KINEMATIC ANALYSIS OF THE TRADITIONAL BACK SQUAT AND SMITH MACHINE SQUAT EXERCISES

Anthony Gutierrez[1] and Rafael Bahamonde[2]

Department of Kinesiology, University of Wisconsin, Madison, USA[1]
Biomechanics Laboratory, Indiana University, Indianapolis, USA[2]

The purpose of this study was to compare the kinematics of the traditional back squat (TBS) and the Smith Machine Squat (SMS). The squat exercise is a common exercise in strength and conditioning programs as well as in rehabilitation settings. Eight experienced college age weight lifters performed both TBS and SMS. Three dimensional video analyses were used to analyze the motions. Lower extremity joints and trunk angular motions were computed and compared using Paired T-test. The TBS generated larger ROM than the SMS in all the joints measured. Due to the linear restriction of the bar motion along the vertical axis in the SMS the subjects positioned their feet forward to enable bar lowering. This feet placement positioned the bar farther away from the knee at the instance of maximal knee flexion.

KEY WORDS: Back Squat, Smith Machine, Kinematics.

INTRODUCTION:

The traditional back squat (TBS) exercise is primarily associated with strength training in athletes at all levels of competition. In addition, due to its classification of a closed kinetic chain exercise (Escamilla, Fleisig et al. 1998), it is often used in rehabilitative settings. The Smith machine (SM) is a type of equipment used for squats and other exercises that is commonly available in health clubs and recreation centers. It consists of a barbell that is fixed within rails, so that it can only move vertically, although new variations allow some forward and backward movement (See Figure 1). Because of its fixed motion it decreases the need for balancing the bar and weight plates which increase the safety of the exercise. In the fitness industry the SMS has been suggested as an alternative exercise to TBS (Glenn, 2009) but it has also been labelled as one of the least effective exercise to perform (Russi, 2008). Although several studies have analyzed the biomechanics of the (TBS) (Escamilla, Fleisig et al., 1998; Escamilla 2001; Escamilla, Fleisig et al., 2001; Zink, Perry et al., 2006; Flanagan and Salem 2007; Robertson, Wilson et al., 2008; Sahli, Rebai et al., 2008; Gullett, Tillman et al., 2009) only a handfull of studies have looked at the mechanics of the SM squat (SMS) (Escamilla, Fleisig et al., 1998; Abelbeck 2002; Jacobson 2003; Cotterman, Darby et al., 2005). Abelbeck (2002), developed a mechanical saggital plane model of the SMS that allowed for variations in foot placement. This model showed a decrease in knee moment and an increase in hip moment as the model's feet were positioned anterior to the body. In contrast, in a study by Jacobson (2003) the SMS generated greater anterior-posterior and compressive knee forces than the TBS. More recently significant differences were found between the 1RM using the SMS and TBS (Cotterman, Darby et al. 2005). Subjects were able to generate greater 1RM using the SMS. Therefore the aim of his study was to compare the kinematics of the TBS and the SMS. It was hypothesized that the fixed vertical motion of the bar during the SMS leads to kinematic changes at the joints and bar motions which may also affect the joints kinetics.

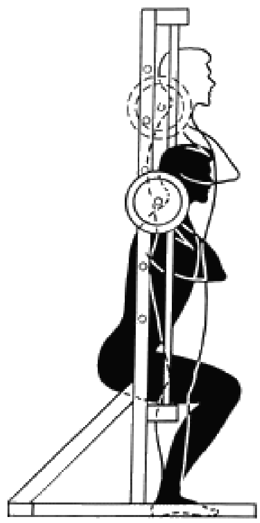


Figure 1

METHODS:

Data Collection: Eight, experienced, college age lifters (3 male and 5 female) with a mean body height (♂= 1.74 ± 0.16 m ♀= 1.64 ± 0.10 m) and a mean body mass (♂= 86.5 ± 11.8 Kg ♀= 64.4 ± 14.1 Kg) were recruited for the study. The TBS used an Olympic weight bar (201.6 N) while the SMS bar weighted (89.6 N). To reduce any variations in technique and to normalize the load, the subject's lifted only 50% of their body weight and were instructed on how to perform the squats according to guidelines of the National Strength and Conditioning Association (NCSA) (Robertson, Wilson et al., 2008). Each subject warmed up 10 min prior to exercise and performed three repetitions of each exercise. StreamPix Video Capture Software (Norpix, Inc., Quebec, Canada) and two Basler A602 cameras (50Hz) were used to record the motions. Video analysis was done using KWON-3D Motion Analysis Software (Visol, Korea).

Data Analysis: The squat motion was divided into two phases, the descending and ascending phases. The end of the descending phase and the start of the ascending phase were determined from the time of maximum knee flexion (MKF). Because of differences in trial length and for comparison purposes the combined times of the ascending and descending phase was normalized to 100%. Joints centers, 12 body landmarks and the weight plates were marked, digitized, and used to define the rigid segments representing the bar, trunk, thighs, shanks and feet. Three dimensional coordinate data were smoothed using a 4th degree Butterworth-low pass filter with a smoothing factor of 6 Hz. Due to the symmetric nature of the movements only the left side of the subjects was used for comparisons. Linear and angular kinematics were computed using Kwon 3D. The joint motions computed were: trunk flexion (relative to the vertical axis), hip flexion/extension, knee flexion and extension, and ankle dorsiflexion-plantar flexion.

