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The Truth on Fitness:
Must the Knees Remain Behind the Toes?

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Of the myriad tenets associated with ground based, or terminally fixed exercises, the most axiomatic appears to be the alignment of the knee over the foot.

The result of a YouTube search on forward lunges, for example, is a score of videos professing the "correct" methodology for executing the lunge. With virtually no exceptions, each video advises the performer to keep their lead knee behind their toe, or even over their ankle, when reaching the lowermost position of the exercise. Along with this, observers are instructed to keep their backs straight and vertically oriented in space. Video hosts claim that from this position, one will activate their quadriceps, hamstrings, and gluteals, and reduce the stress on their knees, the emphasis being placed on knee safety.

Evidently, this precept is derived from clinical practices in which exercises are carefully modified in order to protect patients from further injury. But what, exactly, are the concerns for knee safety, and what evidence is there in support of these practices?

One consideration when doing exercises such as squats, step-ups, and lunges, is the amount of patellofemoral joint force generated by the movements, muscle forces, and joint angles. Patellofemoral joint force, as reported in a previous Truth on Fitness segment (Juris, October, 2010), produces compressive loading of the patella on the femoral condyles. A chronic condition emanating from repeated application of these forces is "runner's knee" or patellofemoral pain syndrome. But is this condition necessarily associated with the alignment of the knee?

This question was addressed by Escamilla and associates (2009), who measured patellofemoral compressive forces while subjects performed a variety of squatting maneuvers. In two of the variations, subjects performed wall squats, in which their backs were vertical, and in contact with the wall. In the "wall squat – long," subjects placed their feet at a distance from the wall, so that their tibias were perpendicular to the floor, and their knees were aligned over their ankles. In the "wall squat – short," the subjects' feet were located at half the distance from the wall as in the long version, forming an angle between their tibias and the ground, and projecting their knees an average of 9 cm beyond their toes. In a third configuration, subjects performed a one-legged squat in free space, wherein their trunks were inclined forward, and their knees translated ahead of their toes by an average of 10 cm.

The investigators discovered significantly greater compressive loads at 90 degrees of knee flexion, during the ascent phase of the wall squat – short, compared with the wall squat – long and one legged squat. From this, one might conclude that the forward position of the knees resulted in greater knee stress.

On the other hand, the authors also found that one legged squats produced significantly less compression than the wall squat – short, and was no different from the long version of the wall squat, despite having the greatest anterior knee displacement. Apparently, knee alignment alone, was not necessarily associated with patellofemoral stress.

While patellofemoral compression is an important consideration, because of the associated chronic exercise syndromes, the real concern here is anterior tibial displacement, or shear stress, and its effects on the anterior cruciate ligament. In an effort to protect the ACL, exercise professionals usually adhere to the form restrictions described above. But once again, the evidence may not support commonly accepted practices.

In a study by Heijne, et al (2004), subjects performed four different exercises, with variable trunk angles and different relative alignments between the knee and the foot. In the step-up, the trunk was inclined slightly forward and the knee projected forward until it was aligned just above the toes. In the step-down, the trunk was vertical and the knee projected beyond the toes. A forward lunge created the same configuration as the step-up, and a one-legged sit to stand positioned the knee above the ankle with the trunk erect.

In order to measure ACL stress, the investigators used an arthroscopic procedure to insert a strain gauge on the ligament, and then conducted an anterior draw, or Lachman test, to establish baseline values of ACL strain. The four exercises were then performed, in random order, and the change in length of the ACL was expressed as a percentage increase above the baseline value.

Interestingly, there were no differences in ACL strain between any of the exercises. More specifically, in the context of this discussion, there was no difference in strain between the sit to stand exercise, in which the knee was aligned over the ankle, and the step-down exercise, in which the knee projected well beyond the toe. It's possible, therefore, that knee alignment is not a critical determinant in ground based exercises.

Parenthetically, in a related study, using the same arthroscopically inserted strain gauge, researchers discovered similar, relatively low levels of ACL strain in a squat exercise and in an open chain leg extension exercise, lending support to the notion that leg extensions are no more stressful to the ACL than ground based exercises (Beynnon, 1997). Because ACL strain values between these two types of exercises were no different, the authors "question the practice of designating closed and open chain exercises as safe and unsafe, during ACL rehabilitation." The same, therefore, could be said about handling normal knees.

The outcomes of these studies truly question the relevance of knee alignment during terminally fixed exercises. More importantly, their findings may provide greater insight into what arguably may be the real "correct" exercise technique.

