Journal of Orthopaedic & Sports Physical Therapy
Official Publication of the Orthopaedic and Sports Physical Therapy Sections of the American Physical Therapy Association

The Influence of Tibial and Femoral Rotation on Patellofemoral Contact Area and Pressure

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Fixed rotation of either the femur or tibia has a significant influence on the patellofemoral joint contact areas and pressures. This is due to the anatomic asymmetry in the knee with respect to all planes, as well as the laterally directed force vector that naturally exists in bipedal lower-limb biomechanics. Specifically, femoral rotation results in an increase in patellofemoral contact pressures on the contralateral facets of the patella, and tibial rotation results in an increase in patellofemoral contact pressures on the ipsilateral facets of the patella. This difference can be elucidated when one considers that rotation of the femur is biomechanically different than rotation of the tibia. For both tibial and femoral rotations, the patella's distal attachment to the tibial tubercle influences the direction of patellar movement.

The biomechanical evidence reviewed in this manuscript suggests that the determining factor in patellofemoral pathology is the derangement of normal joint mechanics. However, despite considerable experimental data supporting this position, there also are theories that suggest otherwise. This illustrates a very important point in patellofemoral joint pathology, where no one factor may be the sole defining etiology. Instead, the patellofemoral joint is one of the most complex diarthrodial joints in the body and there are a number of etiologic factors that can lead to pathology. This should be considered for developing repair and rehabilitation strategies. *J Orthop Sports Phys Ther 2003;33:686-693.*

Key Words: *contact pressure, femur, knee, patellofemoral joint, tibial rotation*

The patella is an essential component of the knee, as it increases the mechanical advantage of the quadriceps mechanism. Other functions of the patella include protecting the articular cartilage of the trochlea and femoral condyles, and transmitting the tensile forces of the quadriceps muscle to the patellar tendon. Normal functioning of the patellofemoral joint is dependent on proper balancing of the active and passive stabilizers. The primary active stabilizers are the quadriceps muscles. Passive stabilizers include the bony and cartilaginous articular surfaces of the patellofemoral joint, the peripatellar retinaculum, and the patellar tendon (Figure 1).

It has been estimated that various activities generate patellofemoral joint reaction forces that far exceed body weight (Table).[3,5,6,11,12,13,14,29,34,35,37,38,42,43,45,46,48,51,54,55] The articular surfaces of the patellofemoral joint are unique in design and have the thickest articular cartilage in the body, which helps to distribute the varying biomechanical demands placed on the joint.[15,18] When the load-bearing surface areas are altered, abnormal distribution of the stresses on the patellofemoral joint occurs. This abnormal distribution of stresses is considered to have a strong correlation with patellar disorders, such as chondromalacia and subsequent osteoarthritis.[28] Because cartilage degradation is a slow process, by the time symptoms arise, the degenerative process on the articular cartilage is already well established.[32] This has been observed clinically and investigators have reported that chondromalacia of the patella is thought to be much more prevalent than is usually recognized.[39]

The pathophysiology of patellofemoral pain is not well understood.[7,40] While some have attributed patellofemoral pain to excessive stresses associated with abnormal patellofemoral joint mechanics,[27,36] others have concluded that chronic overloading of the

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Research supported by VA RR&D Grants and John C. Griswold Foundation
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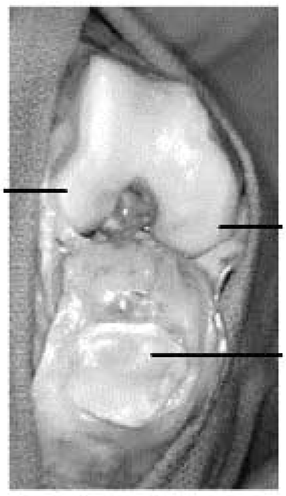

FIGURE 1. Anterior aspect of a right knee, with the patella reflected showing the articulating surfaces of the patellofemoral joint.

