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# The Northwestern University Knee Orthotic System Part II: The Complete Orthosis

**Michael Schafer, M.D.**
**James Russ, C.O.**
**Carl M. Patrnchak, R.P.T., C.O.**
**Richard Tarr, M.S.**

## INTRODUCTION

When an orthosis is applied to the knee, it should, hypothetically, allow a full, unrestricted range of motion, except at limits where orthotic constraints are intentionally introduced. This ideal situation is limited by the type of orthotic joints incorporated into knee orthoses. When using orthotic knee joints which are unable to follow the motion pathways of the natural joint, a tighter fitting interface will magnify the pistoning constraint. This is due to the motion mismatch between the orthotic and natural joint and will cause patient discomfort, motion restriction, and misalignment of the orthosis.[2]

A new orthotic knee joint system was described (as Part I of this report), which decreased the pistoning effect by allowing the orthotic joints to more closely imitate the natural knee kinematics.[2] These semi-constrained, anatomically-shaped joints allow improvements in orthotic suspension, since a tighter fitting orthosis with these joints will not increase the pistoning constraint.

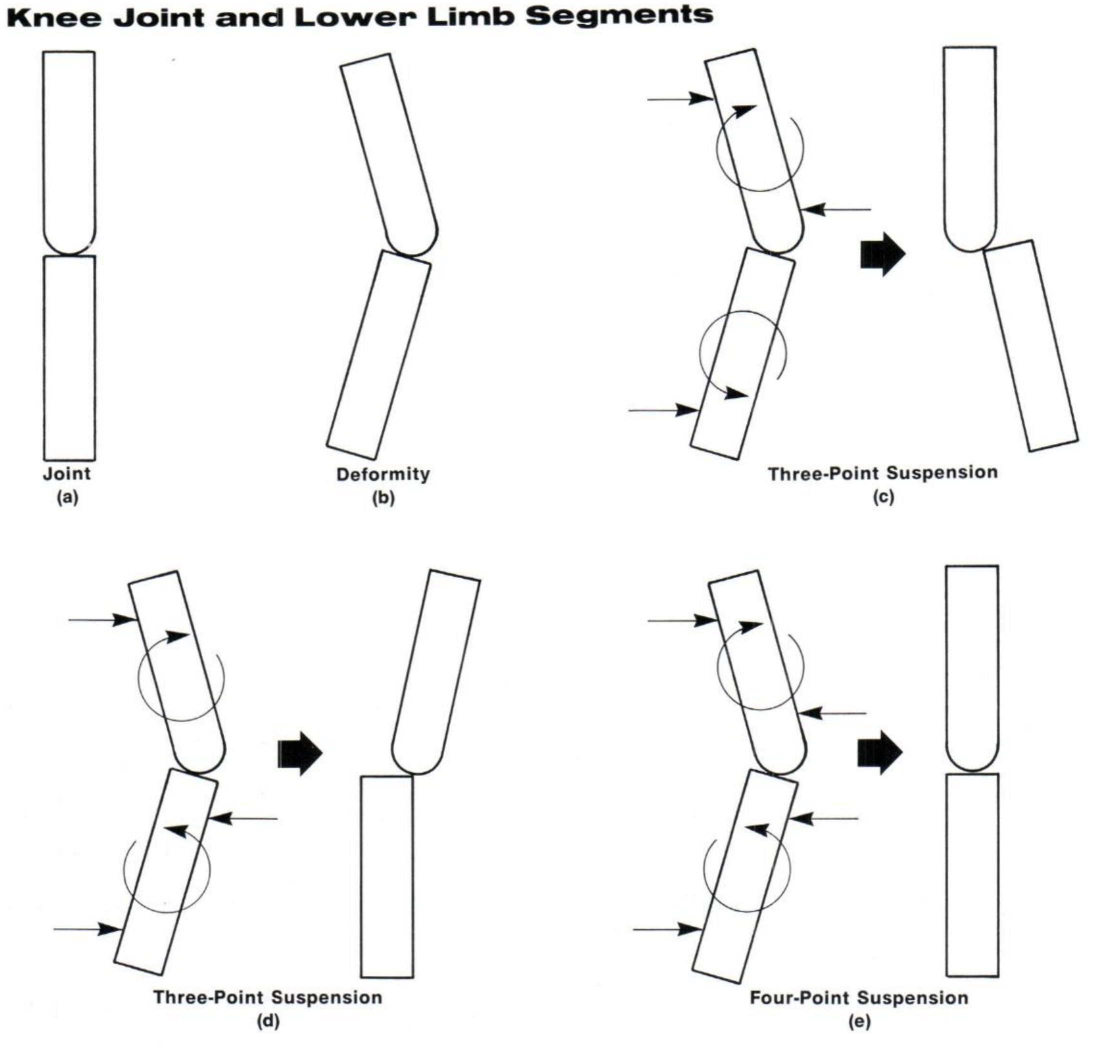
A second requirement for a knee orthosis is that the orthotic interface should be designed to complement the function of the orthotic joints. This interface should be capable of being modified to handle particular knee instability problems.

This report contains a description of a knee orthosis incorporating an improved orthotic joint design, its biomechanical rationale, significant features of the fabrication and fitting process, and a description of several case studies.

## BIOMECHANICS OF KNEE ORTHOSIS SUSPENSION

A basic feature of the proposed orthosis is the use of a "four-point" suspension principle rather than "three-point" fixation, as is commonly practiced in orthotics. Three-point support is suitable for stabilizing a joint when ligamentous integrity exists as a constraint across the joint. Three-point suspension is inadequate with a ligamentous deficit, which is frequently the indication requiring the application of a knee orthosis.

