How Deep Should My Athlete Squat?

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Throughout my professional career whether treating patients in the clinic, athletes in the training room, or training athletes for enhanced athletic performance, parents, coaches, professional peers, athletes, patients and even physicians have all asked me the question "How deep should the athlete squat"? This question has been the subject of controversy over past decades since Dr. Karl Klein published his research stating the deep knee bend squat exercise is detrimental and stretches the ligaments of the knee. Prior to answering the question "How deep should the athlete squat?" the initial question to address is "Why should the athlete squat?" The squat is a total body exercise that provides many benefits in both the rehabilitation and performance enhancement training settings. Research has documented many benefits for the execution of the squat exercise. Some of these include but are not limited to the following:

- Enhanced lower extremity and hip strength qualities
- The body works as a "system" symmetrically, not in isolation
- Takes advantage of the principles of a closed kinetic chain activity
- Is performed with the application of force into the ground surface area as necessitated for athletic performance and activities of daily living
- Enhanced performance in the vertical jump
- Enhanced sprint starting abilities
- Enhanced performance in the 10 yard and 40 yard sprints
- Enhanced levels of work capacity
- Enhanced levels of muscle and joint "stiffness" an essential component for both safe and successful loaded/intense exercise performance and a requirement for an optimal stretch shortening cycle during plyometric activities

Strength is the physical quality from where all other physical qualities evolve. Strength contributes to the success of many athletic endeavors including the testing of such physical assessments as the proficiency to start, sprint, and jump. Various athletic competitions also necessitate the physical confrontation of an opponent where enhanced strength levels may provide an advantage. These are a few of the many reasons to consider the squat exercise as a component of training.

Should my athlete squat deep?

Although the squat exercise has substantiated benefits, the professional must "critically think" and utilize sound judgement to determine if the athlete is appropriate not only to participate in the

performance of the squat exercise but how "deep" a knee bend position the athlete should assume. Some squat exercise considerations include but are not limited to the following:

- The biological as well as the training age of the athlete
- The anatomical variants and morphology of the athlete
- The medical and orthopedic history of the athlete
- The athletes familiarity and demonstrated execution of the squat exercise
- The supervision and coaching the athlete receives during training

Many professionals utilize the overhead squat as an evaluative tool of the athlete's level of "mobility". Thus if this deep knee bend position is assumed "safe" for evaluative purposes why is there such concern with the deep squat exercise itself? Should the concern lie with the deep squat exercise or with the ill-timed incorporation of the exercise in association with inappropriate programming of the executed weight intensities and exercise volumes? Is this scenario a consequence of a poor exercise or a poor implementation of the exercise selection with unfavorable programming by the professional? Why is the squat exercise itself usually blamed?

Hans Selye has established the General Adaptation Syndrome (GAS) principle which asserts that an *unaccustomed* stress is necessary for adaptation to take place. Thus if the programmed applied stress (exercise selection, weight intensity, exercise volume) is unique in that the athlete has never experienced this type and/or increased level of stress previously, couldn't one inquire if *any exercise* is truly 100% safe? The assorted deep knee bend exercises i.e. back squat, front squat, split squat, variations of the deadlift, etc., utilized in both rehabilitation and performance enhancement training all place unaccustomed stress upon the body. This is one reason why specific exercises are incorporated into training. All exercises place "general" and specific "focal" areas of stress upon the body thus why the ability to critically think is vital to the exercise selection, exercise performance, and program design.

Is deep squatting harmful to the knees?

The deep knee bend position places increased stress (forces) at both the patella-femoral (PF) and tibio-femoral (TF) joints of the knee. It is important for the professional to not only determine how deep to squat but the type of squat exercise most beneficial for each athlete as well. The professional must also prepare the athlete prior to their participation in the squat exercise. Preparation of the athlete for the squat exercise performance will be discussed later in the commentary.

Many researchers have demonstrated the benefits of the squat exercise performance without detrimental effects upon the knee joint. The knee joint forces that occur during deep knee flexion are compressive and shear in nature (Figure 1).

