N.S.C.A. POSITION PAPER

The Squat Exercise in Athletic Conditioning: A Position Statement and Review of the Literature

Position Statement: The following nine points related to the use of the squat exercise constitute the Position Statement of the Association. They have been approved by the Research Committee of the Association.

1. Squats, when performed correctly and with appropriate supervision, are not only safe, but may be a significant deterrent to knee injuries.

2. The squat exercise can be an important component of a training program to improve the athlete's ability to forcefully extend the knees and hips, and can considerably enhance performance in many sports.

3. Excessive training, overuse injuries and fatigue-related problems do occur with squats. The likelihood of such injuries and problems is substantially diminished by adherence to established principles of exercise program design.

4. The squat exercise is not detrimental to knee joint stability when performed correctly.

5. Weight training, including the squat exercise, strengthens connective tissue, including muscles, bones, ligaments and tendons.

6. Proper form depends on the style of the squat and the muscles to be conditioned (see **Appendices A** and **B**). Bouncing in the bottom position of a squat to help initiate ascent increases mechanical loads on the knee joint and is therefore contraindicated (6).

7. While squatting results in high forces on the back, injury potential is low with appropriate technique and supervision.

8. Conflicting reports exist as to the type, frequency and severity of weight-training injuries. Some reports of high injury rate may be based on biased samples. Others have attributed injuries to weight training, including the squat, which could have been caused by other factors.

9. Injuries attributed to the squat may result not from the exercise itself, but from improper technique, pre-existing structural abnormalities, other physical activities, fatigue or excessive training.

The following literature review has been prepared by the authors in support of the aforementioned position statement.

National Strength & Conditioning Association

C.S.C.S.® COACHES' SCHOOL

The Squat Exercise in Athletic Conditioning: a Review of the Literature

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Controversy has existed over the safety of the squat exercise for many years. Many strength coaches and professionals consider the squat exercise essential for the full development of athletic potential (19, 55). O'Shea and Wegner stated that "the full squat must be considered the cornerstone exercise, because it quickly stimulates overall strength increases in both men and women. Neglecting this exercise retards overall physical development and prevents the athlete from achieving optimal performance" (48). Yet controversy remains over the safety of the squat exercise in physical conditioning programs (11). Concern has been directed primarily toward the potential for knee and back injuries. Research in the early 1960s indicated that full squats (below parallel) damaged the knee joint by stretching the ligaments (35). Despite the fact that more recent evidence does not support this contention (11, 33, 44, 66), it is still accepted by some practitioners in the strength and conditioning field (12).
Significant benefits of strength training, including the squat exercise, include increased ligament and tendon strength and bone density (6, 7, 22, 41, 60); development of the large muscle groups in the lower back, hip and knee (5, 48, 49); improved strength, speed and power of the leg and hip musculature (53, 54, 55, 59 61); and improved neuromuscular efficiency that aids performance in biomechanically similar movements (49, 50, 55; see also NSCA Position Stance on Explosive Exercises and Explosive Training).

In light of the controversy associated with squat exercises, a review of literature on the subject is appropriate. The purpose of this paper is to evaluate scientific information on the effects of the squat exercise, so that reasonable guidelines may be established and unrealistic fears eliminated. Various types of squats can be performed, and it is not practical to address each type. Although this paper deals primarily with back squats, some conclusions would hold true for other types. The mechanics of each type of squat have both similarities and dissimilarities with the traditional back squat. For this paper, squat exercises will be defined according to Chandler (12). Full squats are defined as squatting to the point where the tops of the thighs are parallel to the floor or below. Other squats include: quarter squats, upright position minus 30 degrees of knee flexion; half squats, upright position minus 60 degrees of knee flexion; bench squat, to a bench at approximately knee height; parallel squats, with the backs of the thighs parallel to the floor; and front squats, with the tops of the thighs parallel to the floor or below and the weight held in front of the neck on the shoulders. Typically, front squats are performed at a depth considerably below parallel.

