[CLINICAL COMMENTARY]

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The Influence of Abnormal Hip Mechanics on Knee Injury: A Biomechanical Perspective

Of the lower extremity joints, the knee sustains the highest percentage of injuries, particularly among physically active individuals. For example, the knee has been reported to be the most common site of overuse injuries in runners,[74] triathletes,[18] and military recruits.[33,73] Females sustain a higher number of traumatic and overuse knee injuries when compared to males.[1,2,9,62]

Given the fact that patients with knee dysfunction comprise a large portion of orthopaedic practice, there is a need to understand the risk factors associated with knee injury as well as primary injury mechanisms. Research conducted over the last decade suggests that the causes of knee injury may have proximal origins. For example, prospective[50] and retrospective studies[37,53] provide evidence that hip muscle weakness is associated with knee injury. Furthermore, studies conducted by Zazulak and colleagues[85,86] have reported that impaired trunk proprioception and deficits in trunk control are predictors of knee injury in female athletes. In a recent review of the literature, Reiman et al[63] cited 51 articles that provide some degree of epidemiological, neuromuscular, or biomechanical evidence to support the concept that proximal factors may influence knee loading and, therefore, contribute to injury.

Given the growing awareness of the interdependence of the hip and knee joints, the purpose of this clinical commentary is to discuss the biomechanical influences of abnormal hip mechanics on knee injury. This will be accomplished through a review of pertinent tibiofemoral and patellofemoral joint biomechanics, as well as the current literature in this area. In addition, the clinical implications of this information will be discussed.

SYNOPSIS: During the last decade, there has been a growing body of literature suggesting that proximal factors may play a contributory role with respect to knee injuries. A review of the biomechanical and clinical studies in this area indicates that impaired muscular control of the hip, pelvis, and trunk can affect tibiofemoral and patellofemoral joint kinematics and kinetics in multiple planes. In particular, there is evidence that motion impairments at the hip may underlie injuries such as anterior cruciate ligament tears, iliotibial band syndrome, and patellofemoral joint pain. In addition, the literature suggests that females may be more disposed to proximal influences than males. Based on the evidence presented as part of this clinical commentary, it can be argued that interventions which address proximal impairments may be beneficial for patients who present with various knee conditions. More specifically, a biomechanical argument can be made for the incorporation of pelvis and trunk stability, as well as dynamic hip joint control, into the design of knee rehabilitation programs.

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TIBIOFEMORAL JOINT

Proximal Contributions to Abnormal Tibiofemoral Joint Kinematics

THE HIP IS THE MOST PROXIMAL LINK in the lower extremity kinematic chain and shares a common segment (the femur) with the knee. At its proximal end, the femur articulates with the acetabulum of the pelvis to comprise the hip joint. As a ball-and-socket joint, the hip provides multiplanar motion and is second only to the shoulder in terms of mobility.[51] At its distal end, the femur is tightly bound to the tibia through a complex system of ligaments, the joint capsule, and tendons.

Although the ball-and-socket configuration of the hip provides a high degree of bony stability, the joint is dependent on a complex set of muscles to create motion and provide dynamic stability. As such, impaired hip muscle performance can

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render the hip joint susceptible to dysfunction in all planes. Abnormal motion of the femur can have a direct effect on tibiofemoral joint kinematics and strain the soft tissue restraints that bind the tibia to the distal end of the femur.

During the loading response phase of walking (first 10% of the gait cycle after heel contact), the hip flexes, adducts, and internally rotates.[55,68] This triplanar motion is caused by the external moments acting at the joint and is resisted by actions of the hip extensors, abductors, and external rotators, respectively. The amount of hip flexion excursion during loading response is minimal (0°-2°) compared to the amount of adduction and internal rotation motion (10°-15°).[16,55] During higher-demand activities, such as walking on an inclined surface and running, peak frontal and transverse plane angles and joint excursions increase significantly.[16] It also has been reported that females display greater nonsagittal plane motion at the hip during walking and running than males.[16,21]

Excessive hip adduction and internal rotation during weight bearing has the potential to affect the kinematics of the entire lower extremity. More specifically, excessive hip adduction and internal rotation can cause the knee joint center to move medially relative to the foot. Because the foot is fixed to the ground, the inward movement of the knee joint causes the tibia to abduct and the foot to pronate, the end result being dynamic knee valgus (**FIGURE 1**). Excessive knee valgus has been shown to be related to diminished hip muscle strength[17,30,32,81] and has been implicated in contributing to numerous knee injuries, including anterior cruciate ligament (ACL) injury[29] and patellofemoral joint dysfunction.[58]