The limitation of the three-point fixation system in the unstable knee is demonstrated in Figures 1-A through 1-D. When




**Figures 1-A–1-E. Sketches representing the knee joint and lower limb segments: (A) with a deformity; (B) showing the effect of a "three-point"; (C, D) a "four-point"; (E) orthotic suspension.**

suspension forces are applied to a joint (Figure 1-A) with a deformity (Figure 1-B), the functional forces, and the moments they create, will tend to bend and shear the joint. With three-point support (Figures 1-C and 1-D), one segment of the limb can be held in place at any one instant; however, only one force remains to support the second bony segment. Even though the point of application of this force may remain fixed, the limb segment can rotate about the single support point, causing a shearing or displacement motion at the joint, which is the very motion that is to be prevented. By contrast, as shown in Figure 1-E, a four-point fixation system will allow two suspension points on each limb segment, thus controlling and preventing motion of both segments.

The orthotic interface components and

Figure 2-A. Anterior view of a representative NuKO derotational knee orthosis.

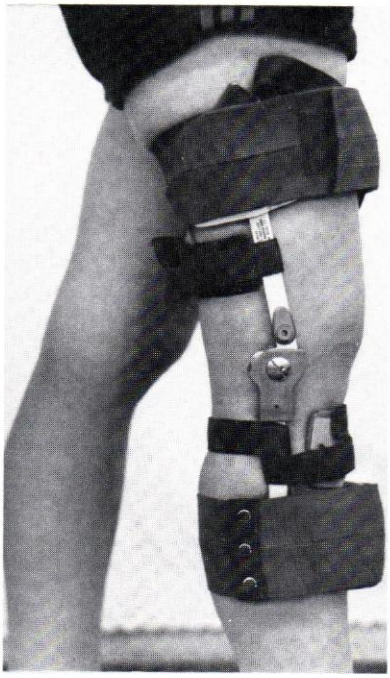


Figure 2-B. Lateral view.

Figure 2-C. Posterior view.

Figure 2-D. Medial view.

strapping arrangement should be such that, given an instability direction (such as varus, valgus, anterior or posterior drawer, or rotation), they are capable of being altered to apply the four forces and resulting moments necessary to provide stability or correct a deformity, while still controlling motion at the joint.

## SIGNIFICANT FABRICATION FEATURES

If a standard plaster negative impression is taken on the patient's lower limb, then as the plaster sets, apply constant pressure to the medial femoral supracondylar region. This is done so that the impression retains an accurate description of the individual's anatomy in this area. An accurate impression of the medial tibial flair region should also be obtained. A positive plaster impression is then made and modified. Emphasis is given to the parallel buildups on both sides of the knee, to ensure that orthotic joints are parallel to each other and perpendicular to the joint space. Sidebars containing the orthotic joint designs are contoured to the positive plaster impression, so that the joint space of each orthotic joint is located at the level of the natural joint space, midway in the anterior-posterior plane of the knee. In the completed orthosis, the orthotic joints are positioned as closely as possible to the natural knee joint. Proximal and distal interface components are fabricated by vacuum-forming a thermoplastic material over the positive plaster impression. In this process, the orthotic joint sidebars are mechanically thermobonded to the interface, which is itself composed of two layers of thermoplastic thermobond. Using the medial femoral supracondylar depression on the positive plaster impression, an adjustable swivel medial femoral suspension pad is fashioned and is securely attached to the proximal medial joint sidebar.

Figures 2-A through 2-D present the four views of a completed derotational orthosis with an NU orthotic joint. The joint sidebars are attached to the proximal and distal interface components, which are in turn circumferentially suspended in the thigh and calf regions by broad straps. To insure adequate fixation of the orthosis, the interface components are accompanied by a swivel medial femoral suspension pad and a proximal tibial suspension pad, each with its own associated strapping arrangement.

## COMMON FITTING MODIFICATIONS

Several modifications of the previously described interface components can be easily made at the time of fitting. The pressure from the medial femoral suspension pad can be increased or decreased depending upon the individual's musculature in this region. The copolymer thermoplastic of the proximal and distal interface components can be easily heated and flaired away from problem pressure areas. The plastic can also be conveniently ground away for comfort considerations. However, the fit of the knee orthosis should remain extremely intimate, as the system was designed to be worn directly against the skin. Given the fact that the improved orthotic joints minimize the pistoning constraint, tightly fitting interface components insure a functionally efficient and reliable knee orthosis system. At the same time, they provide for patient comfort and a cosmetically acceptable device.

The NuKO rehabilitative knee orthosis is intended to provide stability during the period between the plaster fracture orthosis and a definitive knee orthosis. As shown in Figure 10, the NuKO rehabilitative knee orthosis is fabricated with flexible linear low density polyethylene, in a number of sizes, and is more flexible than the NuKO derotational orthosis. This type of orthosis is used in situations (post-surgical or post-injury) in which the lower limb musculature has atrophied, and when the patient will subsequently undergo physical therapy. During this time, the lower limb musculature will increase in volume with therapy, thus making it impractical to fabricate several different "definitive" orthoses during this relatively brief period. Instead, the NuKO rehabilitative orthosis is easily, inexpensively, and reliably applied throughout the period of muscle volume changes. The patient is finally fit with the definitive orthosis only when the lower limb has stabilized in volume and shape.