patellofemoral joint, rather than malalignment, is a common characteristic in patients with patellofemoral pain.[20,49] Many causes of patellofemoral joint dysfunction have been proposed, including vastus medialis weakness, increased quadriceps angle, genu valgum, femoral anteversion, external tibial torsion, tight lateral retinaculum, abnormalities of the shape of the patella, trochlear groove abnormalities, and foot pronation.[47] It also has been recognized that alignment and rotation of the lower extremity may influence the biomechanics of the patellofemoral joint. The purpose of this manuscript was to review the literature with respect to patellofemoral joint contact areas and pressures with particular focus on the influence of tibial and femoral rotations.

PATELLOFEMORAL CONTACT PRESSURES

The distribution of forces across the patellar articular surface during knee flexion involves the complex and dynamic interplay between quadriceps muscle force, soft tissue restraints, and patellar tracking within the bony geometry of the patellofemoral joint. As a result of this complexity, there remains much controversy over the relationship between articular surface pressures and knee flexion. Earlier in vitro studies have demonstrated that, in weight bearing, contact pressures within the patellofemoral joint increase as the knee flexes from 0° to 90° and decrease as the knee extends.[22,24] These results have been used to explain the clinical observation that chondral degeneration seen in patellofemoral pain is most likely to occur in areas that correspond to those contact areas seen between 40° and 80° of knee flexion. Wallace et al[52] demonstrated that statistically significant increases in patellofemoral stress were seen with greater knee flexion angles during a loaded and unloaded squat. Patellofemoral stress increased from 30° to 90°, peaking at 90° for both eccentric and concentric muscle contractions. However, more recent in vitro work utilizing multiplane loading of the extensor mechanism has shown that peak patellofemoral contact pressures are also observed at lower knee flexion angles.[10,33,41] In these studies, the distribution of pressure across the articular surface was remarkably uniform.[24,31]

TABLE 1. Patellofemoral joint force during various activities.

Source	Activity	Patellofemoral Joint Force
Bresler and Frankel[6]	Level walking	840 N
Radcliffe[42]	Level walking	850 N
Morrison[35]	Level walking	490 N
Lindahl et al[34]	Isometric maximum	6100 N
Reilly and Martens[43]	Level walking	0.5 × body weight
Reilly and Martens[43]	Stair climbing	3.3 × body weight
Smidt[48]	Straight leg raise	2.6 × body weight
Smidt[48]	Isometric maximum	3400 N
Wahrenberg et al[51]	Kicking	5800 N
Kelley et al[29]	Rising from chair	3800 N
Winter[55]	Level walking	830 N
Andriacchi et al[3]	Ascending stairs	1500 N
Andriacchi et al[3]	Descending stairs	4000N
Boccardi et al[5]	Level walking	840 N
Dahlkvist et al[11]	Squatting	7.0 × body weight
Winter[54]	Jogging	5000 N
Schuldt et al[45]	Rising from squat	2500 N
Ekholm et al[12]	Lifting	1600 N
Ericson et al[14]	Bicycling	880 N
Ekholm et al[13]	Machine milking	1100 N
Ekholm et al[13]	Isometric maximum	6900 N
Nisell[37]	Jogging	7.0 × body weight
Nisell[37]	Parallel squat	14900 N
Nisell et al[38]	Isokinetic knee extension	8300 N
Scott and Winter[46]	Initial stance phase	7.6 × body weight

Between genders, the patellofemoral joint contact pressures are strikingly different.[10] Csintalan et al[10] reported that, at lower knee flexion angles (between 0° and 30°), there were significantly greater contact pressures in female cadaver knees as compared to male cadaver knees. In addition, the cadaver knees from women showed a greater response to changes in vastus medialis load at lower knee flexion angles. This variability of pressure at the lower knee flexion angles suggests a greater role of the soft tissues in the balance and mechanics of the patellofemoral joint near full extension, before knee flexion causes full engagement of the patella in the trochlear groove. This greater dependence on vastus medialis load to decrease patellofemoral pressures in female cadaver knees may represent a gender difference in the bony geometry of the patellofemoral joint and may explain the greater incidence of patellofemoral pain in females.