The Knee

As early as 1961, Klein researched the effect of the squat exercise on knee stability (35). He examined the knees of competitive weightlifters, using standard orthopedic tests of medial and lateral knee stability, and concluded that deep knee bends with resistance stretched the knee ligaments. He later developed an instrument to test medial and lateral knee stability, with similar results (36). Klein's work is the only research found to indicate that squats are detrimental to knee stability. Subsequent research has indicated that the squatting motion has no detrimental effect on medial and lateral knee stability (43, 44, 66), rotational stability (33), or anterior and posterior knee stability (11). Meyers, using Klein's instrument and assigning subjects randomly to selected variations of the deep- and half-squat exercises, reported no significant differences in collateral ligament stability, quadricep strength or knee joint flexibility (43). It should be noted that Klein's criticism was of "full squats" and that he recommended "parallel squats." The reliability of Klein's measurements has been questioned (52, 64).

Various forms of exercise have been shown to enhance ligament strength. Endurance training in animals has increased the strength of the ligament-to-bone attachment and the diameter and collagen content of ligaments (62). Tipton et al. reported that sprint training in animals increased ligament weight and weight-to-length ratios, without increasing the strength of the ligament-to-bone attachment (63). Some recent reviews report that weight training strengthens connective tissues, including muscle, bone, ligament and tendon (30, 57, 58, 60). It has been speculated that high volume (multiple sets of eight to 12 repetitions) produces greater increases in connective tissue size and strength than does low volume (58).

A knee injury can be devastating, often ending an athlete's career. It is a popular belief that weight training frequently causes such injuries. But appropriate loading of the knee joint actually improves congruity by increasing the compressive forces at the knee joint (31, 65). This improves stability, which protects the knee against shear forces. Exercises that use a more complete range of motion at the knee joint may increase rather than decrease knee stability of the medial collateral ligaments and other ligaments (11, 66). Long-term exercise leads to increased collagen turnover and hypertrophy of ligaments (51, 62, 63). The healing process after microtrauma resulting from exercise may lead to increased ligament fiber strength. In response to specific exercises, collagen fibers align in a direction parallel to load forces (51, 68).

Biomechanical studies of the knee joint have been reported (46, 47). Noyes et al. demonstrated that loading speed is a factor in knee ligament injuries, with bone/ligament preparations tested at a higher loading rate failing at a higher maximum load and strain (46). This property of ligamentous tissue indicates that squatting movements could potentially be performed at relatively high speeds in a portion of the conditioning cycle without increasing injury risk. Bone also adapts positively to higher strain rates (39), which can occur with high-speed or high-force squats.

Klein proposed that loose knees increase the potential for arthritic changes to develop at the joint surfaces, due to increased micro-movements which add "wear and tear" on the joint. (37). Fitzgerald and McLatchie found significant degenerative changes in 15 to 20 percent of the lifters tested, which is no higher than in the general population of the age group studied (18). Herrick et al. surveyed national- and international-caliber weightlifters and powerlifters, and found that they reported more knee pain than non-lifters, but experienced less clinical or symptomatic arthritis (29). Kulund et al., reporting on knee injuries in 80 weightlifters, found no menisectomies, minimal chondromalacia-type complaints and no knee "clicks or pops" (38).

Shearing forces, which cause the bones at the knee joint to slide across one another, occur during the squat motion and are resisted primarily by ligaments statically and by ligaments and muscles dynamically. The degree of shear force at the knee during the squat may be an important measure of the joint's exposure to injury.

Squatting-type movements are being emphasized in the rehabilitation of athletes from anterior cruciate ligament surgery (50), and more clinical research is now being offered to support the use of squats in rehabilitation. It is important to understand the difference between open-chain and closed-chain exercises. In closed-chain exercises the foot is in a weight-bearing position, such as the squat or leg press. In open-chain exercises the joint is loaded indirectly in a non-weightbearing manner, such as the leg extension and the leg curl. In many sports, closed-chain exercises are more sport-specific, and may therefore produce strength gains that would be more applicable to the sport.