Several studies, (Escamilla, 2010; Heijne, 2004; Woo, 1991; Ohkoshi, 1991) for example, have examined ACL strain at varying knee angles, from 90 degrees of flexion to full extension (0 degrees of flexion). In each case, the authors concluded that as knee flexion increased, anterior forces acting on the ACL decreased. In fact, it has been generally reported that beyond 30 degrees of knee flexion, the forces acting on the knee are primarily posterior. In other words, the loading is placed on the posterior cruciate ligament and not the ACL at all. So much emphasis is placed on the alignment of the knee when performers are fully lowered, yet this position bears little relevance to the ACL.

Anterior loading, as noted by Escamilla and others (2010), does arise between 0 and 30 degrees of knee flexion, with peak levels occurring at approximately 10 degrees, but the question is, "so what?" Anterior shear forces arise during most movements involving active knee extension. The issue isn't whether shear exists, but whether it exists at high enough levels to cause damage to the ACL.

To qualify exercise-related ACL strain, one can compare the anterior forces associated with these exercises to the tensile strength of the ligament as a whole. Escamilla et al (2010), for example, measured peak forces of 0 to 50 Newtons, over the 10 degree range of motion, when anterior forces are highest. Woo and colleagues (1991), on the other hand, calculated the tensile strength of the ACL to be from 658 Newtons, for subjects between 60 and 97 years of age, to 2160 Newtons for subjects between 22 and 35 years. In other words, the peak anterior shearing forces generated during these exercises are trivial compared to the overall tensile strength of the ACL, regardless of whether the subject is in a fully lowered or nearly extended position.

In reality, the position and angle of the knee are non-critical factors in establishing the correct body position for ground based exercises. What then, is the most important consideration? Interestingly enough, the common thread through all of these studies, including the examination of patellofemoral joint forces, is trunk position, and its associated hip angle.

In their study examining compressive loading of the patella, for instance, Escamilla and colleagues (2009) reported significantly greater patellofemoral joint force in the wall squat – short as compared with the one leg squat. In both exercises, subjects' knees were aligned well past their toes, but in the wall squat, their trunks were vertical, with their body weight shifted backwards so that they were pressing against the wall. In the one leg squat, their trunks were angled 30 – 40 degrees forward, placing their weight over their lead foot.

According to the authors, the "erect trunk produces a line of force resulting in a small hip moment and a large knee moment," whereas the forward trunk produces the opposite; a "large hip moment and a small knee moment." More plainly stated, by keeping the trunk erect, the performers increase the stress on their knees. To the contrary, while leaning and shifting weight forward, over the lead foot, they decrease knee stress and generate a greater load on the hip.

These findings are reflected in ACL studies as well. Ohkoshi et al (1991) suggest that while shearing forces are primarily posterior during weight-bearing exercises, there is a distinctive shift to an anterior force when the trunk angle is 0 degrees, thus increasing, not decreasing, the stress on the ACL. Heijne and others (2004) agree, stating that ACL strain is minimized when the hip is in a more flexed position.

These findings are corroborated by Farrokhi and associates (2008), who examined various postural configurations during lunging exercises. Two of those variations, in particular, compared an upright trunk position with one in which the trunk was inclined forward significantly, as if the subject were lifting an object off the ground, from in front of the lead foot.

The latter position generated significantly greater torque loading at the hip, as well as significantly higher levels of gluteal and hamstring activity. The result is a more posterior force and improved stabilization of the knee, not to mention the benefits derived from the applied load to the hip extensor musculature.

Say Kellis and Katis (2007), "knee joint movement is achieved through a balanced coactivation of antagonistic pairs, to maintain joint stability and movement efficiency." The real irony here, is that the very posture that practitioners purport to increase hamstring and gluteal function, actually delivers the opposite effect. Additionally, the lowered position of these movements, at which some exercise specialists express the greatest concern for ACL stability, has no effect on the ACL at all.

Another consideration is the ankle joint, and the important plantar flexor muscles which are so critical to gait and other performance maneuvers like leaping and jumping. It is curious, that in virtually all explanations of exercises such as lunges, squats, and step-ups, the plantar flexors are generally disregarded.

As demonstrated in the video analysis of the lunge (Juris, March, 2009), an upright posture actually reduces torque loading at the ankle joint, while a forward posture increases the load on the plantar flexors. This finding is supported by Farokkhi et al (2008), whose postural study revealed significantly greater joint moments at the ankle when subjects performed the forward-inclined lunge.

The truth is that the focus of attention, during terminally fixed exercises, has been largely misdirected. Instead of addressing knee position in space, one ought to first consider weight distribution – over the lead foot – and the corresponding trunk and hip angles that help performers achieve a balanced and efficient position from which to move.

From this point, one may actually discover that the stresses acting on the system are minimized, and that performance really improves. Then, perhaps, we can say that the instructed technique is "correct."

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