PATELLOFEMORAL CONTACT AREAS

It has been shown that moving from 0° to 60° of knee flexion will progressively increase the patellofemoral contact area, decreasing the rise in contact pressures associated with increased force production by the quadriceps.[1,2,41] At knee flexion angles greater than 60°, the relationship between knee flexion angle and patellofemoral contact area is more controversial. Several authors have demonstrated that the total contact area continues to rise with knee flexion angle beyond 60°.[21,22,24,25,26] Others, however, have concluded that the total contact area actually decreases at knee flexion angles larger than 60°.[10,33,41] The discrepancies between these studies are most likely related to inherent differences in study design. Former conclusions were obtained utilizing axial loading of the extensor mechanism,[21,22,24,25,26] while latter results were obtained using a more physiological anatomically based multiplane loading of the extensor mechanism.[10,33,41]

Patellofemoral contact area has been shown to differ between genders. Csintalan et al[10] demonstrated that from 60° to 90° of knee flexion, male cadaver knees showed a significant increase in contact area over female knees. This increase in contact area could not be explained by the larger size of the male knees and suggests that there are inherent gender-specific anatomic differences within the bony geometry of the patellofemoral joint.[10]

INFLUENCE OF TIBIAL ROTATION ON PATELLOFEMORAL JOINT CONTACT PRESSURES AND AREAS

Both tibial and femoral motions have significant effects on the biomechanics of the patellofemoral joint; however, their effects on patellar kinematics are markedly different. This concept is extremely important in understanding the different mechanisms by which various pathological states affect the patellofemoral joint. For instance, with tibial rotation, the primary effect on the patella is rotational when viewed from the coronal (frontal) plane, and not translational, as one may think. This pattern of motion occurs as a result of the patella being fixed to the tibia via the patellar tendon. During external tibial rotation, when the tibial tuberosity moves laterally, the patellar tendon functions to pull on the distal pole of the patella laterally, thus rotating the superior aspect of the patella medially about the center of the patella. The opposite occurs during internal rotation of the tibia, in which medialization of the tibial tuberosity rotates the superior aspect of the patella laterally about an anteroposterior axis located near the center of the patella. At the same time, when the transverse plane is considered, there is an increase in contact pressure and area on the facets of the patella ipsilateral to the direction of the tibial rotation (Figure 2).

External tibial rotation has been associated with a variety of patellofemoral dysfunctions, such as instability[17] and compression syndrome.[30] Such assumptions were partially validated by Turner,[50] who reported that patients with patellofemoral instability demonstrated greater-than-normal external tibial torsion. Cooke et al[9] reported on 12 patients with chronic patellofemoral symptoms unresponsive to conservative treatment. These 12 patients had significantly increased external tibial torsion as compared to those without patellofemoral pain. Increased femoral anteversion was not seen in this population of patients. In these patients, derotational osteotomies of the proximal tibia, along with a lateral retinacular release, were performed with satisfactory results.

Support for the importance of proper tibial alignment comes from experiments by Lee et al,[33] who reported that external tibial rotation has a significant effect on patellofemoral biomechanics. These authors reported that fixing the tibia in 15° of external tibial rotation (beyond neutral) resulted in significant increases in both average and peak patellofemoral joint contact pressures at all knee flexion angles (Figure 3). Moreover, the increased pressure reported by the authors was selectively located on the lateral patellar articular facets. Fixing the tibia in internal rotation was found to have very little effect on either contact areas or pressures.