## INTERFACE SUSPENSION IMPROVEMENTS IN THE NU ORTHOTIC SYSTEM

A common problem which occurs with knee orthoses, is distal slippage during function. To provide additional resistance against slipping, the adjustable suspension pad in the medial femoral supracondylar region is incorporated (Figure 3-A). This particular pad is made from a copolymer plastic, an adjustable screw, and foam. The amount of pressure from the medial femoral pad can be varied by turning the adjustment screw clockwise for more pressure or counterclockwise for less

**Figure 3-A. Inside view of the medial femoral suspension pad. Note the thin layer of padding covering the floating pad.**

**Figure 3-B. Outside view of the medial femoral suspension pad and associated straps. Note the floating pad attaches to the medial sidebar and the straps to the lateral thigh interface.**

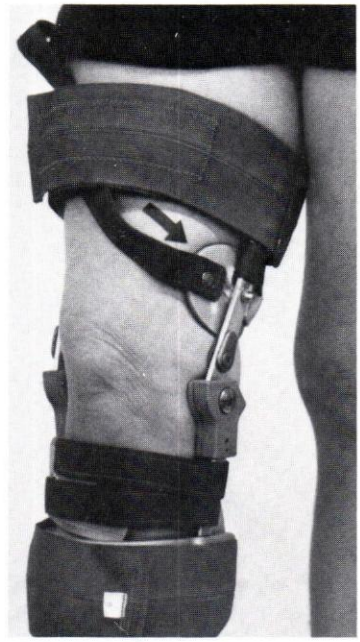


**Figure 3-C. Medial femoral pad engages the medial femoral supracondylar region.**

pressure depending upon the clinical situation. For example, given a patient with associated muscle atrophy, weight or volume loss, or muscle hypertrophy, the depth of the pad can be adjusted accordingly.

Figures 3-B and 3-C show the medial femoral suspension pad securely attached to the inner surface of the medial orthotic joint sidebar. To insure that the medial femoral pad is securely placed against the femur, two straps, of which the origin is on the outer surface of the medial femoral pad, encircle the thigh anteriorly and posteriorly reattach laterally over the broad plastic of the proximal interface (Figures 3-D and 3-E). Tightening this strap pulls the thigh (medial femoral supracondylar region) against the medial femoral suspension pad (Figure 3-E). The forces generated by this pad and strap assure fixation of the orthosis to the patient leg.

## Proximal and Distal Interface Components

Proximal and distal interface components have been designed based on the following criteria. They are:

- rigid and strong enough to withstand repeated functional loads, or correct and hold a deformity;
- lightweight;
- unobtrusive and cosmetically acceptable;
- comfortable; and
- can be modified to generate different combinations of four-point suspension forces.

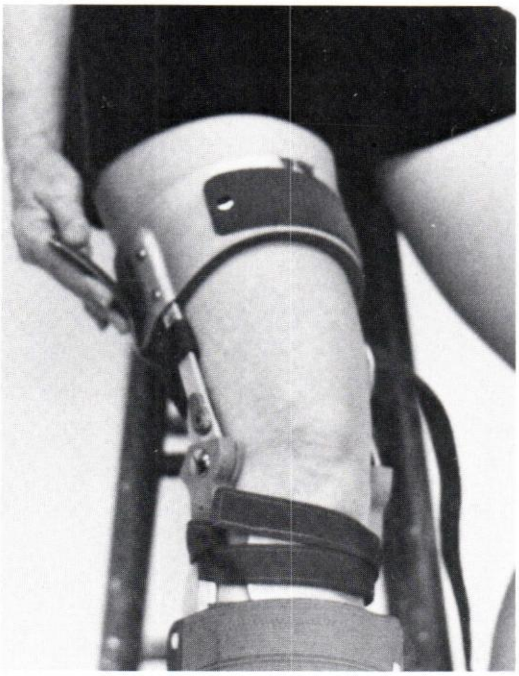


**Figure 3-D. Strapping for the medial femoral pad begins with the posterior gray strap attaching to the lateral thigh band, pulling the pad against the medial femoral condyle.**

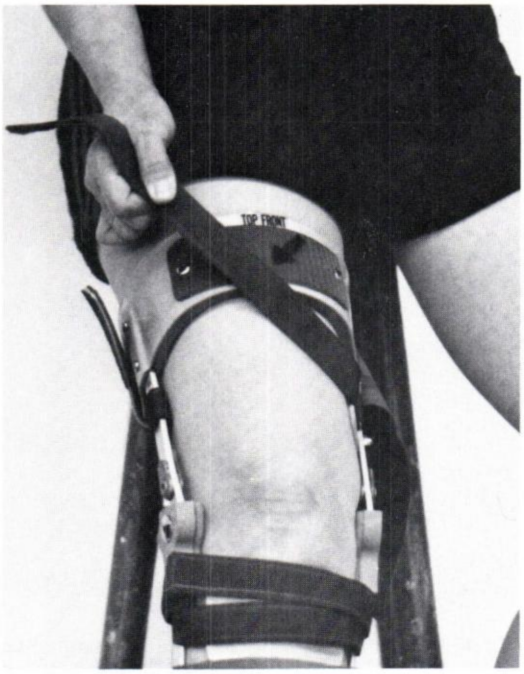


**Figure 3-E. Completed strapping arrangement for the medial femoral suspension pad.**

The proximal and distal interface components of the NuKO derotational knee orthosis are manufactured from a copolymer, with a composition of 10% polyethylene and 90% polypropylene. This material is also used in the automotive industry for such applications as fenders and rocker panels. For the orthosis, this material is lightweight and has high impact resistance. A completed orthosis using this copolymer weighs approximately one pound.