The squatting movement places less stress on the anterior cruciate ligament than do knee extensions, which have been used previously in knee injury rehabilitation (50). This is explained by the fact that the hamstrings are active, which neutralizes the tendency for the quadriceps to cause anterior tibial translation. In a two-dimensional biomechanical study of the knee joint, Lutz et al. demonstrated that closed-chain exercises produce less anterior and posterior shear on the tibia than do open-chain exercises (40). Shear forces were significantly lower in a simulated leg press activity compared to isometric leg extensions and leg curls at 30, 60 and 90 degrees. Compressive forces were significantly greater in the leg press exercise than in knee extensions and curls, due to the axial orientation of the load in a closed kinetic chain activity. It was suggested that the squat and the leg press would be preferable to knee extensions and knee curls in a post-surgical rehabilitation program for reconstruction of the anterior and posterior cruciate ligaments.
Ariel, in a report on three subjects squatting with a heavy barbell load on the shoulders, indicated that shear forces were of greatest magnitude when the knee was initially bent at the beginning of the descent (4). However, he pointed out that

the knee is anatomically more protected in this position. The forward movement of the knee in one subject was associated with the greatest shear forces of the three subjects. The strongest subjects demonstrated less shear force than the weaker subjects. An abrupt increase in all forces at the knee was evident if the subject bounced in the bottom position. Training decreased shear forces, explained by increased strength and improved technique.

Andrews et al. reported that shear forces in both barbell and machine squats are increased with exercise load and speed (3). They also showed that shear forces in the knee are 30 to 40 percent higher with a Universal squat device that placed resistance on the shoulders than with free weights, and that these forces can be minimized by not bouncing at the bottom position and by keeping the lower leg as close to perpendicular to the floor during the squat as possible (3). However, by keeping the lower leg perpendicular, shear forces on the low back may be increased due to increased forward lean of the torso, especially in the L5 region.

The effects of squat execution speed on joint-torques have been investigated using one-, two- and three-second ascents and consistant two-second descents (28). A trend was reported toward higher joint-torques for faster ascents. Dahlkvist et al. developed a model of the leg and primary muscles active during the squatting movement with body weight as resistance (13). Maximal and average quadricep and hamstring forces were greater during fast squats than during slow squats, with the opposite generally found for the gastrocnemius. Slow and fast squats were not defined. Garhammer pointed out that true speed squats, such as jump squats, can be performed only with relatively light weights (20). High torque exercises may increase injury potential, particularly if the athlete is not prepared physically to perform these exercises.

Common Knee Problems

Factors that can contribute to injuries while squatting include inadequate warm-up or stretching, improper technique, attempts beyond the lifter's capabilities and failure to follow accepted principles of exercise program design. The most common weight training-related knee problems are tendinitis or bursitis. Tendinitis is the result of excessive tensile forces or chronic overload. Activities that place stress on the knee and encourage a full range of motion (including squats) eventually cause pre-existing patellar tendinitis to worsen (51). Bursitis is the result of constant or repetitive compressional forces, which injure the bursa and set up a chronic inflammatory condition that includes swelling (34). While squats may not cause these conditions, they could be contraindicated in athletes with these problems.

Chondromalacia patellae is a degenerative process that results in a softening of the hyaline cartilage on the posterior surface of the patella and the condyles of the femur (51). This can result from minor patella injuries and is associated with anatomical abnormalities including thigh and lower leg malalignment, small or high-riding patellae, patella or distal femur deformities, and tight hamstrings or illiotibial band (34, 51). Modifications in the exercise regimen, including squats, may be necessary to avoid making the symptoms worse.

Another potential knee injury is a ligament sprain. This generally results from a direct blow or twisting movement, neither of which should occur with a correct squatting movement. A direct blow or twisting injury also can injure the menisci. The potential for meniscal injuries may be increased by femoral rotation in the flexed knee position.

Athletes who perform the squat exercise often wear knee wraps to provide joint warmth and support and to reduce injury potential. Garhammer stated that a slightly elevated joint temperature can benefit the knee joint by reducing intra-joint friction and increasing the elasticity of the supportive joint structures (20). Joint temperatures above 102 degrees, however, may weaken supportive joint structures due to collagen damage. A single layer of elastic material will usually provide enough warmth. It is possible to improve performance in the squat exercise by tightly wrapping the knees with elastic wraps (25). There is no evidence that wraps reduce injuries, based on an informal survey of health practitioners (25). Multi-layer wraps may increase injury potential by applying pressure to the patella and altering its normal movement pattern (20). It is prudent to avoid using heavy, tight, multi-layer knee wraps for the squat exercise.

To summarize, most evidence seems to show no detrimental effects on the knee joint from proper squat technique, assuming that reasonable exercise intensities and loads are used and other applicable principles of exercise program design are followed. Knee joint injuries likely are not caused by a proper squat, but some injuries and conditions may be aggravated by the squatting movement.