In a study by Csintalan et al,[10] loading was primarily on the lateral patellar facets at the lower knee flexion angles when the tibia was in the neutral position. When the tibia was fixed in 15° external rotation, thus increasing the Q angle, the pressures and contact areas were further increased on the

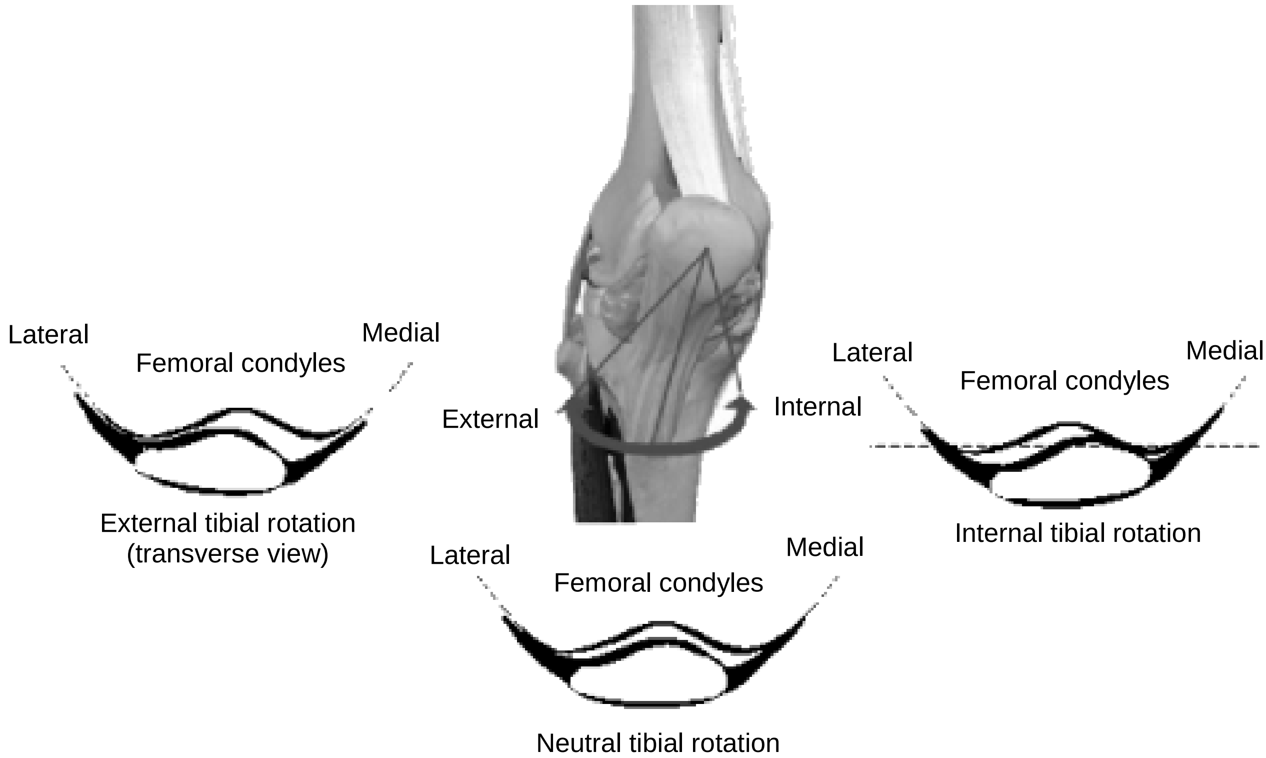

FIGURE 2. Schematic drawing demonstrating the effects of tibial rotation on the patellofemoral joint. External tibial rotation increases contact on the lateral side and internal tibial rotation increases contact on the medial side.

lateral patellar facets. When the tibia was fixed in 15° internal rotation from the neutral position, the pressures and contact areas on the lateral patellar facets decreased, but slightly increased on the medial patellar facets. Thus, the overall average pressure and contact area on the patella surface was not significantly altered.

