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CLINICAL COMMENTARY

The Role of Foot Orthoses as an Intervention for Patellofemoral Pain

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Foot orthoses often are prescribed for patients with patellofemoral pain. The purpose of this clinical commentary is to review the theoretical and research basis that might support this intervention and to provide our own clinical experience in providing foot orthoses for these patients. Literature is reviewed regarding (1) the effects of foot orthoses on pain and function, (2) the relationship between foot and lower-extremity/patellofemoral joint mechanics, (3) the effects of foot orthoses on lower-extremity mechanics, and (4) the effects of foot orthoses on patellofemoral joint position. The literature and our own clinical experience suggest that patients with patellofemoral pain may benefit from foot orthoses if they also demonstrate signs of excessive foot pronation and/or a lower-extremity alignment profile that includes excessive lower-extremity internal rotation during weight bearing and increased Q angle. The mechanism for foot orthoses having a positive effect on pain and function for these patients may include (1) a reduction in internal rotation of the lower extremity; (2) a reduction in Q angle; (3) reduced laterally-directed soft tissue forces from the patellar tendon, the quadriceps tendon, and the iliotibial band; and (4) reduced patellofemoral contact pressures and altered patellofemoral contact pressure mapping. Foot orthoses may be a valuable adjunct to other intervention strategies for patients who present with the previously stated structural alignment profile. *J Orthop Phys Ther 2003;33:661-670.*

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Patellofemoral pain syndrome can be a debilitating problem that is associated with complex etiology and intervention strategies. Foot orthoses are commonly used in treating patients with patellofemoral pain syndrome. However, available literature providing direct evidence of the effects of foot orthoses on patellofemoral joint position for static or dynamic activity is scarce. A few authors have studied the effects of foot orthoses on clinical outcomes of pain and function for patients with patellofemoral pain. The remainder of the support for foot orthosis intervention is theoretical and circumstantial at best. Because foot orthoses entail a mechanical intervention at the foot, the theoretical support for their use involves establishing a model between abnormal foot mechanics and abnormal patellofemoral mechanics that may explain the clinical entity of patellofemoral pain syndrome. The purpose of this paper, therefore, is to review studies that have documented the effects of foot orthoses on clinical outcomes for patients with patellofemoral pain syndrome and studies that detail the effects of foot orthoses on patellofemoral joint mechanics directly. We also will describe possible links between abnormal foot mechanics and patellofemoral joint mechanics and review indirect support that describes the effects of foot orthoses on foot and leg mechanics. We attempt to synthesize all of this information along with our own clinical experience in the use of foot orthosis intervention for patients with patellofemoral pain syndrome and suggest guidelines for the role of foot orthoses as an intervention.

EFFECTS OF FOOT ORTHOSES ON CLINICAL OUTCOME MEASURES

Future imaging studies may document objectively the effects of foot orthoses on patellofemoral joint position for dynamic loading conditions. As will be suggested later in this paper, these effects may be more demonstrable when the knee is in a more extended position and less bony stability is afforded by the medial and lateral walls of the trochlear groove. Until such evidence is available, however, clinicians may need to rely more on clinical outcome studies to guide clinical decision making regarding the treatment efficacy of foot orthoses for patients with patellofemoral pain and the specific criteria that would guide such intervention. Studies of this nature are available and describe the effects of foot orthoses on pain, function, and patient satisfaction.

Pain is one of the signature clinical symptoms associated with

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patellofemoral pain syndrome and usually is associated with functional activities such as ascending and descending stairs, squatting, and prolonged sitting.[3,10,15] We were able to identify 4 research reports for which the investigators used pain ratings as evidence of foot orthosis treatment efficacy for patellofemoral pain. Eng and Pierrynowski[9] reported that an 8-week regimen of soft foot orthoses and a lower-extremity stretching and strengthening program effected significantly greater reductions in pain ratings for running, ascent of stairs, descent of stairs, and squatting, compared with pain reductions for a matched control group that performed only the stretching and strengthening program. The 2 groups did not differ significantly during the course of the study with regard to pain ratings for walking and sitting. The inclusion criteria for both subject groups were: calcaneal valgus in relaxed bilateral standing greater than 6° or forefoot varus greater than 6° measured non–weight-bearing and in subtalar joint neutral position; bilateral knee pain for a minimum of 6 weeks; gradual onset of pain unrelated to any trauma; and retropatellar pain on palpation, pain on patellar compression, or patellar crepitus.

Three additional reports support the findings of Eng and Pierrynowski.[9] Way[31] has provided a single-subject A-B-A-B research report in which a thermoplastic foot orthosis significantly improved ratings of activities of daily living, functional performance during sporting activities, and difficulty during sporting activities for a collegiate athlete with unilateral patellofemoral pain syndrome. The athlete was described as having ''mild forefoot varus and an increased amount of forefoot pronation during the midstance and terminal stance phases of gait.''