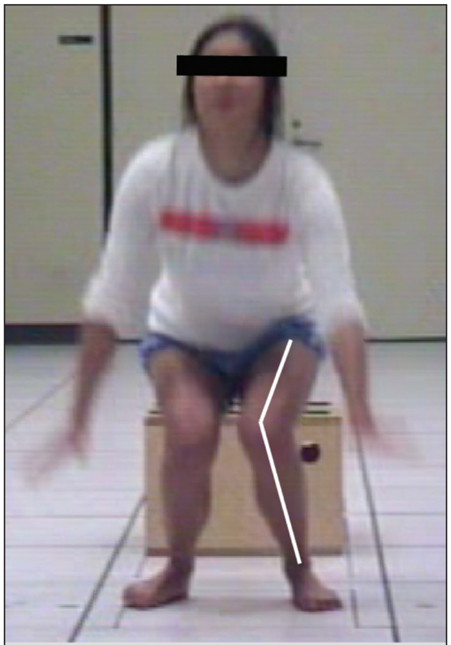

FIGURE 1. Dynamic knee valgus resulting from excessive hip adduction and internal rotation. Because the foot is fixed to the floor, excessive frontal and transverse plane motion at the hip can cause medial motion of the knee joint, tibia abduction, and foot pronation. Reproduced with permission from Powers CM. The influence of altered lower extremity kinematics on patellofemoral joint dysfunction: A theoretical perspective. *J Orthop Sports Phys Ther.* 2003;33:639-646.

It has been reported that hip adduction is the primary contributor to excessive dynamic knee valgus.[30,80] As such, excessive hip adduction would be expected to strain the soft tissue restraints that limit knee valgus (ie, the medial collateral ligament, medial patellofemoral ligament, and ACL). As a transverse plane motion, hip internal rotation plays less of a role in the observed medial collapse of the lower extremity. However, internal rotation of the femur on a relatively fixed tibia would strain the structures that limit this motion (ie, the medial collateral ligament, lateral collateral ligament, and popliteus).

Proximal Contributions to Abnormal Tibiofemoral Joint Kinetics

The moments acting on the tibiofemoral joint play an important role with respect to injury. The external moments created by the resultant ground reaction force vector are resisted internally by muscles and noncontractile tissues such as ligaments and the joint capsule. Generally speaking, the orientation of the resultant ground reaction force vector with respect to the joint center dictates the direction and magnitude of the moments acting at the knee. In turn, the location of the body center of mass relative to the center of pressure can have an influence on the orientation of the resultant ground reaction force vector. Because the location of the body center of mass is largely influenced by the mass of the trunk, aberrant motions of the pelvis and trunk can affect the orientation of the resultant ground reaction force vector and, therefore, the moments acting on the knee. With respect to injury, the moments in the frontal and sagittal plane are larger in magnitude when compared to the transverse plane moments and, therefore, will be discussed in greater detail.

Frontal Plane During weight-bearing activities such as walking and running, the resultant ground reaction force vector passes medial to the knee joint center, thereby creating a varus moment at the knee (**FIGURE 2A**).[55,69] The varus moment is primarily resisted by the lateral soft tissue restraints of the knee, namely the lateral collateral ligament and the iliotibial band. Apart from increasing the tensile strain on the lateral soft tissue restraints, the varus moment creates greater compressive forces within the medial compartment of the knee compared to the lateral compartment.[82]

Medial-lateral movements of the trunk can directly influence the frontal plane moment at the knee. A key factor in this respect is pelvic stability. In the presence of hip abductor weakness, the contralateral pelvis may drop during single-limb support (Trendelenburg sign), causing a shift in the center of mass away from the stance limb. Movement of the center of mass away from the stance limb increases the distance from the resultant ground reaction force vector and the knee joint center, thereby increasing the varus moment at the knee (**FIGURE 2B**). In this scenario, the tensile strain on the lateral collateral ligament and the iliotibial band would be expected to increase, as would the compressive forces in the medial compartment of the knee. Evidence in support of this concept has been provided by Chang and colleagues,[12] who reported that the ability to generate greater hip abductor moments during walking