While both internal and external tibial rotation resulted in greater patellofemoral joint pressures in the above-noted studies, the increases were much lower for internal rotation as compared to external rotation at all knee flexion angles. Also, the largest increases in pressure occurred with the knee in nearly full extension, which is consistent with clinical evidence suggesting that the patellofemoral joint is more susceptible to instability-type injuries in this range of knee flexion.[19] This is most likely related to the bony geometry of the femoral trochlea, which becomes an increasingly prominent contributor to patellar stability as knee flexion angle increases.

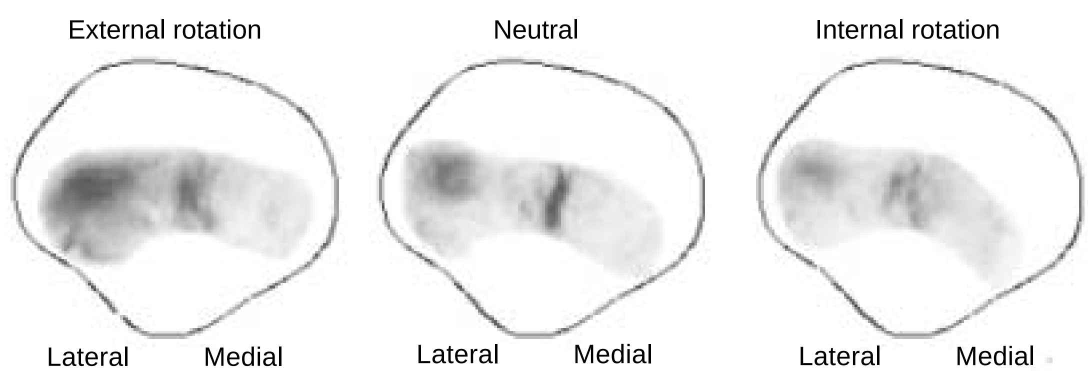

FIGURE 3. The effects of tibial rotation on patellofemoral joint contact pressure and area at 30° knee flexion angle, as shown by Fuji pressure-sensitive film patterns. The darker shade indicates higher contact pressures. External rotation causes increased pressure on the lateral facets.

INFLUENCE OF FEMORAL ROTATION ON PATELLOFEMORAL JOINT CONTACT PRESSURES AND AREAS

Femoral rotation, on the other hand, involves an entirely different cascade of biomechanical events. In this situation, the predominant forces acting upon the patella are the bony geometry of the femoral trochlea, as well as the soft tissue restraints of the peripatellar retinaculum. Because the net effect of these combined forces acts upon the central portion of the patella, the consequences of their influence are translational in nature, rather than rotational. With internal femoral rotation, the lateral articular surface of the trochlea impinges upon the lateral articular facets of the retropatellar surface, in essence, pushing the patella medially. At the same time, the peripatellar retinaculum, whose predominant attachments are at the femoral epicondyles, rotates along with the femur and "pulls" it along. With external rotation of the femur, the medial articular surface of the trochlea impinges upon the medial articular facets of the retropatellar surface, pushing the patella laterally (Figure 4).

The influence of femoral rotation on the contact areas and pressures of the patellofemoral joint system has not been investigated to the same degree as that of tibial rotation. However, the potential of femoral rotational deformities to alter the biomechanics of the patellofemoral joint cannot be denied. To this end, a study by Lee et al[31] analyzed the effects of fixed femoral rotation on patellofemoral joint contact pressures. These authors reported a nonlinear increase in the patellofemoral contact pressures as a function of increasing femoral rotation (Figure 5). Specifically, from 0° to 20° of fixed rotation, either internally or externally directed, there was only a small increase in contact pressures. However, from 20° to 30° of femoral rotation, there was a significantly greater increase in pressure. In general, external rotation of the femur resulted in an increase of the joint contact pressures on the medial facets of the patellar articular cartilage. Conversely, internal rotation of the femur resulted in an increase in contact pressures on the lateral facets of the retropatellar surface. The authors concluded that femoral rotations greater than 20°, such as those caused by congenital, traumatic, or infectious abnormalities of the bones, induce severe alterations to the natural biomechanics of the patellofemoral joint.[31]