More recently, Johnston[16] assessed the effects of semirigid full-length foot orthoses for 15 subjects who had experienced symptoms of patellofemoral pain for at least 2 months. Additional inclusion criteria included a composite score of 200 or greater on the WOMAC Osteoarthritis Index out of a possible score of 2400, and tenderness with palpation on at least 1 patellar facet at the time of screening. Subjects who participated in the study had a mean WOMAC score of 672, while 15 pain-free subjects who participated in a pilot study had a mean WOMAC score of 29. The final inclusion criterion for subjects with patellofemoral pain was marked pronation. Marked pronation was defined as a rearfoot-to-leg angle greater than 9° of valgus and a longitudinal arch angle less than 141° in bilateral weight bearing.[17] Fourteen of the 15 subjects qualitatively were assessed as having appreciable forefoot varus that was addressed by a medial forefoot post in their foot orthoses. Ratings of stiffness, pain, and physical function were significantly improved following 2 weeks of foot orthosis intervention, and follow-up ratings at 3 months were significantly improved compared with the ratings obtained 2 weeks following the initiation of foot orthosis intervention.

Pitman and Jack[25] also assessed the effect of foot orthoses as a treatment for patients with patellofemoral pain syndrome. Fifty-seven patients who had symptoms of patellofemoral pain were fitted with biomechanical foot orthoses fabricated from positive molds. These subjects had no history of acute knee injury, had knee pain of grade 3 (pain before, during, and after exercise) or grade 4 (unable to exercise) magnitude, tenderness to palpation of the patellar facets, Q angle greater than 15° for women or greater than 10° for men, and ''significant foot pronation at rest and/or during treadmill running evaluation.'' The authors did not describe the operational definition for ''significant foot pronation.'' Subjects were mailed a questionnaire 6 months after the foot orthoses were dispensed to determine the effects of the foot orthosis intervention. Forty-one subjects responded and the results indicated that all except 3 subjects were still wearing their foot orthoses. The authors report an average pain reduction of 67%, but the methods used for obtaining a numerical reduction in pain are questionable, based on the qualitative response selections and pain ratings used by the investigators in their questionnaire.

Taken together, the studies by Way,[31] Johnston,[16] Pitman and Jack,[25] and Eng and Pierrynowski[9] suggest that foot orthoses may improve symptoms of pain and ratings of physical function for patients with patellofemoral pain who demonstrate excessive foot pronation. Additional randomized trials, with reliable outcome measures and carefully defined subject inclusion criteria, are needed to assess treatment efficacy. The work of Johnston[16] and of Eng and Pierrynowski[9] provides good guidelines regarding the need for describing structural foot characteristics for subjects in future studies. These descriptions of structural foot characteristics also should assist clinicians in selecting patients with patellofemoral pain who might benefit from foot orthosis intervention. Clinicians also should benefit from having clear descriptions of the material properties and the structural architecture of the foot orthoses used in these studies.

Additional reports are available regarding the effects of foot orthoses on patient satisfaction for individuals with patellofemoral pain syndrome. Blake and Denton's[4] retrospective study included 13 subjects who had been diagnosed with chondromalacia patella and treated with rigid plastic foot orthoses. Insufficient detail was provided regarding the patients' foot characteristics, activity patterns, duration of symptoms, and the specific architecture of the foot orthoses. Seven of the 13 subjects reported that the orthoses were ''definitely helpful'' in treating their problems, 4 reported that the orthoses were ''some-what helpful,'' and 2 subjects reported that the orthoses were ''not at all helpful.''

Amell et al[1] also retrospectively studied patients with patellofemoral pain syndrome to ascertain the patients' satisfaction with foot orthosis intervention. Twenty-one females with bilateral patellofemoral pain were contacted approximately 9 months following the onset of semirigid foot orthosis intervention. Structural foot characteristics of the subjects and the construction characteristics of the foot orthoses were not reported. Subjects rated the improvement of their condition using a 5-point Likert scale for which 0 represented poor improvement, 3 represented fair (50%) recovery, and 5 indicated full recovery. Of the 21 respondents, 85.7% reported a recovery equal to or greater than 3, 47.6% reported a recovery equal to or greater than 4, and 28.6% reported a full recovery. Approximately 14% of the subjects reported less than fair recovery (ratings of 1 or 2). Approximately 80% of the subjects reported that they would ''replace the orthotic if worn out or lost.''

Gross et al[12] surveyed 500 runners who had used or were currently using foot orthoses for the treatment of lower-extremity complaints. Approximately 69% of the sample responded, with 12.6% of the respondents reporting that the foot orthoses had been prescribed for the treatment of patellofemoral disorders. Approximately 75% of the respondents reported that their symptoms either completely resolved or had greatly improved following foot orthosis intervention, results that were independent of the diagnoses for which the orthoses were prescribed. Ninety percent of the runners continued to use the foot orthoses even after resolution of their symptoms. The authors did not report other interventions used by their subjects.

Saxena and Haddad[28] also described a foot orthosis intervention study for patients with patellofemoral pain syndrome. Clinical application of the results of this study is limited because other interventions were used for the patients and no information is provided regarding the structural characteristics of the subjects' legs and feet or the construction features of the foot orthoses. Nevertheless, the authors indicate that 76.5% of 91 subjects reported an improvement in symptoms and 2% of the subjects reported being asymptomatic following 2 to 4 weeks of foot orthosis intervention. The authors reported that 91.2% of their subjects had medial posting of the forefoot in their orthoses to address forefoot varus deformities. They also suggest that future studies address the possible relationship between forefoot varus malalignment and patellofemoral pain syndrome.