The NuKO derotational knee orthosis is a posterior opening design (Figures 2-A through 2-D). The proximal and distal interface components are constructed by vacuum-forming two layers of thermoplastic over the positive plaster impression, providing a rigid interface along with a method of mechanically attaching the orthotic sidebars (Figure 2-D). The interface components are suspended circumferentially in the thigh and calf regions by broad straps composed of Micro-splint™. Micro-splint™ is a semi-elastic breatheable material that offers maximal fixation of the orthosis to the patient's leg. The straps originate just posterior to the thermo-bonded sidebars, encircle the limb, and attach again via Velcro® strips on the anterior surfaces of the proximal and distal components. The plastic and strapping arrangement provides a secure rigid interface. Yet, because of the strapping, the components can accommodate the volume changes of the lower limb musculature during activities.

## Anterior Tibial Suspension Pad

The anterior tibial suspension pad is fabricated from a linear low density polyethylene to obtain rigid fixation over the crest of the tibia. This feature provides the

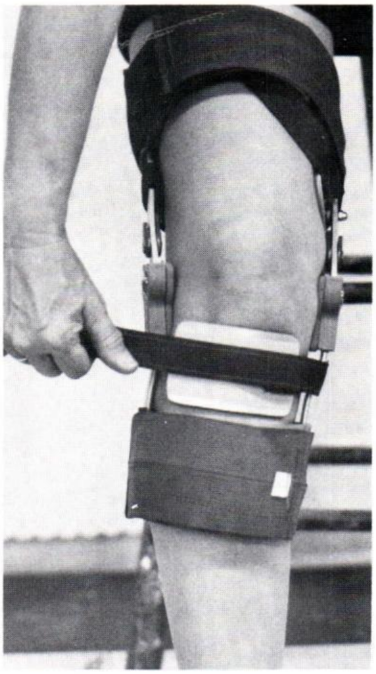


**Figure 4-A. The anterior tibial plate is centered and wrapped around the medial sidebar and back onto its contact closure.**

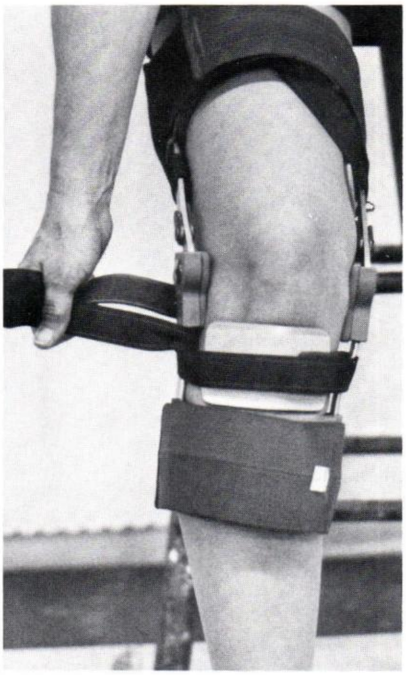


**Figure 4-B. The tibial strap passes laterally around the lateral sidebar and continues posteriorly around the calf.**

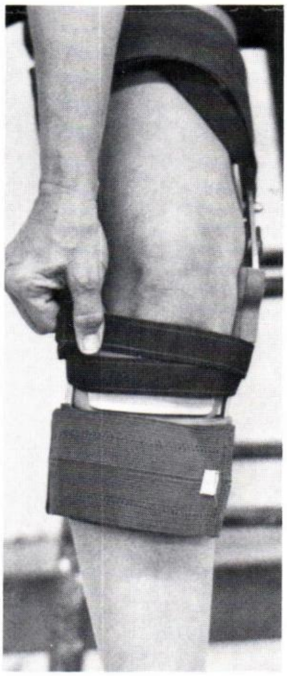


**Figure 4-wc. The tibial strap continues anteriorly under the medial sidebar and onto the tibial plate's contact closure.**

derotational component of the NuKO knee orthosis. With this anterior tibial suspension pad, strapping arrangements for anterior-lateral, anterior-medial, and posterior rotary instabilities can be protected.

Strapping sequence for anterior-lateral rotary instability is as follows:

1. Wrap the tibial plate strap around the medial sidebar with the tibial plate centered on the tibia (the tibial plate may be cold formed by hand to fit the tibia) (Figure 4-A).
2. Bring the strap across the top of the tibial plate securing its position on the Velcro® contact area (Figure 4-A).
3. Wrap the strap around the lateral sidebar (coming off distally) away from the popitial area and continue posterior around the calf (Figure 4-B).
4. Pass the strap under the medial sidebar and continue anteriorly across the lower portion of the tibial plate Velcro® contact area. Tightness is crucial here for derotational control. This strapping mechanism should be as tight as possible based on patient comfort and pressure tolerance (Figure 4-C).

The proposed force system generated by the proximal tibial pad and strap arrangement is shown on the cross sectional sketches in 5-A and 5-B.