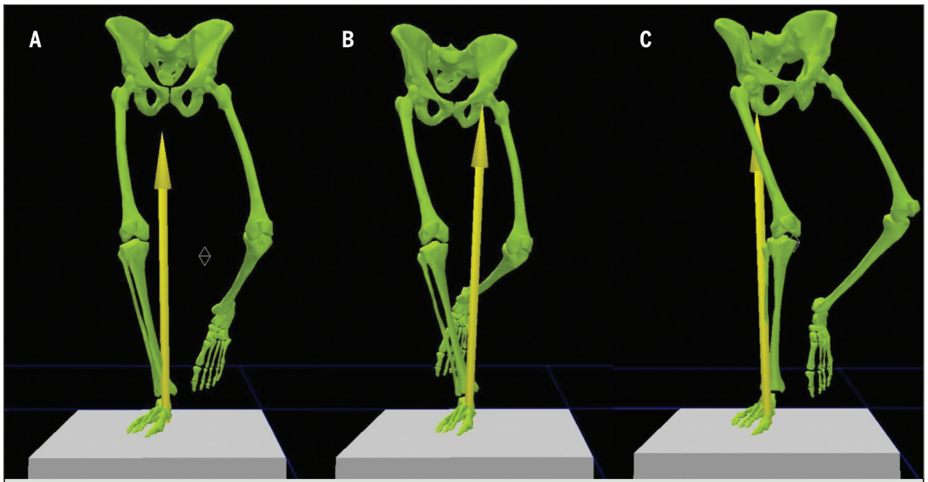

FIGURE 2. Frontal plane motions of the pelvis and trunk can influence the moment at the knee. The example above illustrates landing from a jump on 1 foot. (A) With the pelvis level, the resultant ground reaction force vector passes medial to the knee joint center, thereby creating a varus moment at the knee. (B) Hip abductor weakness can cause a contralateral pelvic drop and a shift in the center of mass away from the stance limb. This increases the varus moment at the knee (ie, the perpendicular distance from the resultant ground reaction force vector and the knee joint center increases). (C) Shifting the center of mass over the stance limb to compensate for hip abductor weakness can create a knee valgus moment (ie, the ground reaction force vector passes lateral with respect to the knee joint center). In this scenario, medial movement of the knee joint center (ie, valgus collapse) exacerbates the problem.

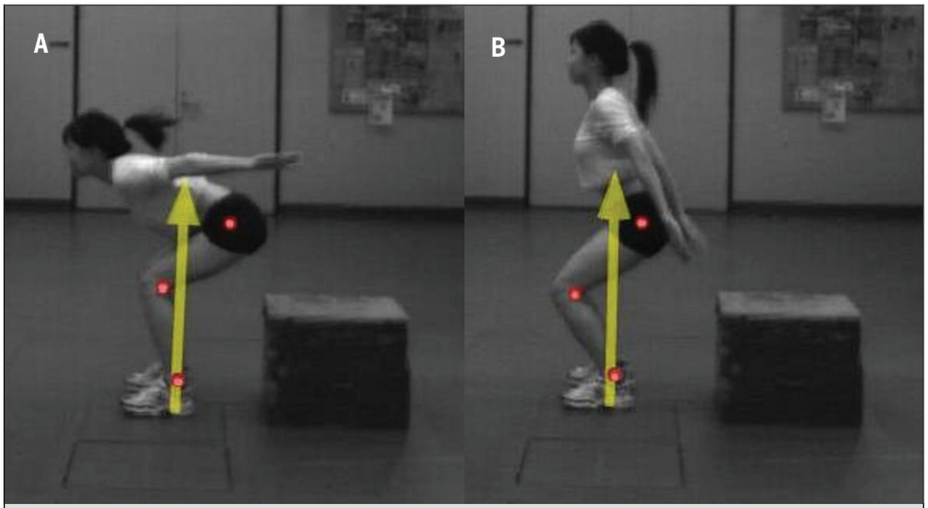

FIGURE 3. Sagittal plane motion of the trunk can influence the moments at the hip and knee. (A) Landing with the trunk forward increases the moment at the hip while decreasing the moment at the knee. (B) Landing with the trunk erect increases the moment at the knee while decreasing the moment at the hip.

was protective against ipsilateral medial compartment osteoarthritis progression in older adults.

A common compensation for hip abductor weakness is to elevate the contralateral pelvis and leaning the trunk towards the stance limb. This maneuver, known as "compensated Trendelenburg sign," moves the resultant ground reaction force vector closer to the hip joint center, thereby reducing the demand on the hip abductors.[51] However, the compensation employed to accommodate hip abductor weakness may have a negative consequence for the knee. For example, excessive movement of the center of mass over the stance limb during an activity such as cutting or a landing from a jump on one foot could move the resultant ground reaction force vector lateral to the knee joint center, thereby creating a valgus moment at the knee (**FIGURE 2C**). In contrast to the typical varus moment, a valgus moment would place a tensile strain on the medial soft tissue restraints of the knee, particularly the ACL and medial collateral ligament. A movement pattern consisting of a shift in the center of mass over the stance limb, combined with medial motion of the knee joint center (resulting from excessive hip adduction and internal rotation), would have the greatest potential to cause a knee valgus moment. As with the knee valgus angles, high valgus moments have been shown to be associated with diminished hip muscle strength.[35]

Sagittal Plane During the loading response phase of walking, the resultant ground reaction force vector falls anterior to the hip and posterior to the knee, thereby creating flexion moments at both joints.[55,69] As such, eccentric actions of the hip and knee extensors are required to counteract these moments. As was the case with the frontal plane, orientation of the trunk in the sagittal plane can influence the muscular demands of the lower extremity. Using a drop-jump task as an example, a forward trunk lean would move the ground reaction force vector anteriorly, thereby increasing the demand on the hip extensors, while simultaneously decreasing the demand on the knee extensors (**FIGURE 3A**). Landing with more of an erect trunk would have the opposite effect, increasing the demand on the knee extensors and decreasing the demand on the hip extensors (**FIGURE 3B**).