The Back

Compressive forces on the spine occur in the squat exercise as a result of placing resistance on the upper back and shoulders. The forces at various joints during the parallel squat have been calculated and are greatest at the lumbosacral joint, followed by the hip, knee and ankle (45). Highly skilled subjects have been reported to minimize trunk segment torques by maintaining a more erect trunk position (42). Stress on the lumbar discs can be reduced by maintaining a normal lordotic posture. This also stabilizes the spine and facilitates neuromuscular control of the trunk during lifting (26).

Cappozzo et al. determined spinal compressive loads at the L3-L4 joint for half squats performed with a loaded barbell, which ranged from 0.8 to 1.6 times body weight (10). L3-L4 compressive forces were six to 10 times the body weight, and calculated erector spinae forces ranged from 30 percent to 50 percent of published maximal isometric levels. Peak forces occurred at or near the point of maximum knee flexion. Garhammer stressed the importance of flexibility at the knee, hip and spine in maintaining an upright torso position during the squatting motion to reduce spinal compression and shear forces (20).

The squat exercise has been implicated as a possible factor in degenerative disk disease (1). White attempted to calculate dynamic forces on the lumbosacral disk during olympic weightlifting (67). Normal loads were previously calculated at 6,000 to 8,000 newtons (32), and the loads during White's olympic weightlifting reached 60,000 newtons. White suggested that improper digitizing may have produced erroneously high estimates of forces on the trunk. Also, he did not include the contribution of anterior support forces due to intra-abdominal pressure by the abdominal muscles, which would have decreased compressive forces by approximately 30 percent (1). Day et al. reported on 12 college football players with lumbar disk disease (16). Three of the injuries were attributed to weightlifting, including exercises other than squats, as the cause of lumbar pain and pain that radiates down the legs. However, a cause-and-effect relationship was not established, because disk disease is usually a multi-factorial problem that cannot be attributed to a single activity.

Weight training, especially the competitive sport of weightlifting, has been implicated in the development of spondylolysis (14, 17). Spondylolysis is a condition in which a stress fracture develops, commonly at the fifth lumbar vertebral element in the vertebral arch near the spinous process. Spondylolysthesis, forward slippage of one vertebrae over another, commonly accompanies spondylolysis. Chronic loading of the low back has been indicated as a cause of forward displacement of the vertebrae on the sacrum (34). Forward slippage of the vertebrae would increase shear forces at the spine. The stresses imposed during weight training could cause either condition, but this tendency can be minimized in squatting by reducing forward lean and increasing intra-abdominal pressure to stabilize the spine. A lifting belt may help if the torso musculature is weak (21, 24). A squat program should be modified for athletes with preexisting spondylolysthesis and spondylolysis.

Back strains and sprains are common injuries often attributed to weight training, especially to the squat exercise. Most sprains and strains are due to a sudden, violent extension of the spine with contraction of overloaded, unprepared or underdeveloped back muscles, especially when the movement involves rotation (9). Davies stated that weightlifting has accounted for proportionally more injuries than any other sport, and that lifting heavy weights to overhead positions with the trunk in a flexed position (which indicates improper lifting technique) causes high shear forces on the lumbar vertebrae (15). The American Academy of Pediatrics does not endorse the sport of weightlifting, stating that it is a competitive sport with a high injury rate that should not be practiced by the preadolescent (2). A review of the literature (58) does not support these contentions.

Kulund et al. reported a relatively low incidence of back injuries in olympic lifters, with only eight of 80 lifters experiencing back pain (38). He suggested that paravertebral muscle strength, spinal flexibility and the straight-back lifting style protect the weightlifter from back pain. Similar findings were reported by Granhed and Morelli (23). This cross-sectional study compared the prevalence of low back pain among retired wrestlers (ages 39 to 62), weightlifters, (ages 40 to 61), and untrained men (ages 40 to

47). Wrestlers reported the greatest incidence of pain (59 percent, n = 32). Untrained men showed a lower incidence (31 percent, n = not reported), and weightlifters showed the least incidence (23 percent, n = 13). Additionally, wrestlers had more vertebral fractures (88 percent) than weightlifters.