In the strapping arrangement just described, tightening the strap would force the tibia posteriorly and promote external rotation (Figure 5-A). This arrangement would be used to restrain a knee with an antero-lateral rotary instability (anterior cruciate plus lateral collateral and/or lateral capsular insufficiency). Note that in the case of antero-medial rotary instabilities, the anterior tibial pad strap is applied in the same way as described above, the only difference being the pad is initially secured

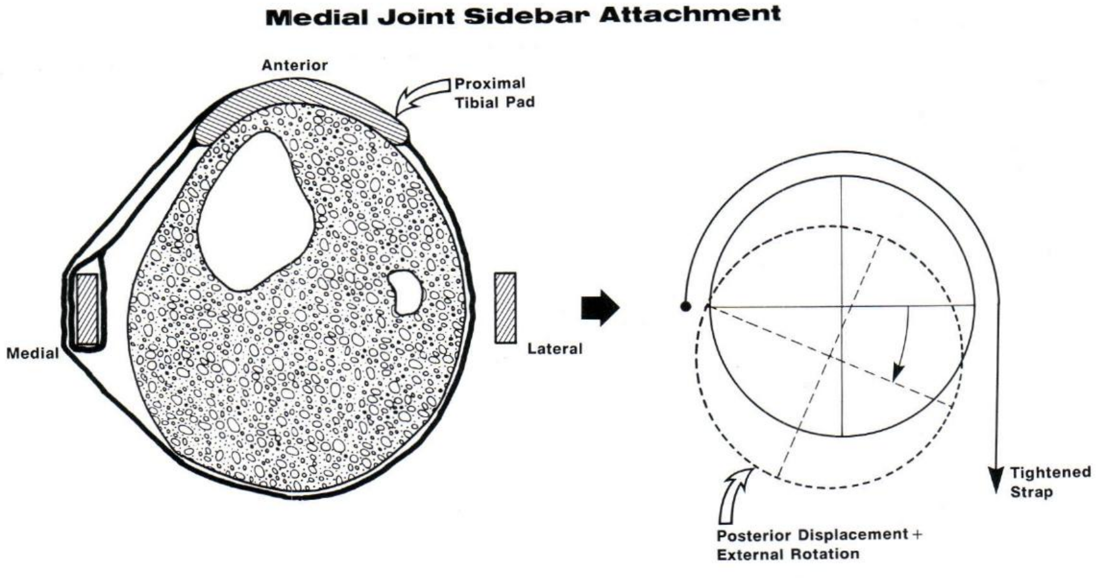



Figure 5-A. If the proximal tibial pad is attached to the medial orthotic joint sidebar, tightening the upper strap displaces the tibia posteriorly and rotates it externally.

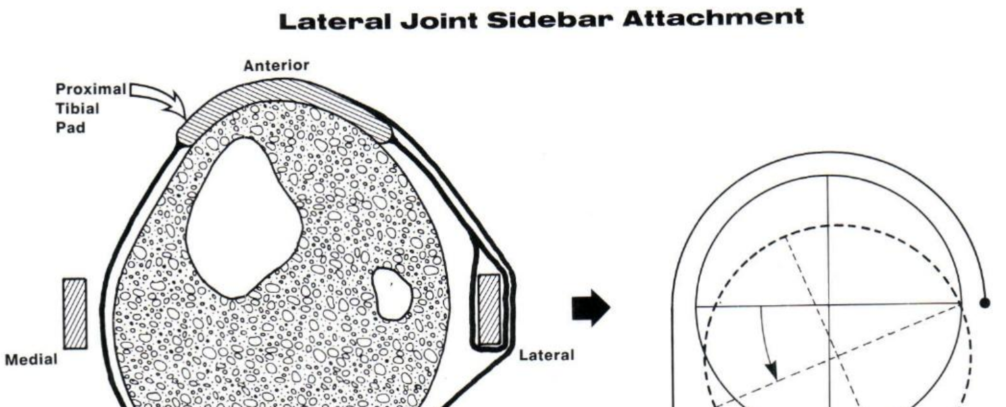



Figure 5-B. If the proximal tibial pad is attached to the lateral joint sidebar, tightening the upper strap which encircles the calf itself displaces the tibia posteriorly and rotates it internally.

to the lateral rather than the medial joint sidebar (Figure 5-B).

The proximal tibial pad also interacts with the other suspension components to provide knee stability. When an orthosis is placed on a knee with the objective of reducing anterior displacement of the tibia, the proximal tibia pad is placed anteriorly (Figures 4-A through 4-E). The four-point suspension forces generated by the orthosis are shown by the sketch in Figure 6-A. When combined with the anteriorly-directed force of the distal interface component, the posteriorly-directed force of the proximal tibial pad creates a moment which forces the tibia posteriorly, as well as straightens the tibia. This prevents it from pivoting about the distal interface component. An anteriorly-directed force of the proximal interface components combines with the posteriorly-directed force of the medial femoral suspension pad (with its strap encircling the thigh anteriorly, thereby forcing the thigh posteriorly) to create a moment controlling motion proximal to the joint. Thus, the above four forces limit the anterior displacement of the tibia and help control the motion at the joint.

If the orthotic objective was to control posterior subluxation at the knee, the proximal tibial pad can be placed posteriorly as demonstrated in Figure 6-B. The sketch shows that the anteriorly-directed force of the proximal tibial pad combines with the posteriorly-directed force of the distal interface component to create a moment which straightens the tibia and forces it anteriorly. The posteriorly-directed force of the proximal interface component combines with the medial femoral pad's anteriorly-directed force (obtained by this strap encircling the thigh posteriorly), controlling the motion proximal to the joint. Thus, the above four forces limit the posterior displacement of the tibia and help control the motion at the joint.