Evidence supporting the premise that sagittal plane trunk position plays a role with respect to knee loading is evident in the work of Blackburn and Padua.[5] These authors reported that landing from a jump with the trunk flexed resulted in 28% less quadriceps activation when compared to landing with the trunk more erect. Although activity of the hip extensors was not quantified in this study, it would be logical to assume that the pattern of neuromuscular recruitment would have been opposite to that observed with the knee extensors (ie, increased hip extensor activity while landing with the trunk flexed compared to landing with the trunk erect).

A posterior trunk lean during the

stance phase of gait is a common compensatory strategy to accommodate hip extensor weakness.[55] Although a posterior trunk lean minimizes the demand on the hip extensors by reducing the hip flexion moment, this maneuver would be expected to increase the knee flexion moment and the demand on the quadriceps. Such compensatory trunk motion may have implications for several injuries at the knee, including quadriceps muscle strain, patella tendinopathy, patellofemoral joint compression, and ACL strain (resulting from quadriceps-induced anterior shear forces acting on the tibiofemoral joint).

Tibiofemoral Joint Injury Mechanisms: Proximal Factors

As noted above, an argument can be made that proximal factors can contribute to abnormal tibiofemoral joint loading. In addition, there is growing recognition that knee joint injuries may stem from proximal dysfunction. In this respect, 2 conditions have received considerable attention in the literature: ACL injury and iliotibial band syndrome (ITBS). Each will be discussed in the context of the proximal influences that may contribute to injury mechanics.

Anterior Cruciate Ligament Injury Tears of the ACL are one of the most common knee injuries sustained by individuals who engage in athletics and recreational activities. ACL tears occur when the external loads placed on the knee exceed the tensile strength of the ligament. In that context, in vitro studies have demonstrated that the greatest ACL strain occurs with a combined loading pattern consisting of frontal and transverse plane joint moments and anterior tibial shear.[45] The strain on the ACL has been reported to be greater when these loads are applied with the knee in a position of relative extension (<40° of flexion) compared to greater flexion values.[20,45]

It has been reported that the incidence of ACL tears is higher in females compared to males,[1,2,28,44,48,62] and, as such, research attempting to identify risk factors for ACL injury has focused on biomechanical differences between genders. To this end, studies in this area consistently have reported that females exhibit a biomechanical profile that is thought to place them at an increased risk for ACL injury. Notably, female athletes have been shown to perform athletic maneuvers with decreased knee and hip flexion,[38,43,47,56] increased quadriceps activation,[43,67] and greater knee valgus angles and moments[13,32,43,47,67] when compared to males. With respect to injury risk, the greater knee valgus moments and angles observed in females are thought to be most problematic, as it has been reported that these variables are predictors of ACL injury.[29]

Although the reasons underlying the biomechanical profile exhibited by females are not entirely clear, there is growing evidence to suggest that proximal factors may play a contributory role. As noted above, several studies have reported that reduced hip strength is related to greater knee valgus angles[17,30,32,81] and valgus moments.[35] Pollard et al[57] suggests that higher knee valgus angles and moments observed in female athletes is representative of a movement strategy in which there is insufficient utilization of the hip extensors to decelerate the body center of mass. More specifically, these authors reported that females who exhibited higher knee valgus angles and moments had lower hip extensor moments and less energy absorption at the hip during the deceleration phase of a drop-jump task. In contrast, females who relied more on the hip extensors to absorb impact forces had lower knee valgus angles and a 53% reduction in the average knee valgus moment.[57] Although hip strength was not quantified as part of this study, the authors proposed that if the hip extensors were unable to adequately contribute to the deceleration of the body center of mass during landing, individuals may compensate by relying more on the quadriceps and the passive restraints in the frontal plane (ie, ligaments) to absorb impact forces.

Although there is evidence to suggest that hip muscle weakness may underlie the biomechanical patterns thought to place female athletes at risk for ACL injury, this finding is not consistent across all studies. For example, 2 investigations have reported no relationship between hip strength and knee valgus angles or moments.[66,76] Furthermore, a recent study by Mizner and colleagues[49] demonstrated that improved landing biomechanics following a single training session (ie, decreased knee valgus moments and angles) was independent of muscle strength. Such a finding suggests that additional factors, such as impaired motor control, may play a role with respect to movement pattern that are thought to be associated with ACL injury. Prospective studies are needed to fully examine the role of proximal impairments in relation to ACL injury.

