FORCES ON THE LUMBAR SPINE DURING THE PARALLEL SQUAT

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INTRODUCTION

The use of the parallel squat in weight-training and general fitness programs has become widespread over the past ten years (Russell & Phillips, 1989). The benefits of the parallel squat include enhanced lower body musculature, the development of explosive strength, and an increase in ligament and tendon strength. These benefits tend to overshadow the fact that squatting places excessive stress on the musculoskeletal system (Shirazi-Adl, 1994). The lumbar spine and surrounding soft tissues must support the loads caused through lifting activities (White & Panjabi, 1990). The study of the stresses placed on the lumbar spine during the parallel squat are critical to ensure safe practices in weight training and general fitness programs.

In the parallel squat, the individual must coordinate several specific and critical movement patterns in order to reduce the forces placed on the spine. One critical factor, the amount of trunk flexion, greatly impacts the total force that must be withstood by the lumbar spine and the supporting structures (Hamill & Knutzen, 1995; Potvin, Kary, McGill & Norman, 1991; Nordin & Frankel, 1989). McClure et al. (1997) suggest that lumbar motion, including both flexion and extension, differ in subjects with and without a history of low back pain. In their study the subjects with low back pain exhibited greater lumbar motion. This study also indicated that velocity of the lift differed between the two subject groups, with the low back pain group having higher velocities during the initial phase of extension (McClure et al., 1997).

The intervertebral discs play a vital role in transferring the loads produced by the trunk and upper extremities. Compression, torsion and shear forces are three forces that act on intervertebral discs of the lumbar spine (White & Panjabi, 1990; Shirazi-Adl, 1994). Compression has been defined as the normal force which tends to push material fibers together, torsion as a load applied by forces parallel and opposite each other about the long axis of a structure, and shear as the intensity of force parallel to the surface within an object (White & Panjabi, 1990). Compressive loads in the parallel squat are created by the normal force of the loaded bar across the shoulders. Torsional loads are produced during the flexion of the trunk as the trunk rotates around an axis in the lumbar region. Shear stress results from the combination of torsion and compression as the two forces work together causing a sliding tendency between the vertebrae (See Figure 1.).

The interaction of spinal muscles and ligaments play a significant role in the lumbar spine. When squatting, muscles and ligaments are essential in providing the force to resist the load on the intervetebral discs. To lift any object, force must be generated by the muscles an4 ligaments of the spine which act on the intervertebral joints. Thus flexion of the spine is accomplished through both the hips and the spine. When spinal flexion occurs the first 60 degrees of movement can be attributed to the movement of the spine, the next 30 degrees occurs from the rotation of the hips (White & Panjabi, 1990; Hamill & Knutzen, 1995; Nordin & Frankel, 1989). As the lordosis of the spine becomes less curved and flattens, the passive structures must support the trunk and the load it carries. These passive structures have been known to fail under rapidly applied loads (Potvin et al, 1991). The purpose of this study was to determine the peak trunk flexion, compression, torsion, and shear forces on the lumbar spine during the parallel squat for experienced and recreational weight lifters.

METHODS

Twenty male subjects, all familiar with the squat, were divided into two groups based on their experience with the parallel squat. A subject was considered experienced if they had used the parallel squat in a regular lifting program for five or more years, or if the subject was instructed by a certified

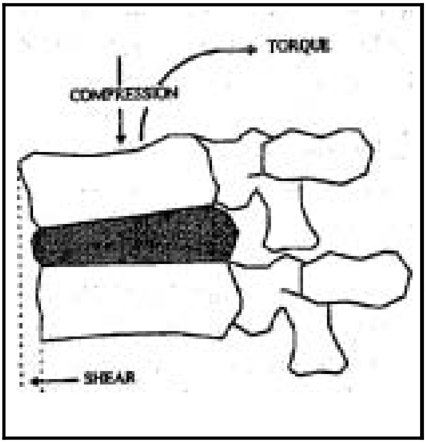


Figure 1. Forces acting on the spine.

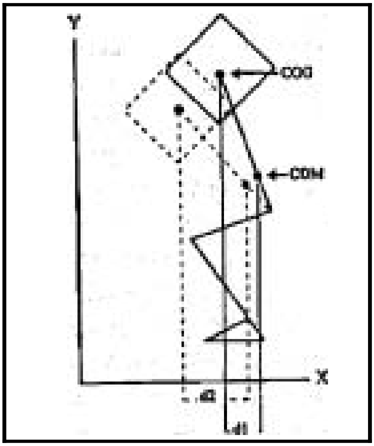


Figure 2. d1 and d2 represent the relative difference between the COM and COG with varying degrees of trunk flexion.

