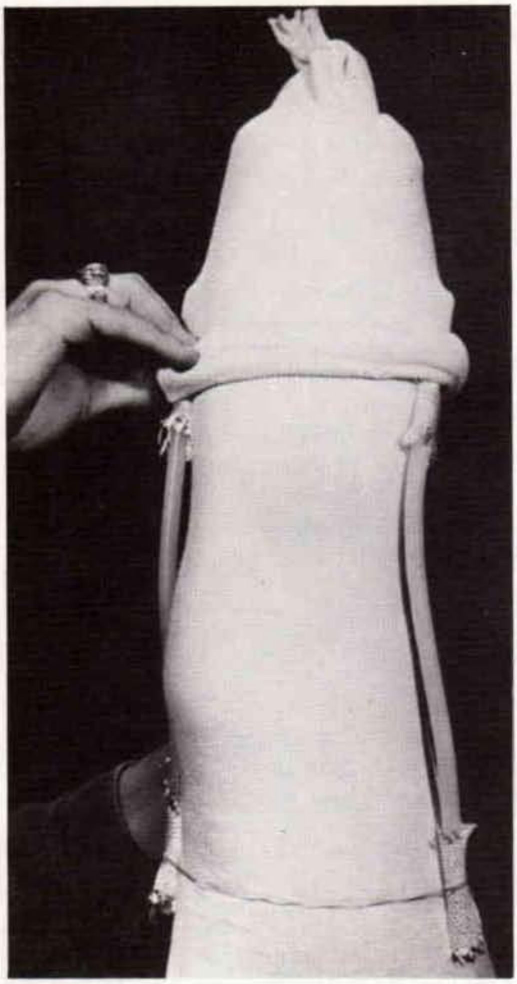

Fig. 5. The polypropylene rods and fiberglass "holsters" are covered with a layer of stockinet, followed by a layer of tricot.

The amount of flexibility selected for the cuff is based upon the activity and objectives of the individual patient. We use a combination of laminating resins, under 10 to 15 lb pressure, to acquire the appropriate rigidity in the orthosis for each patient. We have most frequently used ratios of 75:25 and 80:20 of polyester resin 4134 to polyester resin 4110. We realize that there are differences in the requirements of one who is primarily a motorcyclist and one who is a student of karate. The motorcycle rider's orthosis is flexed and exposed to constant vibration; it should be more rigid than the orthosis worn by the karate student.

When the resin has set up, the laminate is removed from the model, and vertical cuts are made before the horizontal (distal and proximal) circumferential cuts. The initial cut with a sharp knife is made precisely down the middle to the separator. After the entire layup has been cut along its entire length, the required flap is folded back, and another vertical cut is made underneath the flap and through the model (Fig. 6). After the horizontal cuts are made the entire layup is wrapped with an Ace bandage, and the final curing is allowed to take place.

The straps are usually made while the orthosis is curing. Their paths, or routes of travel, are determined by the cruciate ligament that needs to be supported. The "origins" of the straps are

Fig. 6. Vertical cuts are made in the anterior portion of plastic laminate to provide torque for distribution of loads between the cuffs and the soft tissues of the leg and thigh. The first layer is cut directly through the middle. The cut in the second layer, of course, is offset.

distal to the rod ends. One originates on the medial side and one on the lateral side of the leg. The straps spiral around the leg and "insert" on the same side of the limb above the knee. If the anterior cruciate ligament is severed, the straps wind anteriorly from their orgins: conversely, if the posterior ligament is torn, the straps spiral posteriorly. Both ends of the straps should be reinforced with a material such as Naugahyde to prevent fraying. After the resin has cured, the site of the mediotibial plateau is located, transferred circumferentially, and the trim lines drawn on the lamination (Fig. 7). The mediolateral distal trim line of the thigh cuff should be equidistant from the MTP as the mediolateral proximal trim line of the calf cuff. The posterior distal thigh cuff should be equidistant from the posterior proximal calf cuff. The anterior trim lines can be determined proximally at a point 3/4 in. superior to the patella and distally at the apex of the tibial tubercle. The respective points are joined, and trim lines are cut through the plastic, including the polypropylene rods. Attempts to salvage the rods have been unrewarding. The polypropylene must always present a smooth surface because the slightest nick in the material greatly magnifies its fracture potential. An accurate fit is determined and new rods are inserted at the initial fitting.