Studies similar to those by Amell et al[1] and Blake and Denton[4] are limited in their clinical applicability because they depend on subjects' memory of their condition months prior to the time questionnaires are completed or interviews are conducted. These studies and the work of Gross et al[12] and Saxena and Haddad[28] also provide inadequate information regarding subject characteristics, the exact nature of the foot orthosis intervention, and the specific aspects of function or physical symptoms that were affected by the intervention.

RELATIONSHIP BETWEEN FOOT AND PATELLOFEMORAL MECHANICS

A basic premise of using foot orthoses to treat patellofemoral joint dysfunction is that foot orthoses will effect a change in foot function, producing obligatory changes in lower extremity mechanical function and specific patellofemoral joint mechanics. This all assumes that lower-extremity and specific patellofemoral joint mechanics are influenced by foot function. Buchbinder et al[5] provided early anecdotal evidence to support this position. These investigators theorized that prolonged pronation beyond the first 25% of stance phase causes the lower extremity to rotate internally when it would normally undergo external rotation. Prolonged and excessive internal rotation of the lower extremity (leg and thigh segments) would then be associated with the patella being medial to the distal attachment of the patellar tendon on the tibial tubercle and medial to the proximal attachment of the rectus femoris muscle. Excessive foot pronation also appears to be associated with a less varus or increased valgus position of the tibiofemoral joint, based on the work of McClay and Manal.[20] This very scenario is illustrated in Figures 1A and 1B. The alignment profile associated with excessive foot pronation is then associated with an increase in Q angle, as well as an increase in the laterally-directed resultant of the quadriceps tendon and patellar tendon forces in the frontal plane (Figure 2). The lateral resultant force then may increase contact forces and contact pressures on the lateral aspect of the patellofemoral articulation. Buchbinder et al[5] presented a case report in which they described a runner who had been diagnosed with chondromalacia patella and who also presented with bilateral rearfoot varus and forefoot varus. The runner was treated with a rigid foot orthosis to control abnormal pronation and patellofemoral pain symptoms were abolished 2 months following the initiation of foot orthosis intervention.

Tiberio[30] presented a theoretical paper that extended the model of Buchbinder et al.[5] Tiberio[30] agreed that subtalar joint pronation would result in adduction of the talus and compensatory internal rotation of the leg. He also proposed that excessive pronation and obligatory internal rotation of the leg during early stance phase would be accompanied by even greater internal rotation of the femur in space.

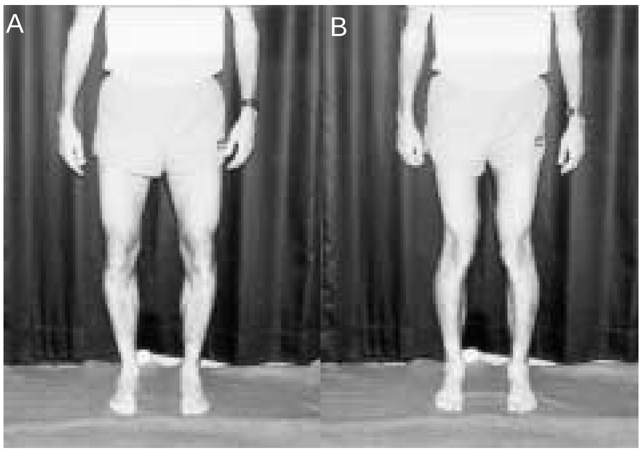

FIGURE 1. The lower extremities are relatively externally rotated at the hip and the patellae are in a more lateral position with a relatively supinated foot posture (A) compared with lower-extremity alignment when the feet are relatively pronated (B). When the feet are relatively pronated (B), the lower extremities move into hip internal rotation and knee valgus, and the patellae are medial to the tibial tubercle and anterior superior iliac spine landmarks.

This greater internal rotation of the femur would occur and provide the necessary relative external rotation of the tibial plateau on the femoral condyles that is associated with knee extension during midstance phase of gait. The combination, then, of a resultant lateral soft tissue force and the excessive internal rotation of the distal femur proposed by Tiberio would lead to excessive compressive stress between the lateral articular surfaces of the patellofemoral articulation. Buchbinder et al[5] and Tiberio[30] provided what appeared as sound theoretical support for the link between excessive pronation and abnormal patellofemoral joint mechanics.

Lafortune et al[19] documented that shoes with medial and lateral rearfoot wedges were associated with obligatory external and internal rotations (respectively) of the entire lower extremity at the hip joint rather than changes in horizontal plane knee joint rotations. Contrary to Tiberio's model,[30] then, excessive internal rotation of the femur on the tibia may not occur with prolonged and excessive foot pronation. Excessive internal rotation of the entire lower extremity at the hip joint, however, does displace the patella and tibial tubercle medially relative to the anterior superior iliac spine. This change in alignment causes an increase in Q angle and a subsequent increase in laterally-directed resultant force from the quadriceps and patellar tendon soft tissue forces. The increase in laterally-directed force may be responsible for excessive lateral contact forces, pressures, and pain at the patellofemoral joint articulation. A limitation of the study by Lafortune et al[19] is that the investigators induced a shoe perturbation, but did not monitor rearfoot motion or other indicators of foot pronation.