Iliotibial Band Syndrome ITBS is a common cause of lateral knee pain and is the second most common overuse injury in runners.[74] The iliotibial band has its origin at the outer lip of the anterior border of the ilium and the outer border of the anterior superior iliac spine (ASIS) and inserts distally on the lateral aspect of the tibia (Gerdy's tubercle).[51] The iliotibial band also has a broad fibrous expansion that serves to anchor this structure to the femur and patella.[75]

Because the iliotibial band crosses the lateral aspects of the hip and knee, excessive frontal and transverse plane motions of the lower extremity can affect tissue strain. For example, hip adduction would be expected to increase iliotibial band tension, as its insertion would be moved further from its origin. Additionally, an increase in the varus moment of the knee would increase iliotibial band strain, as this structure plays a major role in resisting this moment.

Iliotibial band strain also can be influenced by transverse plane motions of the lower extremity. Given that the iliotibial band is anchored to the distal femur and inserts into the proximal tibia, internal rotation of the femur relative to the tibia could increase strain at the distal attachment site. Internal rotation of the tibia relative to the femur could have the same effect. A combination of altered frontal and transverse plane motions of the hip would be expected to compound the loading of the iliotibial band. Apart from the magnitude of frontal and transverse plane motions at the hip, the joint angular velocity may play a role. For example, a modeling study performed by Hamill and colleagues[27] suggests that development of ITBS may be more related to strain rate as opposed to the magnitude of strain.

Biomechanical and clinical studies support the proposed injury mechanisms described above. In a prospective study of 100 female runners, Noehren et al[54] reported that the strongest predictors of individuals who went on to develop ITBS were excessive hip adduction and knee internal rotation (ie, internal rotation of the tibia relative to the femur). The results of the study by Noehren and colleagues[54] are supported by the work of Ferber et al,[22] who reported that female runners with a history of ITBS exhibited significantly greater hip adduction compared to those who did not have a history of ITBS (10.4° versus 7.9°).

In contrast to the studies noted above, Grau and colleagues[25] have reported that persons with ITBS demonstrate less hip adduction during running when compared to control subjects. It should be noted that the cohort evaluated by Grau et al[25] consisted mostly of males, while Noehren et al[54] and Ferber et al[22] only evaluated females in their studies. Grau and colleagues[25] also assessed barefoot running as opposed to shod running, as was done in the studies by Noehren et al[54] and Ferber et al.[22]

Clinical evidence in support of a proximal contribution to ITBS has been provided by Fredericson et al,[23] who compared hip abductor strength of the involved limb of long-distance runners with ITBS to their noninvolved side, as well as to an asymptomatic control group. These authors reported that the hip abductor strength of the involved limb in the runners with ITBS was significantly reduced when compared to the noninvolved limb and the control group (20% and 18%, respectively). Following a 6-week rehabilitation program consisting of hip abductor strengthening, 92% of those with ITBS were able to return to pain-free running. At 6-month follow-up, all athletes had returned to full participation.

Although the findings of Fredericson and colleagues[23] provide evidence that hip abductor weakness may contribute to ITBS, a recent study by Grau et al[26] failed to find hip strength differences in persons with ITBS when compared to asymptomatic control subjects. It should be noted that the subjects evaluated by Grau et al[26] were asymptomatic at the time of testing. To date, comprehensive studies that have combined assessments of hip muscle performance and lower-limb kinematics/kinetics have not been performed in this population. Such data are needed to further elucidate potential mechanisms that may contribute to ITBS.

PATELLOFEMORAL JOINT

Proximal Factors Related to Patellofemoral Joint Dysfunction

PATELLOFEMORAL JOINT PAIN (PFP) is the most prevalent lower extremity condition seen in orthopaedic practice and has been cited as the most common overuse injury in persons who are physically active.[18,33,39,74] The incidence rate of PFP in females has been reported to be 2.2 times greater than in males.[9] Historically, the etiology of patellofemoral dysfunction has been attributed to abnormal tracking of the patella, which has led to the adoption of conservative interventions aimed at influencing patella motion (ie, patella taping/bracing, training of the vastus medialis oblique, patella mobilization, etc). Given that the patella articulates with the distal femur, there has been recent interest in understanding how abnormal hip motions may be contributory to PFP.