The Squat Versus Machine Exercises

The squat exercise is certainly not the only exercise that can be performed for the lower body musculature. Several machines are widely used to strengthen the lower body. General advantages of machines over free weight exercises include convenience and, in some movements, the ability to isolate specific muscle groups. Advantages of free weights include lower cost and increased specificity of exercise. Training specificity is important if the strength gained from conditioning is to carry over to functional sports activities.

Neural adaptation to training is also specific to the exercise chosen. Strength increases early in a conditioning program are caused primarily by neural adaptation (56) due to the ability to maximally recruit prime mover muscle groups, the ability to inhibit antagonistic muscle groups and the improved ability to synchronize the recruitment of motor units. Neural adaptation may differ drastically, depending on exercise specificity.

The squat has an advantage over leg extensions and leg curls, because it is a closed-chain exercise and is more specific to most sporting activities. Also, as previously mentioned, the leg extension and leg curl cause more shear forces at the knee than the squat exercise (50). In many cases, the squat is functionally more specific than leg press or hip sled devices.

Additional Factors

Although the potential exists for knee and back injuries during the squat, many injuries attributed to weight training may have resulted from other activities. Billings et al. studied 100 athletes with low back pain, and found that rotation and rotation/flexion commonly occurred at the time of the injury (8). These movements are not used in the squat exercise. Herrick et al. found that weightlifters and powerlifters who ran as part of their training programs reported more knee pain than those who did not run (29). Furthermore, some studies have suggested that injuries among weightlifters and weight trainers, including knee and back injuries, may be of lower incidence than those in other sports, including gymnastics and football (58, 69). It seems reasonable, therefore, that many injuries attributed to squat training should be viewed as multi-factorial problems. Additionally, evidence exists that weight training, including the squat, may reduce injury potential by strengthening muscle, ligament, tendon and bone (6, 7, 22, 49).

Fatigue, rather than the squat exercise, probably is responsible for many of the injuries noted. Hattin et al. observed that during the half squat, fatigue increased all articular force components and most affected the anterior/posterior shear force on the tibio-femoral joint (27). Subjects were required to perform 50 repetitions of a half squat exercise at two cadences (one-second and two-second intervals) and three loads (15, 22 and 30 percent of 1 RM). Faster cadence had a significant effect on muscular fatigue, which resulted in increased medial and lateral shear and compressive forces at the knee. Similar arguments for fatigue as an underlying mechanism for injury could be made for other joints, including the vertebral joints. Garhammer reported that in an unpublished study of one subject by Malone, fatigue affected the kinematics of the last two compared to the first two repetitions of an eight-repetition set of squats at 90 percent of 1 RM (20; also see 28). Thus, fatigue or excessive training may be the actual cause of many injuries attributed to the squat, rather than the exercise itself.

Proper Form in the Squat Exercise

Although it is beyond the scope of this paper to address the proper form for all types of squat exercises (i.e. front squats, back squats, low bar, high bar, etc.), the following general guidelines are reasonable considerations for reducing the potential for squatting-related injuries (see also Appendices A and B, NSCA checklists for the back and front squats):

— Use approximately a shoulder-width foot stance.

— Descend in a controlled manner. Ascent can be made at a variety of speeds. At faster speeds there should be no compromise in technique.

— Proper breath control is important to support the torso. The breath should be held from the start of the decent until the athlete passes the sticking point on the ascent.

— Avoid bouncing or twisting from the bottom position.

— Maintain a normal lordotic posture with the torso as close to vertical as possible during the entire lift.

— Generally, in typical back or front squats, descend only until the tops of the thighs are parallel to the floor or slightly below. Exceptions can be made for sports that require lower positions.

— Feet should be kept flat on the floor.

— Forward lean of the knee increases shear forces on the knee. Keeping the shin perpendicular may increase shear forces on the back as a result of forward trunk inclination. Although there are exceptions, the shin generally should remain as vertical as possible to reduce shear forces at the knee. Maximal forward movement of the knees should place them no more than slightly in front of the toes. Depending on the type of squat being used, volume and intensity should not be increased at a rate that exceeds the body's ability to adapt to the imposed demands.

— Every effort should be made to maintain a consistant stable pattern of motion for each repetition, in order to load the muscles in a consistant manner and help prevent injury. ●

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