## CASE STUDIES

### Case #1

A 22 year old female collegiate basketball player sustained an acute injury to the anterior cruciate and medial collateral ligaments of her left knee (Figure 7). She underwent arthrotomy which included a medial collateral ligament repair, a pes anserinus transfer, and a medial menisectomy. She was evaluated 9 months post-surgery for knee instability symptoms. Her affected knee exhibited anterior laxity, an antero-medial rotatory instability, and a valgus deformity, but had a negative pivot shift test. The orthotic goal in this case was to stabilize the chronically unstable knee resulting from her injury.

The patient was fit with an NuKO derotational orthosis. In the sagittal plane, the interface components and strapping resisted the anterior displacement of the tibia by generating the four-point suspension forces (Figure 6-A). Since an antero-medial rotatory instability was present, the anterior tibial suspension pad was attached to the lateral orthotic sidebar, similar to that shown in Figure 5-A. Tightening the anterior tibial pad strap pre-positioned the tibia in internal rotation, while limiting the antero-medial instability. After being fit with the orthosis, the patient was able to resume vigorous athletic activity, including basketball while wearing the orthosis.

### Case #2

A 20 year old male, who played basketball for a local university, injured his right knee when he went up for a rebound, and came down off-balance while simultaneously being hit by another player. Examination revealed an antero-lateral rotatory instability, with a possible anterior cruciate injury. The patient was initially treated with two weeks in a knee immobilizer and then sent back to full pre-injury activity.

Subsequently the patient reinjured the same knee, this time sustaining a partial tear of the medial collateral and anterior cruciate ligaments. He was put in a long leg cast for two weeks, then was fit with a NuKO rehabilitative knee orthosis (Figure 10). Following rehabilitation, the patient was fit with the NuKO derotational knee orthosis shown in the sequence of pictures in Figures 8-A–C. The construction of this orthosis is identical to the first case, except for anterior-lateral instability strapping.

**Four-Point Suspension Forces with Anterior Tibial Pad Placed Posteriorly**

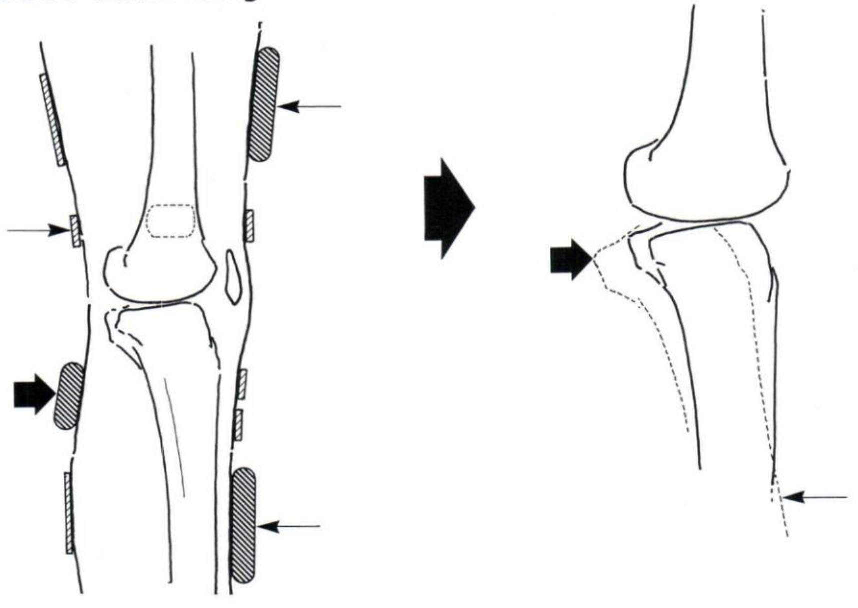


Figure 6-A. Four-point suspension forces generated by the orthosis to control anterior subluxation of the tibia. Note the anterior position and subsequent posteriorly-directed force of the proximal tibial pad.

**Four-Point Suspension Forces with Anterior Tibial Pad Placed Anteriorly**

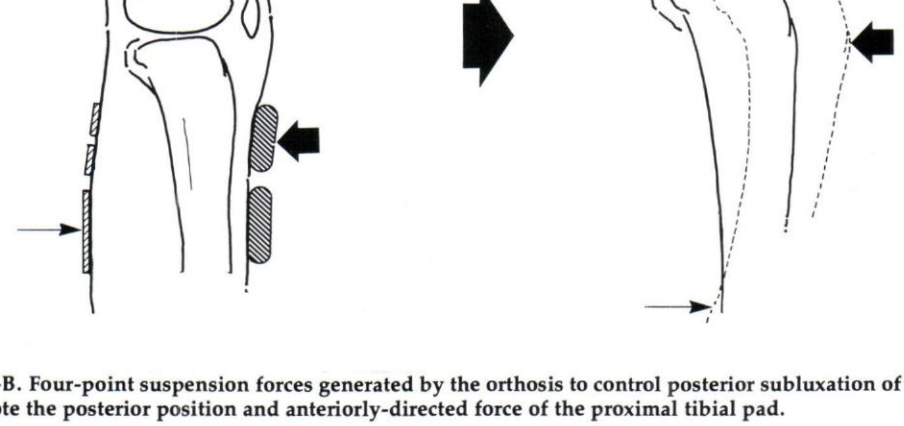


Figure 6-B. Four-point suspension forces generated by the orthosis to control posterior subluxation of the tibia. Note the posterior position and anteriorly-directed force of the proximal tibial pad.

Figure 7. An orthosis for the patient in Case Study #1, providing correction for her antero-medial rotatory instability.