The assumption that abnormal patella tracking is the result of abnormal motion of the patella relative to the femur is based on kinematic studies that were performed under non–weight-bearing conditions or under conditions in which the femur motion was constrained.[11,34,42,59,83,84] However, recent evidence suggests that patellofemoral joint kinematics may be different during weight-bearing tasks. Using dynamic magnetic resonance imaging techniques, Powers and colleagues[60] compared patellofemoral kinematics during non–weight-bearing (seated knee extension) and weight-bearing movements (single-limb squat) in females with lateral patellar subluxation. During the non–weight-bearing condition, the patella was observed to tilt and displace laterally relative to the fixed femur (**FIGURE 4A**). In contrast, the primary contributor

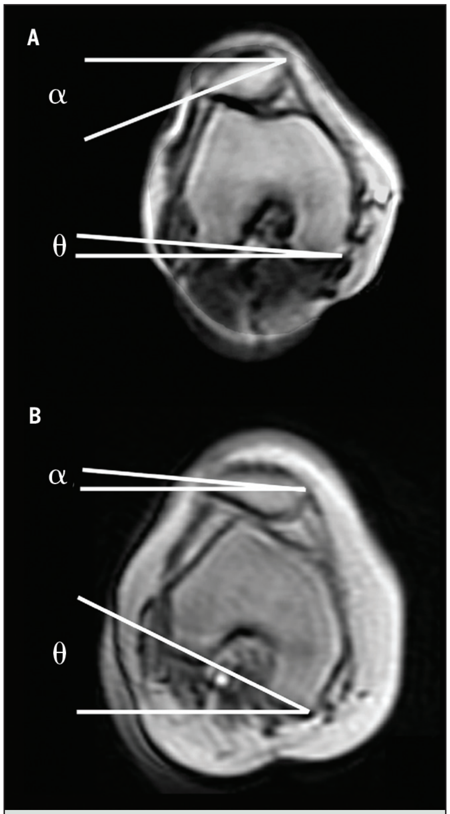

FIGURE 4. Comparison of patellofemoral joint kinematics during non–weight-bearing (A) and weight-bearing (B) conditions, as assessed using dynamic MRI. In the non–weight-bearing task (knee extension), lateral patella tilt and displacement is the result of the patella moving on a fixed femur. During the weight-bearing task (single-limb squat), lateral patella tilt and displacement is the result of the femur rotating underneath the patella. Reproduced with permission from Powers CM, et al. Patellofemoral kinematics during weight-bearing and non–weight-bearing knee extension in persons with lateral subluxation of the patella: a preliminary study. *J Orthop Sports Phys Ther.* 2003;33:677-685.

to lateral patella tilt and displacement during the weight-bearing condition was internal rotation of the femur underneath a stable patella (**FIGURE 4B**).[60] The observation that the femur moves relative to the patella during weight bearing can be explained by the fact that the patella is attached to the tibia via the quadriceps tendon. As such, quadriceps contraction during weight bearing anchors the patella to the comparatively stable tibia, allowing the femur to move underneath the extensor mechanism. Conversely, movement of the tibia during non–weight-bearing knee extension allows the patella to move relative to the fixed femur.

Using the same imaging techniques employed by Powers and colleagues,[60] Souza et al[70] compared patellofemoral joint kinematics, femoral rotation, and patella rotation between females with PFP and pain-free controls during a single-limb squat. These authors confirmed the earlier observations of Powers et al,[60] in that altered patellofemoral joint kinematics in females with PFP was the result of excessive internal rotation of the femur (nearly twice the amount observed in the control group). Taken together, the findings of Powers et al[60] and Souza et al[70] suggest that the control of femur rotation may be important in restoring normal patellofemoral joint kinematics. In addition, minimizing femoral rotation may impact patellofemoral joint kinetics, as studies have shown that abnormal femur motion relative to the tibia can result in decreased patellofemoral contact area[36,64] and increase joint stress.[4,36]

It has been proposed that altered hip kinematics may influence the lateral forces acting on the patella. The natural tendency of the patella to experience laterally directed forces is a result of the valgus orientation of the lower extremity.[24] As the quadriceps muscle follows the longitudinal axis of the femur, the quadriceps angle (Q-angle) is formed, thereby predisposing the patella to lateral forces with quadriceps muscle tension.[65] Clinically, the Q-angle is measured as the angle formed by the intersection of the line drawn from the ASIS to the midpoint of the patella and a proximal extension of the line drawn from the tibial tubercle to the midpoint of the patella.[51]

As the Q-angle reflects the frontal plane forces acting on the patella, frontal plane motion of the lower extremity would be expected to adversely affect the patellofemoral joint. In particular, excessive knee valgus resulting from hip adduction and/or tibial abduction would increase the Q-angle as the patella would be displaced medially with respect to the ASIS (**FIGURE 1**). Using a subject-specific, 3-dimensional model of the patellofemoral joint,[15] Chen and Powers[14] have reported that females with PFP exhibit excessive "dynamic" Q-angles. Most notably, the dynamic Q-angle during stair descent was found to average 39° in females with PFP compared to 24° in a pain-free control group.