Cornwall and McPoil[6] recently have attempted to establish tibial rotation as a reliable and valid indicator of foot pronation because shoes generally cover most of the foot, resulting in difficulty monitoring foot motion directly during clinical interventions or research studies. Establishing tibial rotation as a marker of subtalar joint pronation would provide a strategy for assessing the effects of shoe wear, foot orthoses, or other shoe inserts on subtalar joint function without direct measurement or visualization of the foot. This line of investigation also assessed the link between foot and lower-extremity mechanics. Because rearfoot inversion and eversion have been used as a frontal plane indicator of subtalar joint pronation, Cornwall and McPoil[6] have studied the relationship between rearfoot inversion/eversion and tibial rotation using 2-dimensional imaging techniques and a single tibial pointer to measure tibial

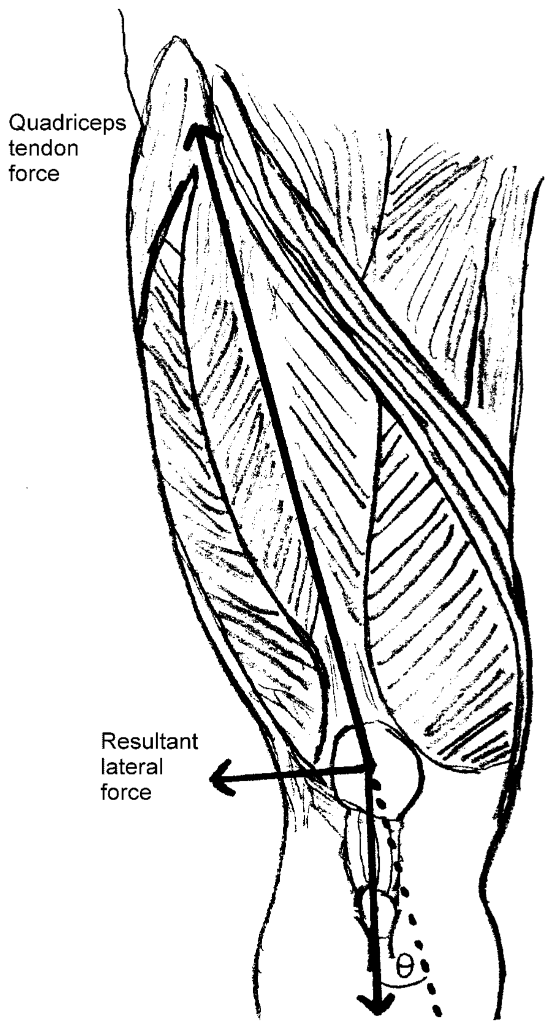

FIGURE 2. The influence of Q angle (θ) on producing a laterally directed soft tissue resultant force. As Q angle increases, the resultant of the patellar tendon and quadriceps tendon forces increases in the lateral direction.

rotation. Internal rotation of the tibia could be driven by subtalar joint pronation that involves movement of the talus on a calcaneus that is relatively fixed by the ground during weight bearing. The talus plantar flexes, adducts, and inverts on the stabilized calcaneus to produce subtalar joint pronation (a triplanar motion). Adduction of the talus would then drive internal rotation of the leg given the relatively tight fit of the talar dome within the ankle mortise. Internal rotation of the leg, however, might be related to variables other than subtalar joint pronation, resulting in relatively more internal rotation of the leg than rearfoot-to-leg angular displacement. Additional internal rotation of the leg might be tied to the conical shape of the dome of the talus, motion perhaps unrelated to calcaneal inversion/eversion. Talar dome morphology explains coupled motions of dorsiflexion and internal tibial rotation at the talocrural joint that are attributable to the greater radius for the curvature of the lateral aspect of the talar dome compared with the medial aspect of the talar dome.[22]

Cornwall and McPoil[6] reported that the correlation between rearfoot inversion/eversion and tibial rotation was 0.953. This correlation coefficient, however, was computed on the collapsed, or pooled, data for all 16 feet in their subject sample. The correlation between rearfoot inversion/eversion and tibial rotation for each of the 16 feet in the sample ranged between r = 0.526 and r = 0.960.[6] The investigators did not report the mean of these 16 correlation coefficients. Instead, they collapsed all of their data into 1 data set to examine the relationship between rearfoot inversion/eversion and tibial rotation as 0.953. The result may reflect a ''washout'' effect that involves weak correlations in opposite directions among the 16 individual correlation coefficients. For example, tibial rotation for one subject may increase, while tibial rotation data for another may decrease, with the pooled tibial rotation data then ''following'' the pattern for rearfoot inversion/eversion data. The pooled data may then combine in a spurious manner to give a composite correlation coefficient that appears impressively large. It is difficult to imagine that a correlation of 0.953 is representative of individual correlations that range between r = 0.526 and r = 0.960. The work of Cornwall and McPoil, however, does suggest that internal tibial rotation is concurrent with rearfoot eversion, a frontal plane indicator of subtalar joint pronation.