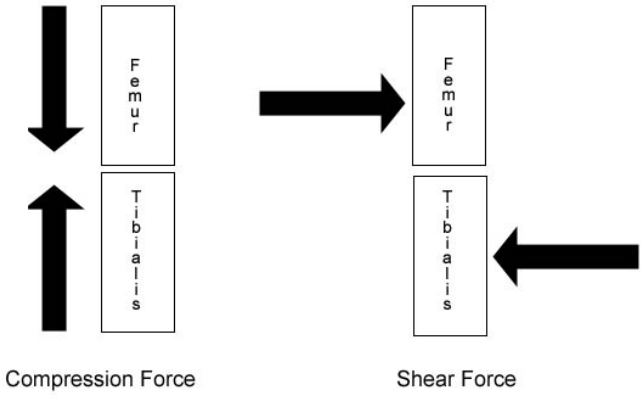

Figure 1 Compressive and Shear Joint Forces

Most shear forces that transpire during the squat exercise performance occur in the transverse (i.e. rotational) and sagittal (i.e. front to back) planes. These forces are primarily absorbed by both the anterior cruciate (ACL) and posterior cruciate (PCL) ligaments. It is important to note that when knee joint muscles are loaded active tibial rotation and translation actually remain unchanged between 50 and 120 degrees of knee flexion and even decrease between 120 and 150 degrees of knee flexion (8). ACL forces peak between 0-30 degrees, significantly decrease at 60 degrees, and remain constant through maximal knee flexion (9). This information would indicate that as knee flexion angles increase and the knee translates anteriorly as the squat progresses past parallel, the joint shear forces and consequential ligament stress do not increase. Tissue such as the menisci, structures with the role of absorbing tibio-femoral compression forces are susceptible to shear forces and based on the individual circumstances, may be at risk when loaded knee flexion surpasses 90 degrees. These individual based precautions are part of the critical thinking process.

Compressive forces also occur during the execution of the deep squat exercise. These forces are found at both the PF and TF joints of the knee. These compressive forces increase as a result of:

- Joint contact areas (i.e. patella and trochlea)
- Muscle contractile force
- Squat depth
- Load
- Velocity
- Increase in loading-duration

Increased compressive forces correlate with squat depth and muscle contractile force thus there is concern with excessive joint compression forces that could lead to the possible breakdown of menisci and articular cartilage. Therefore the determination of compression force risk once again lies in the critical thinking capacity of the professional to determine what is necessary (exercise depth, weight intensity, and repetition volume) and what is excessive for each individual athlete. It is also important to

note that PF and TF knee joint shear and compressive forces occur with ALL deep knee bend type exercises.

Increases in PF compression forces (Figure 2) that transpire with increased knee flexion peak at 70 – 100 degrees, however the PF contact area (patella and trochlea) continue to enlarge with increased knee flexion. Due to this phenomenon PF stress actually decreases when knee flexion exceeds 90 – 100 degrees (3).

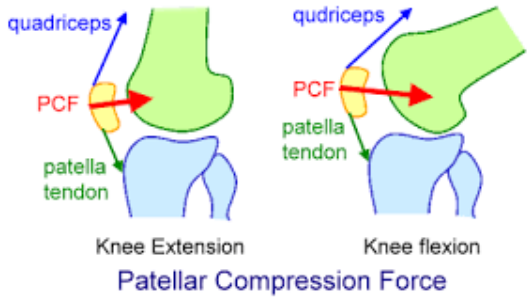

Figure 2 Patella Compressive Force

One may also contend that the higher intensity loads that may be utilized during limited (partial) squat range of motion (ROM) i.e. 0 – 45 degrees, 0- 70 degrees, etc. exercise performance may actually result in excessive PF compressive forces vs. the comparative lighter loads that are utilized during deep squat exercise performance. During limited ROM squat exercise performance higher weight intensities may be lifted with the resulting PF compressive forces distributed over a smaller PF contact area. It should also be noted that it has been recognized that weightlifters and sprinters display significantly greater patella cartilage thickness than the non-athletic population. (5, 6)

Deep Squat Knee Joint Stress vs. Other Activities

The literature has also demonstrated that a 78kg male marathon runner training for 6 months at a speed of approximately 4 meters/second gives rise to peak TF compressive forces of approximately 6400 N when compared to a deep squat of 250kg resulting in TF compressive forces of approximately 7000 N. (11) This accumulative stress of running likely exceeds the TF stress of squatting even with heavy loads. That stated neither of these activities likely surpass the stress capacity of the TF joint. It has also been noted that in 117 older age soccer players and weightlifters (45-68 years) have approximately the same prevalence of knee osteoarthritis (OA) 29% and 31% respectively. Soccer players had the highest incidence of tibio-femoral OA (26%) and the weightlifters had the highest incidence of patella-femoral OA (28%). (7)

In a publication by Fitzgerald and McLatchie (4) reviewing 25 experienced national and/or international weightlifters, age range 24 – 49 years (mean 35.3 years) with 6-32 years of weightlifting experience (mean 17 years) and body weights ranging from 51Kg to 127 Kg (mean 83 Kg) the knee joint

degenerative changes found via radiological evaluation did not exceed the incidence found in the general population.