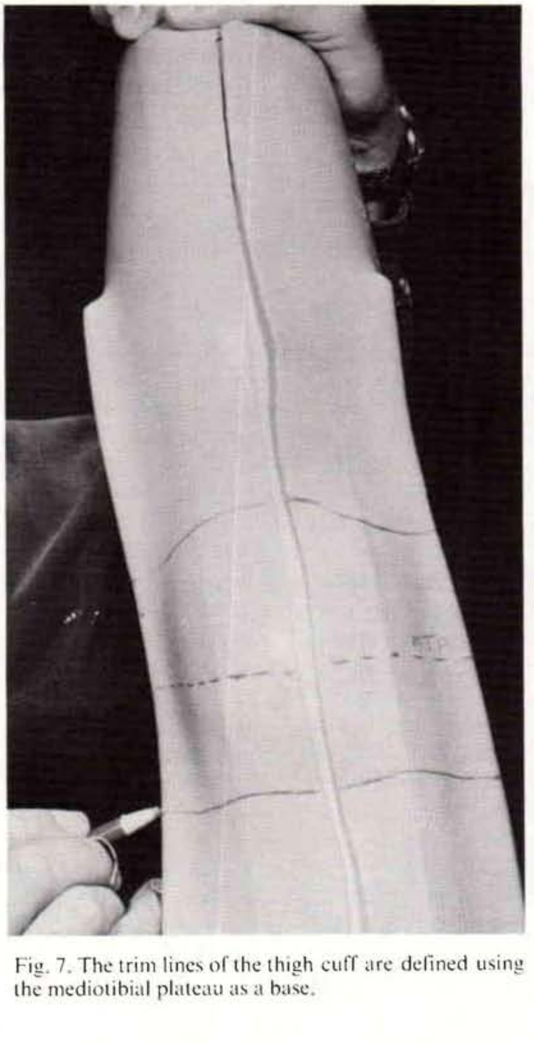

Fig. 7. The trim lines of the thigh cuff are defined using the mediotibial plateau as a base.

At the time of initial fitting we ensure that there is no piston action and that there is ample room for flexion; also, we determine the proximal attachment point for the elastic straps (Fig. 8). We put the orthosis on the leg over a stockinet with the knee in the same degree of flexion as it was during the casting procedure. The orthosis is held in position by applying nylon reinforced tape. The individual is asked to stand and then to sit again. Any indication of piston action must be

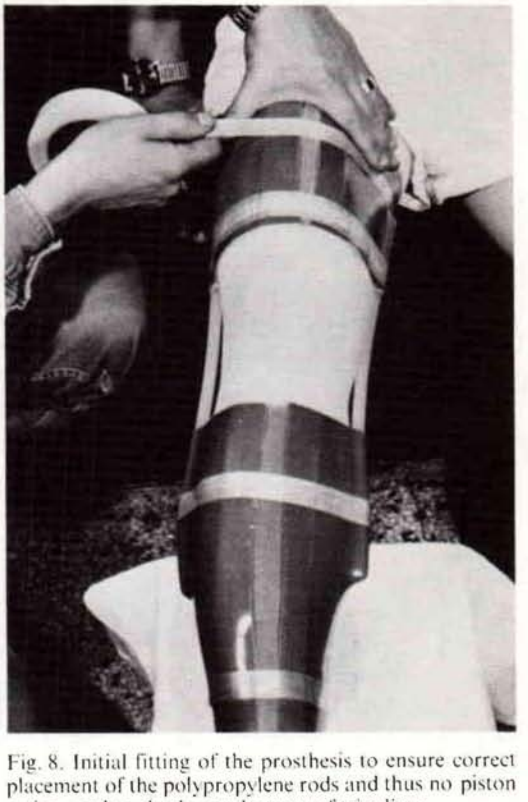

Fig. 8. Initial fitting of the prosthesis to ensure correct placement of the polypropylene rods and thus no piston action, and to check on adequacy of trim lines.

eliminated either by tightening the closure with tape or retrimming the periphery of the orthosis at the knee joint. If the patient can flex his leg to 90 deg. while sitting, it has been our experience that acceptable trim lines have been made and enough rod is exposed. *This is a dynamic orthosis, and to impede other motion or to require an excessive amount of energy to flex the knee is contrary to its design and principle.* The proximal attachment points are determined by the amount of tension needed for each individual. When the amount of elasticity has been determined, patellar-tendon-bearing (PTB) studs are inserted into the cuffs and the initial fitting is concluded (Fig. 9).

Fig. 9. Determination of the location of the elastic straps. The "origins" are distal to the calf end of the rods and the "insertions" are proximal to the thigh end of the rods. The path is determined by the nature of the injury.

