

The Biomechanics of Squat Depth

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The squat is widely employed as a staple exercise in exercise programs, both for athletic and recreational populations. However, significant controversy exists as to optimal squat depth, both in terms of safety and muscular activity. This paper will seek to clarify these issues, and provide recommendations for performance.

Squatting safety continues to be a concern amongst some practitioners, particularly as it relates to performance at high knee flexion angles. The theory that deep squats heighten injury risk can be traced to studies conducted by Karl Klein at the University of Texas. Using a self-developed measuring device, Klein noted that weightlifters who frequently performed deep squats displayed an increased incidence of laxity in the collateral and anterior cruciate ligaments compared to a control group that did not (8). Klein concluded that squatting below parallel had a detrimental effect on ligamentous stability and should therefore be discouraged. Soon thereafter, the AMA came out with a position statement cautioning against the performance of deep knee exercises because of their potential for severe injury to the internal and supporting structures of the knee joint.

Subsequent research, however, has refuted Klein's findings, showing no correlation between deep squatting and injury risk (13,15,18). In fact, there is some evidence that those who perform deep squats have increased stability of the knee joint. In a study using a knee ligament arthrometer to test nine measures knee stability, Chandler, et al. found that male powerlifters, many of them elite class, demonstrated significantly tighter joint capsules on anterior drawer tests compared to controls (3). Moreover, both the powerlifters as well as a group of competitive weight lifters were significantly tighter on the quadriceps active drawer tests at 90 degrees of knee flexion than control subjects.

Contrary to Klein's hypothesis, ACL and PCL forces have been shown to diminish at higher degrees of knee flexion. Peak ACL forces occur between 15 – 30 degrees of flexion, decreasing significantly at 60 degrees and leveling off thereafter at higher flexion angles (7, 11, 16). PCL forces rise consistently with every flexion angle beyond 30 degrees of knee flexion, peaking at approximately 90 degrees, and declining significantly thereafter (10). Beyond 120 degrees, PCL forces are minimal (12).

The reduction in ACL and PCL forces associated with deep squatting is believed to be a result of an impingement between the posterior aspect of the upper tibia with the posterior femoral condyles as well as compression of various soft tissue structures including menisci, posterior capsule, muscle, fat, and skin (9). This helps to constrain the knee joint, significantly reducing anterior and posterior tibial translation and tibial rotation compared to lesser flexion angles. Hence, tolerance to load is enhanced in the deepest portion of the squat with a protective effect conferred to ligamentous structures.

It can be argued that ligamentous injury risk during squatting is actually greatest in the parallel squat—the position where PCL forces are at their apex. However, the magnitude of maximal posterior shear during squat performance (approximately 2,700 N) is well below the strength capacity of a young, healthy person's PCL, which is estimated to exceed 4,000 N (5). It should also be noted that regimented resistance training confers an adaptive response in connective tissue, increasing its strength capacity (1). A stronger ligament serves to improve tolerance to load, thus further reducing the prospect of injury.

The greatest risk for injury during deep squatting would theoretically be to the menisci and articular cartilage (5, 10). Tibiofemoral compressive forces have been shown to peak at 130 degrees of knee flexion where the menisci and articular cartilage bear significant amounts of stress (14). Deep squats may also increase susceptibility to patellofemoral degeneration given the high amount of patellofemoral stress that arises from contact of the underside of the patella with the articulating aspect of

the femur during high flexion (6). However, there is little evidence to show a cause-effect relationship implicating an increased squat depth with injury to these structures in healthy subjects.

Squat depth has been shown to have a significant effect on muscular development at the hip and knee joints, particularly with respect to the gluteus maximus (GM). Caterisano, et al. demonstrated that while average muscle activity of the GM was not significantly different in both the partial squat ($16.92 \pm 8.78\%$) and parallel squat ($28.00 \pm 10.29\%$), it increased significantly during the full squat ($35.47 \pm 1.45\%$) (2). Similar results were shown for peak values, which displayed significantly greater activity during performance of the full squat as compared to lesser squat depths.

As opposed to the GM, squat depth has little effect on hamstrings involvement. Maximum hamstrings activity tends to occur between 10 to 70 degrees of flexion, but the magnitude of variation in peak and mean torque is not significant between partial squats, parallel squats and full squats (4, 17, 19). This is consistent with the bi-articular structure of the muscle complex. Since the hamstrings function both as hip extensors and knee flexors, muscle length remains fairly constant throughout performance, providing a relatively even force output.

Muscular forces at the knee are largely produced by the quadriceps femoris, with muscle activity peaking at approximately 80 to 90 degrees of flexion and remaining relatively consistent thereafter (4, 19). This would seem to infer that squatting past 90 degrees is superfluous if the goal is to maximize the development of the quadriceps.

In conclusion, there is scant evidence to show that deep squats are contraindicated in those with healthy knee function. The decision as to how low to squat should therefore be based on an individual's performance-oriented goals and considered in conjunction with any pathological issues that may be apparent. Those with PCL disorders should refrain from squatting below 50 to 60 degrees until the injury is fully healed. Disorders such as chondromalacia, osteoarthritis, and osteochondritis may also contraindicate the performance of deep squats. To optimize development of the gluteus maximus, squats should be carried out through their full range of motion. To target the quadriceps femoris, a squat depth of 90 degrees appears to be optimal.

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