Research published by myself and Hall of Fame S&C Coach Johnny Parker (12) where 32 NFL players consistently performed the squat exercise below parallel twice weekly with an average weight intensity of 130% to 200% body weight over a 21 week period of training. Of the 2440 knee ligament (arthrometer) tests performed only 8 tests demonstrated knee joint excursions of greater than 2 millimeters. Thus there was no adverse effect to the ACL or PCL ligaments of the knee as a result of deep squat exercise performance. There was also no evidence or documented complaint of meniscal, articular cartilage, or other knee joint impairment during this 21 week period of training. The same may be said of my experience as the Head S&C Coach at St. John's University of New York. Our athlete's squatted as deep as individually possible. This did take some time and coaching with our tall and inexperienced squatting athletes however, in my 10 years at SJU not one of our athletes tore their meniscus, ruptured a lumbar disc, etc. during their weight room training. The similar results occurred with the athletes I supervised at the Professional football and soccer teams where I held the same Head S&C position.

What about the back?

Concern has also been expressed regarding the stresses that occur to the spine during deep knee bend exercise performance. These same compressive and shear forces that occur at the knee joint also transpire at the spine and sacroiliac (SI) joint (Figure 3).

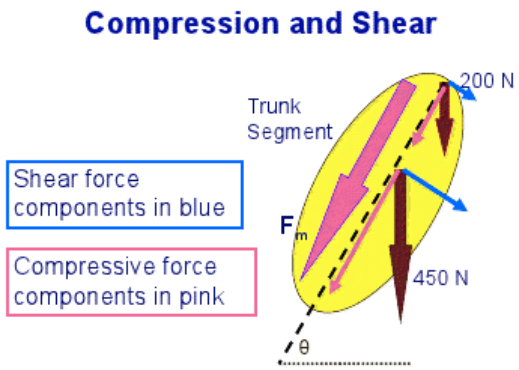

Figure 3 Compression and Shear Forces at the Spine

Exercises such as the back squat and deadlift produce high stress forces at the low back/lumbar spine while a split legged lower extremity position i.e. lunge, Bulgarian squat, and etc. produce higher stresses upon the SI joint. It should be noted that up to 30% of all low back pain occurs due to SI joint pathology (2). These low back exercise stresses are counteracted with factors such as proper exercise technical performance, intra-abdominal pressure and appropriate low back strength levels to name a few. Regardless of the nature of the standing posture lower extremity exercise performed stress reactions will occur at the spine and SI joint. The athlete's adopted posture during the specific lower extremity exercise performance will determine the areas of focal stress.

The most advantageous way to avoid the incidence of injury during the execution of the squat or any exercise performance for that matter is to prepare the athlete for the ensuing task at hand. The preparation for the performance of an applied weight intensity deep knee bend exercise should include, but is not limited to the following:

- Ample joint mobility and soft tissue compliance to assume a proper deep knee bend exercise posture
- Technical proficiency in the execution of the deep knee bend exercise
- Ample low back strength
- A sufficient work capacity for repetitive non-fatiguing deep knee bend exercise performance
- Experienced and qualified coaching and supervision
- Safe training environment

The execution of any exercise places unaccustomed stress as well as emphasized focal area stress upon various anatomical structures of the body. Appropriate candidate selection, exercise selection, training preparation, and ideal programming will ensure a safe training process resulting in optimal exercise performance.

Why the athlete should squat deep

Various authors have demonstrated that the deep knee bend position results in greater levels of hip and lower extremity muscle activity. A recent publication by my friend Dr. Loren Chiu (1) has demonstrated that squat depth independent of barbell load has a significant effect on the extensor mechanism (quadriceps) muscle activity. Dr. Chiu has also established that the deep knee bend position (greater than parallel) is necessary for optimal relative muscular effort (RME) of the knee extensor musculature to occur. RME may be defined as the muscular force required when performing a task relative to the maximum force a muscle and/or muscle group can produce. In fact the depth of the squat exercise performance was found to be a greater contributor to knee extensor RME when compared to the barbell load. In addition, research has also shown sit to stand tasks involve the same muscle and joint actions as the concentric phase of the squat exercise as lower chair heights also increase knee extensor RME.