FUTURE RESEARCH

It is evident from the information presented in this manuscript that further in vitro and in vivo investiga-

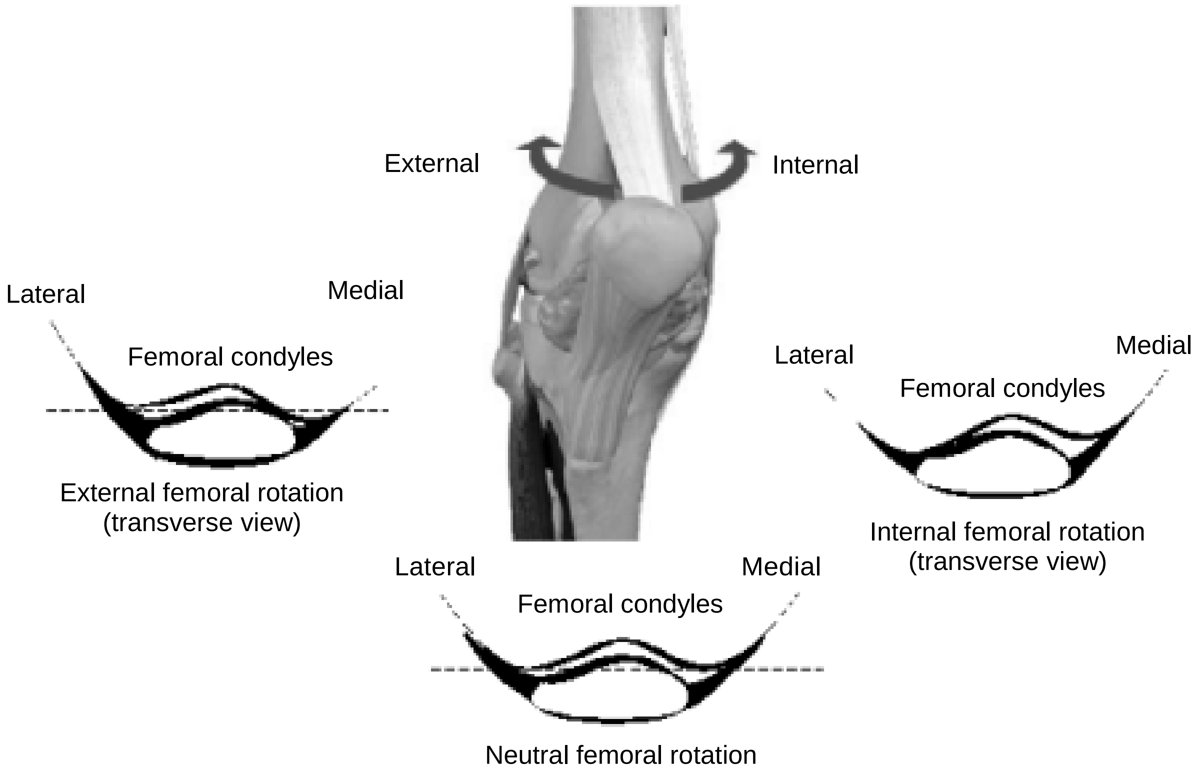

FIGURE 4. Schematic drawing demonstrating the effects of femoral rotation on the patellofemoral joint. External femoral rotation increases contact on the medial side and internal femoral rotation increases contact on the lateral side.