## Case #3

A 15 year old female sustained a torn left posterior cruciate ligament from a "dashboard injury" during an automobile accident. The torn posterior cruciate was surgically repaired by a modified Jones procedure.

The patient also developed a large pressure sore on her mid-posterior calf from a postoperative cast. The orthotic objective in this case was to prevent knee motions and loads which would disrupt the posterior cruciate repair, while still allowing the patient to undergo a physical therapy program.

The patient was initially placed in an NuKO rehabilitative knee orthosis with the posterior cruciate instability strapping set up (Figure 9). The NuKO rehabilitative knee orthosis allowed the patient to complete a physical therapy program, rebuilding her lower limb musculature, and provided stability during normal walking. The orthosis was initially fit so as not to impinge upon the pressure sore region, allowing it to heal rapidly.

Figure 8-A. Anterior view for anterior and medial instability.

Figure 8-B. Lateral view.

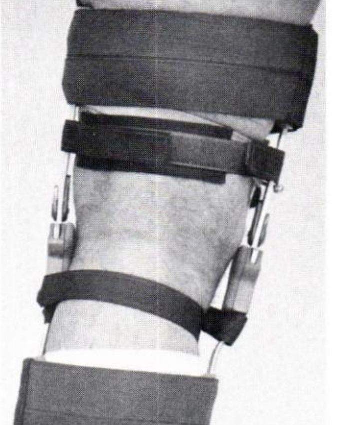


Figure 8-C. Posterior view.

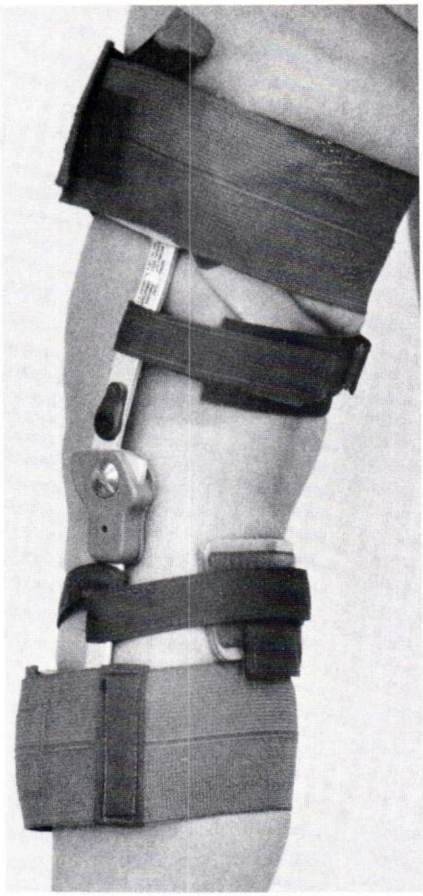


Figure 9. Posterior cruciate design for the patient in Case Study #3. Note the posterior position of the proximal tibial suspension pad. The four-point suspension in this case is the same as in the sketch of Figure 6-B.

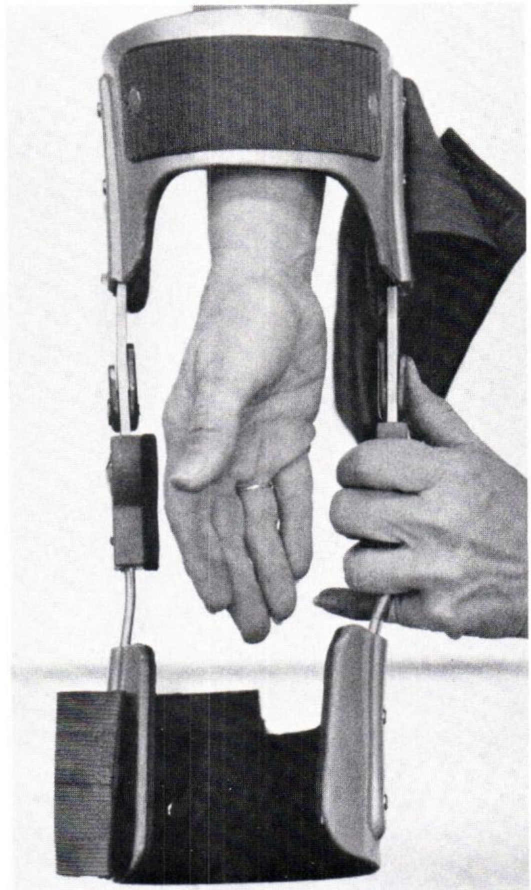


Figure 10. A typical rehabilitation orthosis design using linear low density polyethylene incorporating NuKO knee joints and an anteriorly placed tibial pad.

Four months postoperatively, as the patient's muscle volume increased to near normal, she was fit with an NuKO derotational posterior cruciate control knee orthosis. The NuKO derotational knee orthosis was used in conjunction with posterior placement of the proximal tibial pad and normal posterior-opening of the proximal and distal interface components. The patient was soon able to resume daily activities while the ligament repair continued to heal.

## Case #4

A 21 year old male sustained a hyperextension injury to both knees. Examination of his left knee revealed a fracture of the medial tibial plateau, and an antero-lateral rotatory instability. His right knee exhibited both antero-lateral and postero-lateral rotatory instabilities. Since the patient also presented a marked posterior instability, a special posterior tibial pad was used in conjunction with an anteriorly placed anterior tibial pad (Figures 11-A and 11-B).