Reischl et al[27] continued the analysis of coupled foot and lower-extremity kinematics. These investigators used 3-dimensional analysis techniques with reflective markers placed on the rearfoot, dorsum of the foot, and the first and fifth metatarsal heads. Pronation of the entire foot was then modeled as inferomedial movement of the dorsal foot marker, eversion of the calcaneal marker, and frontal plane movement of the metatarsal head markers. The magnitude of peak foot pronation was not significantly correlated with the magnitude of peak tibial rotation (r = 0.08, P = .67), nor was the timing of peak pronation correlated with the timing of peak tibial rotation (r = 0.03, P = .88). Peak pronation occurred at 26.8% of the gait cycle, while peak internal tibial rotation occurred at 15.2% of the gait cycle. The timing of peak tibial rotation, however, was significantly correlated with the timing of peak femoral rotation (r = 0.66, P = .001). The investigators concluded ''the lack of a relationship between peak foot pronation and the rotation of the tibia and femur is contrary to the clinical hypothesis that increased pronation results in greater lower-extremity rotation.'' The investigators, however, required that movement of all of the markers on the foot indicate foot pronation. Subtalar joint pronation and pronation of midfoot articulations might easily occur without any movement of first and fifth metatarsal head markers when the forefoot is in firm contact with the support surface. Internal rotation of the leg would occur in the absence of any movement of the metatarsal head markers. This methodological factor in the work of Reischl et al[27] limits their conclusions regarding the link between pronation within the foot and tibial rotation.

The theoretical work of Buchbinder et al[5] and Tiberio[30] provides a basis for linking excessive foot pronation with abnormal patellofemoral joint mechanics. The study by Lafortune et al[19] provides indirect support for the link between excessive foot pronation and abnormal patellofemoral joint mechanics by documenting that foot pronation is coincident with tibial and femoral internal rotation. The remainder of the argument, then, may be that excessive internal rotation of the lower extremity tends to increase Q angle, thereby increasing laterally-directed soft tissue forces and patellofemoral joint contact pressures.

EFFECTS OF FOOT ORTHOSES ON LOWER-EXTREMITY MECHANICS

The next logical step in this analysis might be to analyze the effects of foot orthoses on lower-extremity mechanics. D'Amico and Rubin[7] assessed the effects of foot orthoses on Q angle by studying 21 subjects who had been wearing foot orthoses prior to recruitment into their study. The authors did not report the reasons why their subjects were using foot orthoses, nor do they report specifics of the subjects' alignment profiles or the structural or material properties of the orthoses, only that a wide range of foot orthoses were used across their subject sample. Subjects' Q angle was measured bilaterally using a goniometer, both with and without foot orthoses, while subjects were positioned in bilateral standing.

Mean Q angle for standing with orthoses was 6° less than mean Q angle for standing without foot orthoses. A bilateral reduction in Q angle was observed for approximately 92% of the subjects. The authors, however, did not report the reliability of their measurements, nor do they indicate that they were masked to the conditions under which the Q angle measurements were made.

More recently, Nawoczenski et al[24] used 3-dimensional analysis techniques to study the effects of foot orthoses on leg and rearfoot kinematics during running. Recreational runners with either pes cavus or pes planus foot structures were recruited to run with TEVA sport sandals (Teva Sport Sandals, Flagstaff, AZ) both with and without semirigid foot orthoses. The foot orthoses used in the study were fabricated from custom-molded impressions of the subjects' feet and included posting configurations to promote subtalar joint neutral position. The authors do not report the actual posting configurations used across their subject sample, nor the specific structural foot characteristics of their subjects. The foot orthosis condition resulted in a 2° reduction in maximum internal leg rotation, which corresponded to an average 31% reduction in internal leg rotation from heel strike to maximum leg internal rotation during stance phase of running gait. This decrease in internal leg rotation supports the work of D'Amico and Rubin,[7] as well as the theoretical mechanism for patellofemoral pain caused by increased laterally directed soft tissue forces.

Eng and Pierrynowski[8] also assessed the effects of soft foot orthoses on 3-dimensional foot/leg and knee joint kinematics. Subjects were 10 female individuals with patellofemoral pain syndrome who also demonstrated forefoot varus greater than 6° and/or calcaneal valgus greater than 6°. Movements between the foot and leg were monitored by the placement of markers on the shoe rather than the foot. The foot orthoses were posted medially under the forefoot and the rearfoot based on the screening measurements for forefoot varus and calcaneal valgus.