The increase in the lateral forces on the patella resulting from an increase in the dynamic Q-angle would be expected to increase the lateral pressures within the patellofemoral joint. This assumption is supported by the work of Huberti and Hayes,[31] who reported that a 10° increase in the Q-angle resulted in a 45% increase in peak contact pressure on the lateral aspect of the patellofemoral joint. As such, small changes in lower limb alignment during dynamic tasks may have a large influence on patellofemoral joint loading.

Although there is growing evidence that altered hip mechanics may influence the patellofemoral joint, biomechanical studies evaluating hip kinematics in persons with PFP have produced inconsistent results. Souza and Powers[71] reported that females with PFP exhibited significantly greater peak hip internal rotation than that of a control group (7.6° versus 1.2°), when averaged across 3 different tasks (running, step-down, and landing from a jump). However, no group differences in hip adduction were observed in their study. In contrast, Willson and Davis[79] reported that females with PFP demonstrated significantly greater average hip adduction (3.5°) compared to asymptomatic subjects during running, hopping, and single-limb squatting. Interestingly, these authors found significantly less hip internal rotation in their group with PFP. Bolgla and colleagues[6] reported no differences in hip adduction or hip internal rotation between females with PFP and pain-free controls during stair descent. Finally, a recently published prospective study of biomechanical risk factors for PFP reported that increased hip internal rotation during a jump-landing task was a significant predictor of individuals who went on to develop symptoms.[10] Hip adduction did not enter into the predictive model.

The inconsistent findings noted above may be related to differences in kinematic methods and/or modeling procedures across studies, or the fact that measurement of transverse and frontal plane motions at the hip tend to be susceptible to measurement error. Alternatively, it could be that the presence of specific motion impairments at the hip may vary from person to person. Additional research is needed to determine whether a subset of patients with PFP demonstrate proximal impairments that may be contributory to their patellofemoral joint symptoms.

Despite the lack of agreement with respect to a common kinematic profile at the hip in females with PFP, a systematic review of 6 studies that compared hip muscle strength between females with PFP and control subjects concluded that there is strong evidence that females with PFP exhibit impaired strength of the hip extensors, abductors, and external rotators.[61] Recent studies by Boling et al[8] and Baldon et al[3] further support this conclusion. Lastly, Long-Rossi and Salsich[40] have reported that diminished hip external rotator strength is a predictor of self-reported functional status (Kujala rating scale) in females with PFP.

Given the retrospective nature of the studies that have reported diminish hip strength in females with PFP, care must be taken in assuming a cause-and-effect relationship. For example, it cannot be determined from these investigations whether diminished hip strength was a cause of PFP or whether diminished hip strength was the result of symptoms. Nonetheless, the findings of the above-mentioned studies are consistent with investigations that have reported successful clinical outcomes in patients who have undergone hip focused training.[7,46,77]

Despite the fact that altered hip motion and diminished hip strength are common findings in females with PFP, only 2 studies have evaluated hip strength in conjunction with hip kinematics in this population (as oppose to evaluating both separately). Bolgla and colleagues[6] reported significant reductions in isometric hip external rotator and hip abductor strength (24% and 26%, respectively) in 18 females with PFP compared to a control group, but no differences in hip adduction and internal rotation motion during stair descent were observed. Souza and Powers[72] reported that females with PFP exhibited diminished hip muscle strength in 8 out of 10 measures of muscle performance, but only isotonic hip extension endurance was found to be correlated with hip internal rotation during running. Although isometric strength was the most common mode of assessing muscle performance in the above noted studies, future investigations should consider obtaining muscle performance measures that are more representative of biomechanical function (ie, eccentric muscle power, endurance, rate of force development, etc).

CLINICAL IMPLICATIONS

In light of the studies reviewed above, there is evidence to support the contention that impairments at the hip may adversely impact tibiofemoral and patellofemoral mechanics in multiple planes. Although additional mechanistic studies and randomized controlled trials are needed before definitive treatment recommendations can be made, it can be argued that interventions which address proximal impairments may be beneficial for patients who present with various knee conditions. More specifically, a biomechanical argument can be made for the incorporation of 2 general principles into the design of an intervention program to address proximal impairments related to knee injury: (1) pelvis and trunk stability and (2) dynamic hip joint control. A brief discussion of each of these principles follows.

Pelvis and Trunk Stability

As discussed above, aberrant movements of the pelvis and trunk can influence the moments acting on the knee. During dynamic tasks, excessive trunk motions in the frontal and sagittal plane may reflect compensatory adjustments to accommodate hip muscle weakness and/or lack of pelvic control. In this respect, the muscles that maintain a level pelvis in the frontal plane (ie, the hip abductors) play an important role. In theory, improving performance of the hip abductors would result in a more optimal alignment of the pelvis during single-limb activities and, in turn, protect the knee joint from excessive frontal plane moments created by compensatory adjustments of the trunk and the resulting movement of the body center of mass.