The patient underwent surgery, having a partial medial menisectomy of his right knee, as well as a repair to the anterior cru-

**Figure 11-A. Anterior view NuKO derotational.**

**Figure 11-B. Medial view of NuKO derotational showing construction for both anterior and posterior instability.**

ciate ligament and postero-lateral capsule of the same knee. The orthotic objective for his right knee was to prevent the repaired structures from becoming overloaded. The anterior and posterior tibial pads kept the knee in its neutral anterior-posterior position during flexion/extension and allowed the repaired tissue to remain unloaded. The anterior tibial pad was attached to the medial orthotic sidebar, restraining the anterior lateral instability as shown in Figure 5-A. The patient also eventually received an NuKO derotational knee orthosis to provide restraint for chronic antero-lateral rotatory instability in his left knee.

## DISCUSSION

We have applied the NuKO orthotic knee system to a wide range of patient problems, including those with chronic ligamentous laxity, post-traumatic instability, and postoperative ligamentous reconstructions, and patients with total knee replacements, post-polio applications, and others. These applications probably represent the spectrum of potential users of knee orthoses. The results to date have been excellent. There have been complaints common to all knee orthoses, such as cosmesis and inconvenience, but generally, the clinical results have fulfilled our design expectations of a tighter fitting, more functional orthosis with minimal pistoning by virtue of the improved anatomically shaped orthotic joints. Early clinical follow-up has demonstrated improved results compared to our previous experience with other commercially available orthoses.

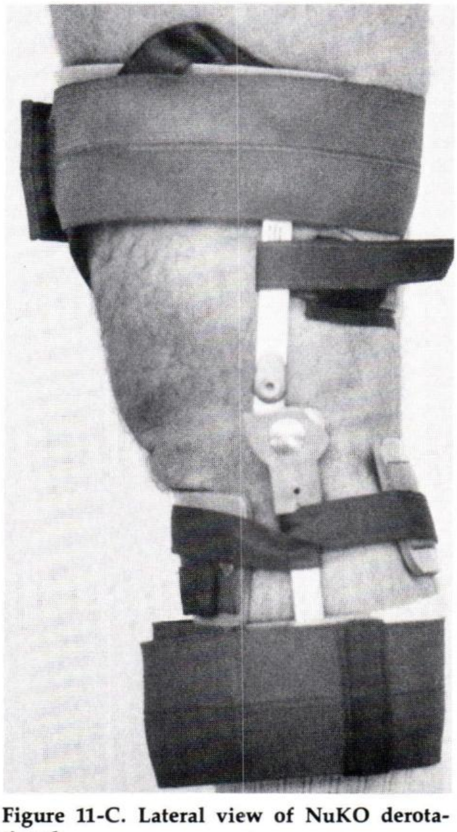


**Figure 11-C. Lateral view of NuKO derotational.**

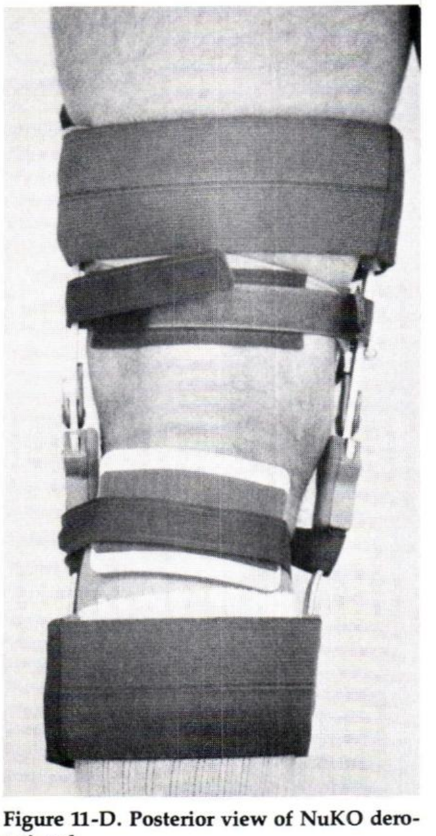


**Figure 11-D. Posterior view of NuKO derotational.**

## REFERENCES

[1]Lewis, J.L., W.D., Lew, C.M. Patrnchak, and G.T. Shybut, "A New Concept in Orthotics—The Northwestern University Knee Orthosis System—Part I: Orthotics Joints," *Orthotics and Prosthetics,* Vol. 37, No. 4, 1983, pp. 15–23.

[2]Lew, W.D., C.M. patrnchak, J.L. Lewis, and J. Schmidt, "A Comparison of Pistoning Forces in Orthotic Knee Joints," *Orthotics and Prosthetics,* Vol. 36, No. 2, 1982, pp. 85–95.

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Photography by Frank Cazzola and Janice Russ.

Illustrations by Vere Shenefield and Lloyd Jillberg.

## AUTHORS

Michael Shafer, M.D., is Orthopedic Surgeon, Ryerson Professor, and Chairman of the Department of Orthopedic Surgery, Northwestern University Medical School, 345 E. Superior Street, Chicago, Illinois 60611.

James Russ, C.O., is Director of Orthotics Education of the Department of Orthopedic Education within the Department of Orthopedic Surgery at Northwestern University Medical School.

Carl M. Patrnchak, R.P.T., C.O., is National Orthotics Coordinator for the Baxter Physical Therapy Division and Clinical Orthotist to the Knee Rehabilitation Clinic, McGaw Medical School.

Richard Tarr, M.S., is Director of Product Development in Depuy, a division of Boehringer Mannheim Corporation, Warsaw, Indiana.