Outcome variables for Eng and Pierrynowski's[8] work were range-of-motion displacements for the foot/leg articulation and the knee joint for 3 portions of the stance phase of running and walking gait. The authors reported that the random error in determining a segment's rotation was less than 0.54° in all planes. The soft foot orthoses studied effected a significant reduction in foot/leg motion in the frontal plane during the initial contact and midstance portions of walking gait, and during the initial contact and propulsive portions of running gait. The orthoses also effected a reduction in foot/leg range of motion in the transverse plane for the propulsive portion of walking and running gait. Orthosis use resulted in a decrease in transverse-plane knee joint motion for the initial contact portion of walking with less than 0.6° changes for other portions and for running gait. The orthoses effected a reduction in frontal plane knee motion for the initial contact portion of walking gait, but increases (0.8°-0.9°) in frontal plane knee motion for the initial contact and midstance portions of running gait. The authors suggest that reductions of 0.8° to 2° at the foot/leg articulation appear to cause a reduction of knee joint motion. Eng and Pierrynowski[8] also suggest that reductions of foot/leg motion greater than 2.5° necessitate a transfer of greater motion at the knee joint to accomplish weight-bearing progression because insufficient motion may be available at the foot/leg articulation to accomplish weight bearing over the stabilized foot. The authors do not report the direction of displacement, nor do they report the absolute joint positions or maximum positions observed.

McPoil and Cornwall[21] examined the control of magnitude and acceleration of internal tibial rotation effected by soft premolded foot orthoses and premolded rigid orthoses with posting material added. Both orthoses significantly reduced the magnitude and the acceleration of internal tibial rotation compared with barefoot or shoe-alone testing conditions. Results for the rigid orthoses were not significantly different than results for the soft orthoses. Readers should take note, however, that both orthoses were premolded devices. The comparable results observed for the 2 types of orthoses tested in this study may not generalize to orthoses that are custom molded to patients' feet or plaster-positive impressions of patients' feet.

Foot orthoses, therefore, do appear to limit the magnitude of internal tibial rotation.[21,24] Foot orthoses also should constrain femoral internal rotation based on the coupling of internal rotation of the leg and internal femoral rotation.[19] Additionally, by limiting internal rotation of the leg and thigh segments, foot orthoses also appear to decrease the magnitude of Q angle at the patellofemoral joint.[7] This latter effect may be responsible for reducing laterally directed soft tissue resultant forces and excessive patellofemoral contact pressures.

DIRECT EVIDENCE FOR EFFECTS OF FOOT ORTHOSES ON PATELLOFEMORAL JOINT POSITION

The previous line of argument is a combination of theoretical and circumstantial evidence implicating abnormal foot mechanics as a cause of patellofemoral joint dysfunction, as well as establishing a role for foot orthoses in the management of patellofemoral joint pain syndrome. Obtaining direct evidence for the effects of foot orthoses on patellofemoral joint mechanics is no easy matter. Objective data are required to detail the position of the patella and distal femoral segments under various loading conditions. Such evidence could be provided by percutaneous bone pins,[26] or using radiographic[18] or magnetic resonance imaging (MRI) techniques.[2,23] The use of skin markers to explore the effects of foot orthoses on patellofemoral joint kinematics is ill advised. Reinschmidt et al[26] have documented that such analyses result in errors ranging from 21% to 70% for the 3 planes of knee motion compared with knee kinematics documented with bone pin markers. We were able to identify only 2 studies that investigated the effects of foot orthoses on patellofemoral joint position during weight-bearing conditions.[16,18]

Klingman et al[18] examined the effects of a medial-wedge orthosis on patellofemoral position during unilateral weight bearing. The medial-wedge orthosis was designed to control excessive pronation. Patellofemoral joint position was examined utilizing an axial radiological view of patellar alignment. The investigators reported that foot orthoses caused a mean medial displacement of the patella relative to the femoral trochlear groove equal to 1.08 mm (SD, 0.52) compared with weight bearing without the foot orthoses. The foot orthoses also resulted in a medial displacement of the patella for all subjects. Study subjects were pain-free individuals who demonstrated excessive foot pronation evidenced by a standing calcaneal valgus angle equal to or greater than 6° in unilateral stance. Even though the changes in patellofemoral joint position were statistically significant for this subject sample, the question remains whether similar mechanical effects would occur for subjects with patellofemoral pain and would be sufficient to influence symptoms significantly. Klingman et al[18] also only examined the conditions of barefoot and barefoot with a medial wedge orthosis. The investigators did not address the effects of shoe wear on patellofemoral position. The investigators also did not report the resolution of their measuring system or their SEM for measurements of patellofemoral joint position. Knowing the error involved in making these measurements would be helpful in evaluating the significance of the change in position (1.08 mm) effected by the medial wedges used by the investigators.

Johnston[16] attempted to address some of these concerns by evaluating the effects of foot orthoses for a group of subjects with patellofemoral pain as the subjects performed a unilateral squatting maneuver. Custom foot orthoses were fabricated for 15 subjects with patellofemoral pain who demonstrated excessive foot pronation. Measurement of lateral patellar displacement was assessed using axial radiographs for barefoot standing, standing with shoes, and standing with shoes plus orthoses. Statistical analysis of the results indicated no significant differences in medial-lateral patellofemoral joint position among the 3 testing conditions. Because subjects were positioned statically at approximately 70° of knee flexion for the radiographic imaging, Johnston suggested that foot orthoses might only effect a change in patellofemoral joint position in lesser positions of knee flexion before the patella becomes more stabilized in the trochlear groove of the distal femur. Johnston[16] also assessed the effects of foot orthoses on pain and function for her subject group. These results were presented in a previous section of this paper. Other issues for this type of study include differences in patellofemoral joint position between dynamic tibiofemoral joint extension efforts and static positioning of the tibiofemoral joint.