instructor and had used the parallel squat in a regular program for 2 or more years. Nine subjects were considered experienced, while the other 11 subjects were placed in a recreational lifting group (See Table 1.). Each subject squatted the bar, 225 lbs, his body weight (BW), and 125% of his body weight (1.25xBW). The subjects were instructed to attempt five repetitions of each weight load, with the fifth repetition digitized for analyzation:

On the day of filming, the subjects were provided a standard squat rack and any safety equipment they typically used. Subjects were only instructed on safety procedures, no instruction was provided concerning technique. Subjects recovered from each set until they felt ready to move to the next load in order to minimize the effect of fatigue. A six link body model was used. The bar, as well as the subject's toe, heel, ankle, knee, and hip were marked. The camera filmed the subjects within the squat rack from the sagittal plane at a speed of 60 Hz. The Peak Performance (v5.1) system was used to digitize, smooth and analyze the data.

Data acquired from digitization was used to calculate the forces on the spine. The formulas used to calculate the compression and torsion were dynamic equations of motion from a similar study conducted by McLaughlin, Lardner, & Dillman (1978). An estimate of shear force was obtained using the 5 cm equivalent moment arm model (Nordin & Frankel, 1989). Trunk flexion was measured at the deepest point of the squat using the bar, hip and X-axis. A MANOVA was used to determine differences ($P<.05$) between the 2 groups across the 4 weight loads for trunk flexion, compression, torque and shear forces.

Table 1. Group Mean Summary Descriptive Data.

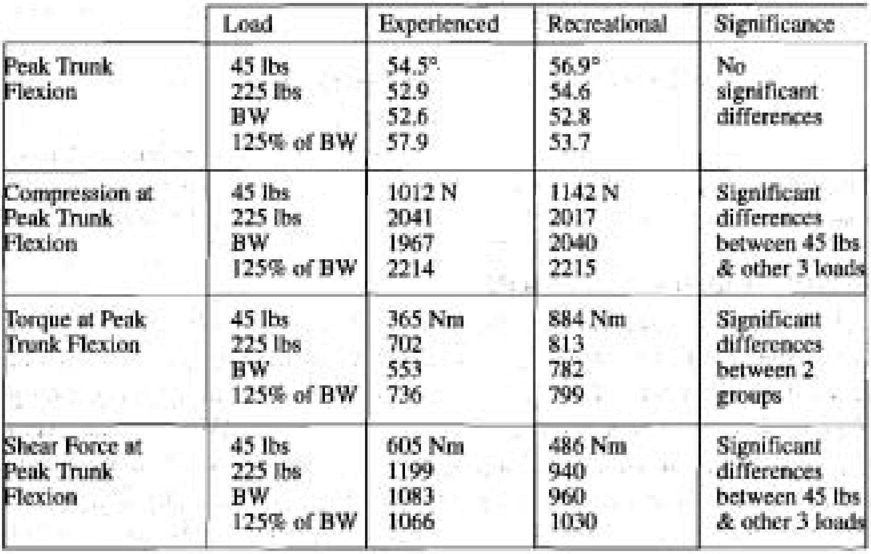
Group	Experience	Age	Weight
Recreational	3.5 yrs	21.4 yrs	212.2 lbs
Experiened	7.8 yrs	22.6 yrs	196.5 lbs

RESULTS AND DISCUSSION

Peak trunk flexion was not significantly different between the groups or across the four weight loads. Mean peak trunk flexion was greatest for the recreational lifters at 45 lbs (56.9 degrees), while the experienced group showed their greatest mean peak trunk flexion at 1.25xBW (57.9 degrees) (See Table 2.) In the parallel squat, the greater the trunk flexion (lower angle), the greater the distance between the COM and the COG (Figure 2.). This bending moment produced by the load on the disc must be counteracted by the bending moment produced by the muscles and ligaments (White & Panjabi, 1990). With increasing flexion the normal lordosis of the lumbar spine becomes less curved and flattens. This in turn places the passive structures of the spine in a position where they must support the trunk and the load it carries when flexion is less than 60 degrees (Potvin et al., 1991). These passive structures have shown to fail under rapidly applied loads (White & Panjabi, 1990). Both groups across each of the weight loads flexed beyond the recommended 60 degrees. This indicated that the ligaments were used to support the weight on the bar for at least part of the lift. As fatigue becomes a factor disc injury could occur for these lifters. Although the interaction between load and experience was not significant, a trend could be viewed. The experienced group showed lower values at the lighter lifts, with 1.25xBW nearing the 60 degree criteria. The recreational lifters had their highest values with the lighter lifts, thus flexing more with the heaviest lift. This could indicate that the recreational lifters are placing more stress on the passive tissues of the spine under heavy loads.