Since squat depth appears to be a major component to knee extensor RME a planned progression should be emphasized to achieve a technically proficient and pain-free deep knee bend exercise depth. At the time appropriate deep knee bend exercise depth is achieved, loads may be increased to ensure adaptation of all contributing exercise muscle groups (i.e. hip extensors, quadriceps, plantar flexors, etc.). This is especially true of the hip and plantar flexor musculature as enhanced RME levels transpire at these muscle groups with both squat exercise depth AND barbell load. Enhancing the strength levels of the musculature of the hip has been demonstrated to be beneficial for sprinting, jumping,

deceleration, and change of direction abilities. Increases in hip muscle strength have also been noted to assist in resolving PF pathology.

Additional exercises are also incorporated by the athlete during training to enhance their physical quality capabilities. More often than not these additional exercises are performed through a full ROM. Why should the performance of the squat exercise be any different? Since lower extremity muscle activity is influenced upon executed squat exercise depth, without the documentation of exercise contraindications, why would the most beneficial ROM of the squat exercise performance be deliberately avoided by the training athlete?

Contraindications for the deep squat position

The deep squat exercise as well as any other deep knee bend or planned exercise performance may not be applicable for every athlete. Contraindications to consider include but are not limited to the following:

- Poor demonstrated technical exercise performance
- Morphology and anatomical variants
- Medical history
- Orthopedic pathologies of the low back, hip, knee, and ankle
- Insufficient low back strength
- Poor work capacity
- Absence of reliable coaching/supervision

Summary

The enhancement of the athlete's physical qualities is imperative for optimal athletic performance to ensue. The utilization of various exercises for the purpose of the application of unaccustomed stress will accomplish this goal. The incorporation of the deep squat exercise will also assist in the evolvement of these physical qualities as well as overall performance. The application of the deep squat exercise in the appropriate setting under proper supervision and programming, as with any exercise, can be accomplished without increased adherent risk to the athlete. Professionals should be aware of the medical and physical characteristics of their athlete, the scientific literature for familiarization of the benefits as well as the "stresses" of the deep squat exercise, and incorporate a "critical thinking" process to ensure a safe and appropriate exercise selection and program design for the well being of the athlete.

References

1. Bryanton MA, Kennedy MD, Carey JP, and Chiu LZF, "Effect of Squat Depth and Barbell Load on Relative Muscular Effort in Squatting", J Strength Cond Res 26(10): 2820-2828, 2012
2. Cohen SP, Chen Y, and Neufeld NJ, "Sacroiliac joint pain: a comprehensive review of epidemiology, diagnosis and treatment", Expert Rev Neurotherapeutics 13(1): 99-116, 2013

3. Escamilla RF “Knee biomechanics of the dynamic squat exercise”, Med Sci Sports Exer 33: 127 – 141, 2001
4. Fitzgerald B and McLatchie GR, “Degenerative Joint Disease in Weight-Lifters Fact or Fiction?” Brit J Sports Med, 14 (2,3):97-101, 1980
5. Gratzke C, Hudelmaier M, Hitzl W, Glaser C, and Eckstein F, “Knee Cartilage Morphologic Characteristics and Muscle Status of Professional Weight Lifters and Sprinters”, Amer J of Sports Med 35(8): 1346 – 1353, 2007
6. Grzelak P, Domzalski M, Majos A, Podgordki M, and Stefanczk, “Thickening of the knee joint cartilage in elite weightlifters as a potential adaptation mechanism”, Clinical Anatomy 27(6): 920-928, 2014
7. Kujala UM, Kettunen J, Paananen H, Aaalto T, et al, “Knee Osteoarthritis in Former Runners, Soccer Players, Weight Lifters, and Shooters”, Arthritis and Rheum 38(4): 539 – 546, 1995
8. Li G, Zayontz S, DeFrate LE, Most E, et al, “Kinematics of the knee at high flexion angles: an in vitro investigation”, J Ortho Res 22: 90-95, 2004
9. Li G, Zayontz S, Most E, DeFrate LE, et al, “In situ forces of the anterior and posterior cruciate ligaments in high knee flexion: an in vitro investigation”, J Ortho Res 22: 293-297, 2004
10. McBride JM, Blow D, Kirby TJ, Haines TL, et al, “Relationship Between Maximal Squat Strength and Five, Ten, and Forty Yard Sprint Times”, J Strength Cond Res 23(6): 1633 – 1636, 2009
11. McCormack and Mansour JM, “Reduction in tensile strength of cartilage precedes surface damage under repeated compressive loading in vitro”, J of Biomech 31:55 – 61, 1997
12. Panariello RA, Parker JW, Backus S, “The Effect of the Squat Exercise on Anterior-Posterior Knee Translation in Professional Football Players”, Amer J Sports Med 22(6): 768 – 773, 1994