On a theoretical note, patellofemoral position documented via plane radiography, MRI, or some other form of imaging may not necessarily correlate directly with clinical symptoms of pain and functional limitations. Pain and functional limitations may be more influenced by patellofemoral contact pressures and the pressures transmitted through articular cartilage into neural subchondral bone. Two patellofemoral joints might have very similar mediolateral patellofemoral joint positions documented on MRI, but have very different contact pressure distribution patterns, both in terms of magnitude and mapping of these pressures. The differences would be explained by different soft tissue forces being imposed on the 2 patellofemoral joints. Huberti and Hayes[14] have documented quite nicely the effect of knee Q angle on patellofemoral joint contact pressures using pressure-sensitive film with 12 cadaveric specimens. A 10° increase in Q angle was associated with increased peak patellofemoral contact pressures, including a 45% increase at 20° of knee flexion. Decreased Q angle alignment was associated with unloading of the vertical crest of the retropatellar surface, as well as decreased lateral facet contact pressures in some knees. The ability of foot orthoses to decrease Q angle,[7] therefore, may very well be associated with improved patellofemoral contact pressures as documented by Huberti and Hayes.[14] Future cadaveric studies that employ pressure-sensitive film might elucidate more directly the relationships among foot position, knee joint position, and patellofemoral joint contact pressures.

OUR CLINICAL EXPERIENCE

We follow a general problem-solving strategy prior to proceeding with foot orthosis intervention for patients with patellofemoral pain. We first try to determine if a patient's lower-extremity alignment profile may be associated with abnormal patellofemoral mechanics such as patellofemoral soft tissue forces that are abnormal either in terms of magnitude or direction. Then we attempt to identify factors that contribute to the patient's weight-bearing lower-extremity alignment and the related soft tissue forces. Finally, we analyze whether foot orthosis intervention might effect a change in lower-extremity alignment that might improve patellofemoral mechanics and decrease pain.

Patients with patellofemoral pain for whom we fabricate foot orthoses most commonly demonstrate the lower-extremity alignment profile demonstrated in Figure 1B. An anterior view of the patient typically reveals internal rotation of the entire lower extremity, increased knee valgus, and increased Q angle compared with the unloaded lower-extremity alignment. The patient usually is able to use hip external rotators and foot supinator muscles to move lower-extremity alignment out of the weight-bearing alignment profile seen in Figure 1B. In doing so, they move toward an alignment profile depicted in Figure 1A, exhibiting reduced foot pronation, less-excessive internal rotation of the lower extremity, and less-pronounced knee valgus and Q angle. The intent of foot orthosis intervention is to enable the patient to maintain this latter structural alignment profile during functional weight-bearing activities, without overtaxing muscles that ordinarily might not be capable of meeting this demand. Most of these patients demonstrate excessive foot pronation that we associate with the lower-extremity alignment profile depicted in Figure 1B.

We have tended to see 2 general profiles among patients who have presented with complaints consistent with patellofemoral pain syndrome, and for whom we have fabricated and dispensed foot orthoses. One group of patients tends to exhibit hypermobility of the patella. This hypermobility can be assessed by having the patient positioned supine. The examiner then imposes medially-directed force on the lateral aspect of the patella (gliding the patella in the medial direction) to assess laxity of lateral peripatellar soft tissues, followed by imposing laterally-directed force on the medial aspect of the patella (gliding the patella in the lateral direction) to assess laxity of medial peripatellar soft tissues. The second group of patients tends to demonstrate hypomobility during attempts to glide the patella medially, and perhaps laterally as well. Both groups often exhibit excessive foot pronation as evidenced by valgus rearfoot-to-leg alignment, medial talonavicular bulge, qualitative assessment of inferior displacement of the navicular tubercle during weight bearing, and/or a smaller medial longitudinal arch angle.

A structural screening examination[13] of these patients often indicates that issues such as tibial varum, genu varus, femoral antetorsion, or forefoot varus may be ''driving'' the excessive foot pronation that is observed. We very commonly note excessive forefoot varus[11] as a structural malalignment that may be causing foot pronation, as has been noted by Johnston[16] as well as Saxena and Haddad.[28] Occasionally, we have evaluated patients who demonstrate increased knee valgus and increased Q angle without substantial foot pronation. We sometimes proceed with foot orthosis intervention for these patients if we can determine that maintaining the patient in a more supinated foot position achieves a preferred patellofemoral alignment. This assessment can be accomplished by asking the patient to supinate the foot, using hip external rotators and foot supinator muscles and noting if activation of these muscles decreases the patient's knee valgus and Q angle.