EXPERIENCE

During the two-year period that we have fabricated the external-cruciate orthosis, we have fitted 32 patients, the age range being 19–82 yr., the weight range, 120–220 lb., and the height range, 5 ft. 2 in.–6 ft. 4 in. One patient was unsuccessful, probably because he was a victim of multiple combat-inflicted injuries which included brain damage, and he has not been able to cooperate in a therapeutic regimen. Ten patients were lost to follow-up evaluations. Table 1 shows the length of time 15 patients wore the orthosis and their ages. There are two women in the group, and the 68-year-old woman is the only patient on whom we have fitted the orthosis bilaterally. The six patients not listed in the table paralleled the picture of the typical candidate—a man in his middle 20s, who has an old knee injury from repeated trauma sustained in intramural or varsity sports; he wishes to continue participation in "backyard" activities, individual sports, and is on active duty with the Army.

CONCLUSIONS

Our orthosis is designed for active people—persons who want to continue to participate in a sport even though stability of the knee has been compromised by a previous injury. Failures have not occurred because of cold, wetness, rotational shearing, or sudden temperature changes while wearing this orthosis.

The experience in designing and fabricating the external-cruciate-ligament orthosis emphasizes the importance of fore-and-aft subluxation of the knee. It also has shown that orthotists can provide a supportive appliance made from plastic materials which will *stabilize* effectively a deranged knee so that an athlete may continue to participate in active sports.

We want to reassert our total agreement with Thorkild Engen (*1*) who suggested at an Academy seminar in 1972 that old concepts, traditional rationale, and historical conclusions must be reevaluated by orthotists when using plastics in fabrication of appliances. The external-cruciate-ligament orthosis made from polypropylene meets the standards of our profession and the needs of those with deranged knees who wish to participate in sports.

TABLE 1. SUMMARY OF PATIENTS WHO ARE WEARING THE EXTERNAL CRUCIATE ORTHOSIS

Case No.	Age	Cause of Injury	Extent of Injury	Comment
1	30	Trauma	Posterior cruciate	First patient to use external cruciate orthosis (ECO): active-duty Army doctor who wears ECO for jogging and softball. Has used ECO over two years.
2	30	Trauma; surgery	Posterior cruciate and other internal weakness	Active-duty military policeman who uses ECO primarily while participating in company athletics (practice and competition).
3	22	Trauma from participation in sports; Surgery	Posterior cruciate and other internal damage	Active-duty soldier, 6 ft. 4 in. 220 lb., who uses ECO primarily for skiing, tennis, and team sports.
4	24	Trauma	Posterior cruciate	Wears ECO primarily while playing his favorite sport—handball.
5	45	Old injury; repeated trauma	Posterior and anterior cruciate ligaments	Active-duty physician; sports participant, primarily wears ECO while playing tennis.
6	23	Trauma	Medical meniscus tear with posterior cruciate injury	Active-duty Army nurse (woman) who wears ECO primarily while skiing.
7	68	Arthritis	No patellae; joint deterioration; spurs; generalized muscle and ligamentous weakness	Woman, bilateral ECOs; one ECO is primarily for support; wears ECOs every day for all activities. Has Velcro enclosures because of arthritic hands.
8	28	Trauma from varsity football	Posterior cruciate, mediolateral instability	Lawyer, 6 ft. 3 in. who continues to participate in sports—basketball, tennis, skiing.
9	19	Trauma; surgery	Posterior cruciate	Karate participant and wears ECO during this activity.
10	27	Trauma	Anterior cruciate; excessive hyperextension	Uses ECO for sports participation, particularly basketball. Because of excessive hyperextension, an extra strap has been added posteriorly.
11	35	Trauma; surgery	Anterior and posterior cruciate ligaments; patellectomy with patellar prosthesis; hyperextension	By wearing ECO, he is able to stay on active duty as a air-traffic controller.
12	28	Trauma	Posterior cruciate; mediolateral instability	Uses ECO to ski and play handball; active-duty physician stationed in another country.
13	25	Trauma from collegiate football participation; surgery	Posterior and anterior cruciate ligaments; (medial compartment surgically reconstructed)	Uses ECO while skiing and playing softball; alternates with derotation orthosis to see which is more effective.
14	23	Trauma	Posterior, anterior and collateral ligaments	Used ECO originally for karate, but has strengthened quadriceps muscles sufficiently so that he only uses ECO while skiing.
15	82	Arthritis and trauma	Fracture distal femur; mediolateral instability; hyperextension	Uses ECO in order to stand; wears it over a fracture-brace stockinette; hyperextension strap works well.

ACKNOWLEDGMENTS

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