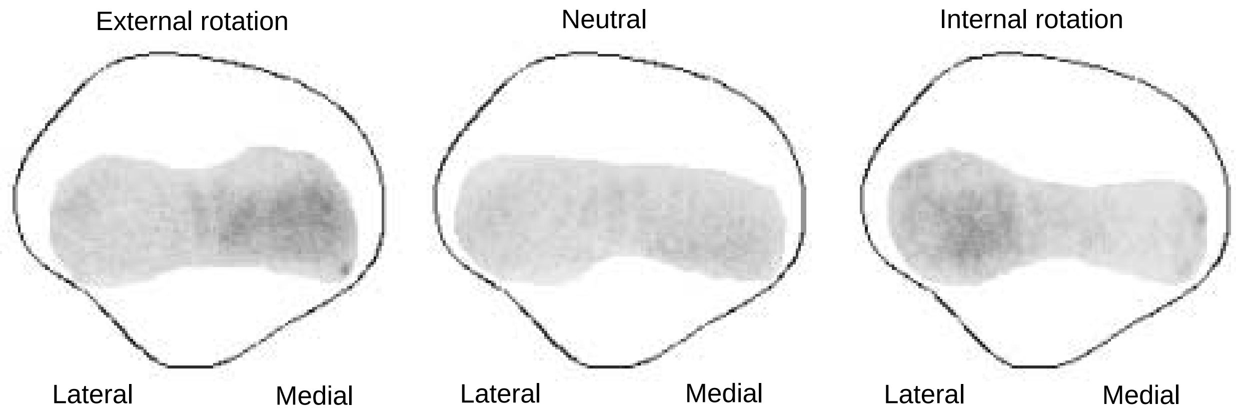

FIGURE 5. The effects of femoral rotation on patellofemoral joint contact pressure and area at 30° knee flexion angle, as shown by Fuji pressure-sensitive film patterns. An increase in shade indicates an increase in contact pressure. External rotation causes increased pressure on the medial facets while internal rotation causes increased pressure on the lateral facet.

tions into the biomechanics of the patellofemoral joint are needed. Specifically, patellofemoral joint research should include the role of femur and tibia dynamics. For example, the performance and function of the knee is dependent on the complex interplay between the patellofemoral joint and tibiofemoral joint. As the knee flexes, there is a posterior displacement of the femoral-tibial contact location, primarily on the lateral side.[8,23,44,53] This displacement is thought to increase the lever arm of the quadriceps, thereby improving its efficiency in activities such as stair climbing and rising from a chair.[4] Conversely, when the knee extends, the contact point moves anteriorly and the lever arm of the posterior muscles increases. By changing the tibiofemoral joint contact points, not only is the lever arm for the extensors affected, but the patellofemoral joint contact points may be affected. Therefore, the interplay between the patellofemoral joint and the tibiofemoral joint may be important in understanding the etiology of patellofemoral joint pain.

SUMMARY

Based on a review of the literature to date, it is clear that fixed rotations of either the femur or tibia can have a significant influence on patellofemoral joint contact areas and pressures. The results of the studies presented demonstrate that the effects of tibia and femur rotations on the patellofemoral joint contact pressures and areas are similar, but opposite in terms of the patellar facets affected. Specifically, femoral rotation results in an increase in patellofemoral contact pressures on the contralateral facets of the patella, and tibial rotation results in an increase in patellofemoral contact pressures on the ipsilateral facets of the patella. This subtle difference can be explained by the fact that rotation of the femur is biomechanically different than rotation of the tibia (Figures 2 and 4). However, in both situations, the patella's distal attachment to the tibial tubercle influences the direction of patellar movement.

The biomechanical evidence presented here would suggest that one determining factor related to patellofemoral pathology is altered joint mechanics. However, despite considerable experimental data supporting this position, other theories exist that suggest otherwise. For example, Fairbank et al[16] presented data illustrating the similarities between patients with patellofemoral pain and control subjects. These authors concluded that it is not altered biomechanics, but, rather, chronic overloading associated with athletic activity that is an important predisposing factor leading to patellofemoral joint pathology. Such a discrepancy illustrates an important point, in that no one attribute has been identified as the defining etiological factor leading to patellofemoral pain.

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