The compressive forces were calculated using the dynamic equations of motion by McLaughlin et al. (1978). A significant difference was found in compressive forces across the four weight loads. (See Table 2.) It was found that the compressive forces were significantly different between the bar and the other three weight loads. There were no significant differences found between the groups or in the interaction effects.

Table 2. **Trunk** Flexion, Compression, Torsion, and Shear by Group & Weight Load.



	Load	Experienced	Recreational	Significance
Peak Trunk Flexion	45 lbs	54.5°	56.9°	No significant differences
	225 lbs	52.9	54.6	
	BW	52.6	52.8	
	125% of BW	57.9	53.7	
Compression at Peak Trunk Flexion	45 lbs	1012 N	1142 N	Significant differences between 45 lbs & other 3 loads
	225 lbs	2041	2017	
	BW	1967	2040	
	125% of BW	2214	2215	
Torque at Peak Trunk Flexion	45 lbs	365 Nm	884 Nm	Significant differences between 2 groups
	225 lbs	702	813	
	BW	553	782	
	125% of BW	736	799	
Shear Force at Peak Trunk Flexion	45 lbs	605 Nm	486 Nm	Significant differences between 45 lbs & other 3 loads
	225 lbs	1199	940	
	BW	1083	960	
	125% of BW	1066	1030	

Compressive forces are managed well by the spine (White & Panjabi, 1990). They are produced by the normal force of the bar applied to the shoulders. As would be expected, a significant difference was found across weight loads. As the load applied increased, so did the compressive force applied. A recent study by Chaffin & Page (1994), set the maximum compressive force at 7000 N. In vivo recordings of the compressive force at the L3 vertebrae by Granhed, Johnson & Hansson (1987), revealed compressive force between 18.8 and 36.4 kN. It was concluded that an increase in bone mineral content brought about through training allowed subjects to withstand extraordinary loads. All values for compression obtained in this study were well below the maximum compression limit found by Chaffin & Page (1994), indicating that compressive force was not a possible cause of extreme stress on the spine during this study.

The torque produced was calculated using the dynamic equations of motion proposed by McLaughlin et al (1978). The experienced group had significantly less torsion than the recreational group. (See Table 2.) This indicated that torsional forces decreased with experience. A study by McLaughlin et al (1978), found that world class lifters generated maximum torques values of 705 Nm. In this study, using less skilled subjects, the mean torque values were slightly higher for both groups during heavy lifts than that of world class athletes. Although mean torque values were not excessive, individual data with the recreational lifters showed maximal torque values produced by two subjects exceeded 2200 Nm. Through further investigation into the extreme values, it was determined that the angular acceleration component of torque was the variable that influenced trunk torques significantly. The highest torques were observed in the subjects with the largest angular accelerations at the hip. Undue stress on the spine caused by torque can leave the lifter vulnerable to back injury (Cappozzo, Felici, Figura, & Gazzani, 1985). Russell and Phillips (1989), as well as McLaughlin et al (1978), found that a reduction in torque was obtained through upright posture and control of the weight. The trunk extensors play a significant role in reduction of torque (Isear et al, 1997; Delitto & Rose, 1992), and they may have played a role in the more controlled lift by the experienced lifters in the current study.

The shear force was calculated using a 5 cm equivalent lever arm model compiled by Nordin and Frankel (1989). There were significant differences between the 45 lb lift and the three other loads for both groups. (See Table 2.) There were no significant differences between the groups or with the interaction effect. Shear forces create the internal deformation of the spine through the coupling of compression and torsion (White & Fanjabi, 1990). Shear forces are difficult to measure and the model used in this case provides only a rough estimate. Shear force was represented by a simple vector, when in fact shear force impacts all passive structures of the spine (Goel & Weinstein, 1990). In a study by Russell and Phillips (1989), the largest shear forces were experienced by the subjects with the greatest trunk flexion. In this study the same conclusion can be drawn since the shear force was a vector quantity and a function of the trunk inclination. As the load increased the amount of trunk flexion increased thus causing more strain on the lumbar region. This may be a function of weaknesses in supporting muscles of the trunk thus causing flexion at the trunk, or an inability to coordinate the neuromuscular patterns of motion. It was evident that the less skilled subjects would continue to flex at the hip after the knee had reached maximal flexion. It is also important to note that fatigue of the soft tissues could cause more strain to the intervetebral discs with this delayed flexion, thus increasing shear force on the spine.

CONCLUSION

Recreational and experienced lifters should not be encouraged to increase the weight lifted until the weight can be lowered at a constant slow speed with a minimum trunk angle of 60 degrees. Recreational lifters need to be aware of continued hip flexion after reaching maximal knee flexion. To reduce injuries, proper form should be stressed over increased weight loads. It was also evident that continued instruction is needed for lifters, as even the experienced lifters in this study had high torque values with heavy loads.

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