With respect to the sagittal plane, excessive anterior tilting of the pelvis resulting from weakness of the posterior rotators of the pelvis (ie, gluteus maximus, hamstrings, and abdominals) and/or tightness of the hip flexors may result in compensatory lumbar lordosis and a resulting posterior shift in the trunk position. As described earlier, a posterior shift in the center of mass during functional activities would increase the knee flexion moment and the demand on the knee extensors, while simultaneously decreasing the hip flexion moment and the demand on the hip extensors. In such a scenario, the compensatory posterior shift of the trunk and center of mass may perpetuate hip extensor weakness and, in turn, result in greater anterior tilting of the pelvis. This chain of events may explain the clinical observations of hip extensor weakness in persons who present with excessive anterior tilt of the pelvis.

In light of the discussion above, an argument can be made that dynamic trunk stability cannot exist without pelvis stability. Although the trunk musculature (ie, abdominals, transverse abdominis, obliques, multifidi, erector spinae) plays an important role in stabilizing the spine, these muscles would not be expected to prevent compensatory trunk motions associated with poor pelvis control. Given the fact that impaired trunk proprioception and deficits in trunk control have been shown to be predictors of knee injury,[85,86] the development of "core" programs should consider dynamic pelvis stability as an integral aspect of the training protocol.

Dynamic Hip Joint Control: A Case for Improving Gluteus Maximus Muscle Performance

Throughout this commentary, a case has been made that abnormal hip and femur motions can have a deleterious effect on the tibiofemoral and patellofemoral joints. While there is some debate whether abnormal hip kinematics are the result of diminished hip muscle strength or impaired motor control, both aspects of muscle performance should be considered when implementing a rehabilitation or injury prevention program. In particular, the muscles that control hip adduction and internal rotation appear to be most relevant to this discussion.

As noted above, the tendency of the hip is to collapse into adduction and internal rotation as the hip flexes during weight bearing. This triplanar motion is most commonly observed during the weight acceptance phase of high-demand activities such as running or landing from a jump. As a single joint muscle, the gluteus maximus is best suited to provide 3-dimensional stability of the hip, as this muscle resists the motions of hip flexion, adduction, and internal rotation.[52] In contrast, the gluteus medius mainly functions to stabilize the femur and pelvis in the frontal plane.[52] Although the posterior fibers of the gluteus medius can assist in hip extension and external rotation, the overall contribution to these motions is modest at best.[52]

Apart from being a strong hip extensor, the gluteus maximus is the most powerful external rotator of the hip.[52] Its external rotation capacity is supplemented by the actions of the deep hip rotators (ie, piriformis) and the posterior fibers of the gluteus medius. Furthermore, the upper portion of the gluteus maximus has the ability to abduct the hip and demonstrates an activation pattern similar to that of the gluteus medius.[41] Thus, the frontal and transverse plane control afforded by the gluteus maximus suggests that this muscle is well suited to protect the knee from proximal movement dysfunction. Lastly, the data of Pollard and colleagues[57] suggest that improving use of the gluteus maximus in the sagittal plane may serve to "unload" the knee by decreasing the need for compensatory quadriceps action to absorb impact forces.

The ability of the gluteus maximus and gluteus medius to provide dynamic stability of the hip and pelvis may be influenced by the biomechanics of the task being performed. For example, Ward and colleagues[78] have reported that during weight bearing, the ability of the gluteus maximus and gluteus medius to generate torque decreases with increasing hip flexion. The reduction in torque generation with hip flexion can be attributed to both mechanical and physiological factors (ie, diminished leverage and less optimum muscle length-tension characteristics, respectively).[78] In addition, Neumann[52] reports that the gluteus maximus produces less hip external rotation torque at hip flexion angles greater than 60° owing to the fact that the anterior fibers of the muscle shift anterior to the hip joint axis of rotation (effectively turning this portion of the muscle into an internal rotator). As such, dynamic control of the hip and pelvis may be more of a challenge during tasks that require greater hip and knee flexion angles (ie, performing a lunge or landing from a jump).

SUMMARY

AS EVIDENT IN THE BIOMECHANICAL and clinical studies reviewed as part of this commentary, there is a large body of literature to support the assertion that proximal factors can affect tibiofemoral and patellofemoral joint mechanics. In addition, there is mounting evidence suggesting that impaired control of the hip, pelvis, and trunk likely plays a role with respect to injury mechanisms. The literature also suggests that females may be more disposed to proximal influences than males. Through an improved understanding of the potential contribution of the hip in relationship to knee injury, it is hoped that clinicians will use this information to better guide the examination process and to inform clinical decision making. Furthermore, it is anticipated that this commentary will stimulate additional research to improve our understanding of underlying pathomechanics. Such information is needed for the development of more efficient and effective knee rehabilitation and injury prevention programs. ◉

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