We fabricate foot orthoses using a process that involves molding semirigid foot orthosis blanks to the feet with the patient seated on a stool.[11] Synthetic cork is then used to support the arch space and produce a medial rearfoot post to address problems such as tibial varum or genu varus. Nickelplast (AliMed, Dedham, MA) is used to add any medial posting to the forefoot to address forefoot varus malalignment. Nickelplast is well suited for this purpose because it is very stiff to compression, yet bends easily to allow a relatively unencumbered toe break for toe-off.

We have noted that patients with patellofemoral pain often exhibit reduced extensibility of the iliotibial band. For several patients we have seen, a particular perturbation test has confirmed the link between iliotibial band tightness and patellofemoral pain syndrome. We refer to this test as the ''Iliotibial Band Bowstring Test.'' No reliability or validity studies have been performed for this test. The patient is positioned in side lying with the lower extremity to be tested in the superior position. The lower extremity to be assessed is slightly adducted at the hip and the knee is positioned in approximately 20° of knee flexion (Figure 3). The examiner then compresses the iliotibial band just superior to the lateral femoral condyle. The reproduction of patellofemoral pain indicates a positive test result and implicates the tight iliotibial band as a potential contributor to the patient's patellofemoral pain. Positive results for this test would seem consistent with previously reviewed literature, suggesting a combination of excessive foot pronation and iliotibial band tightness as a contributor to patellofemoral pain syndrome. As excessive foot pronation causes obligatory lower-extremity motion, the knee moves medially relative to the foot and pelvis, which places the hip in a more adducted and internally rotated position. The combination of hip adduction and internal rotation then stretches an already tight iliotibial band, increasing the laterally directed soft tissue force imposed on the patella through the attachments of the distal iliotibial band on the lateral aspect of the patella.[29] The increase in laterally directed soft tissue force from the iliotibial band may add to lateral soft tissue forces from the patellar tendon and the quadriceps tendon created by an increase in Q angle, thereby further increasing patellofemoral contact pressures.

FIGURE 3. The Iliotibial Band Bowstring Test. The patient is positioned in side lying with the tested lower extremity in hip adduction and slight knee flexion. The examiner imposes medially directed force over the distal iliotibial band. A positive test result is indicated by the reproduction of patellofemoral pain.

We generally find that patients who have patellofemoral pain and who demonstrate excessive foot pronation benefit from foot orthoses that address directly the alignment problem that may be driving their foot pronation. These patients may also have other problems that are identified at the time of examination which may be related to their patellofemoral pain, including tightness of the iliotibial band, tight quadriceps muscles, tight hamstring muscles, tight peripatellar soft tissues, weak hip external rotators that allow movement of the lower extremity into a position of internal rotation and increased knee valgus, and weak quadriceps muscles. We do try to address these problems with strengthening and stretching protocols. We realize, therefore, that the ability to attribute a positive effect for foot orthosis intervention is confounded by the presence of these other interventions. Often, however, we receive reports of improvements in pain and function within the first week of foot orthosis intervention. In these instances, we tend to think that the improvements in pain and function are more attributable to the foot orthosis intervention given the relatively short time frame. We would expect improvements in pain and function to occur after a longer period of intervention for other interventions that may relate to strengthening of weak muscles and stretching tight structures.

CLINICAL IMPLICATIONS AND FUTURE DIRECTIONS

The previously reviewed literature and our own experience suggest that patients with patellofemoral pain may benefit from foot orthoses if they also demonstrate signs of excessive foot pronation and/or a lower-extremity alignment profile that includes excessive lower-extremity internal rotation and increased Q angle during weight bearing. The mechanism for foot orthoses having a positive effect on pain and function for these patients may include: a reduction in internal rotation of the lower extremity; a reduction in Q angle; reduced laterally directed soft tissue forces from the patellar tendon, the quadriceps tendon, and the iliotibial band; and reduced patellofemoral contact pressures and altered patellofemoral contact pressure mapping. Foot orthoses could also be effective for patients who do not demonstrate excessive foot pronation if the orthoses are able to improve lower-extremity alignment.

Additional studies are needed to assess the treatment efficacy of foot orthoses for patients with patellofemoral pain, with reliable outcome measures and clearly defined subject selection criteria. These additional studies should assist clinicians in selecting patients with patellofemoral pain who might benefit from foot orthosis intervention. Perhaps the greatest challenge in this area of research involves documenting the mechanisms by which foot orthoses effect positive clinical outcomes. Future studies are needed to determine the effects of foot orthoses on static and dynamic measures of Q angle, patellofemoral joint position, and tibiofemoral joint position. Cadaveric specimens might also be useful to model the effects of foot orthoses on patellofemoral and tibiofemoral kinematics. Finally, patellofemoral kinematics may not fully identify the effects of foot orthoses on patellofemoral mechanics and symptoms of patellofemoral pain. Patellofemoral joint position may appear identical for 2 loading conditions (eg, with and without foot orthoses), while patellofemoral joint contact pressures may differ. As suggested previously, cadaveric studies that employ pressure-sensitive film might elucidate more directly the relationships among foot position, knee joint position, and patellofemoral joint contact pressures.

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