Figure 2. Mean Joint Range of Motion During Squats

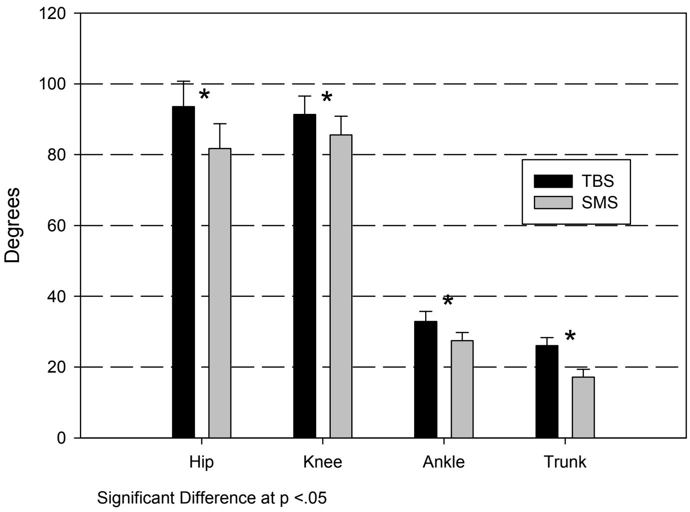
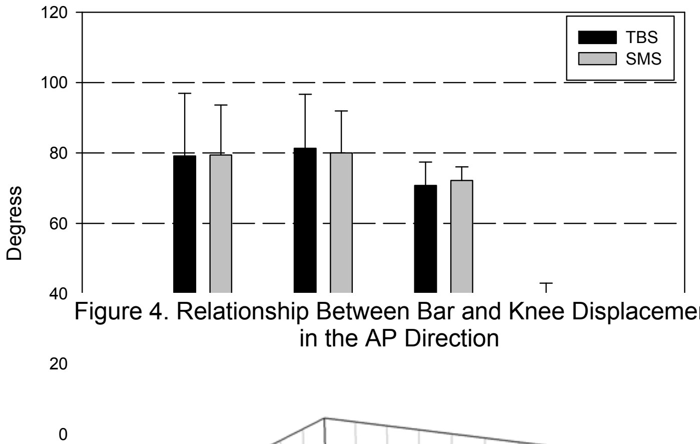
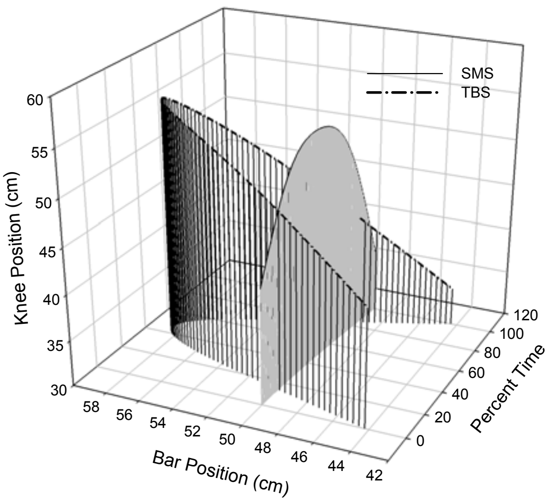


Figure 3. Joint Angles at Maximum Knee Flexion



Paired t-tests (Sigma Stat, Systat Software, Inc.) were performed on the following parameters: ROM of the hip, knee, ankle and trunk angles, angular position at MKF, and horizontal position of the bar relative to the knee at MKF. Effects size was calculated according to Cohen (1977).

Figure 4. Relationship Between Bar and Knee Displacement in the AP Direction



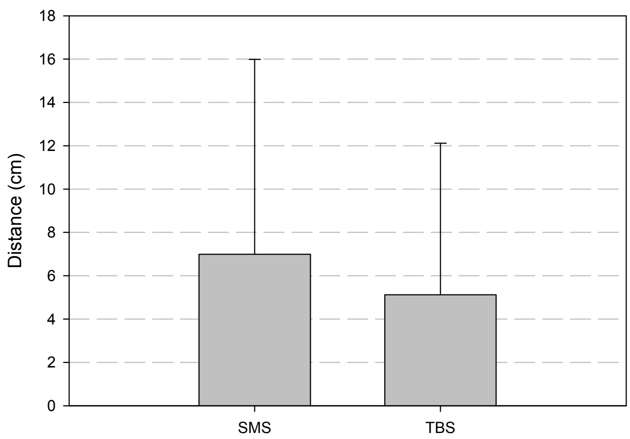
RESULTS:

Mean MKF occurred at about the same normalized time for both type of squats techniques (53% and 51% for TBS and SMS respectively). Figure 2 shows the mean ROM values for hip and knee flexion/extension, ankle dorsiflexion and plantar flexion and trunk flexion. All subjects exhibited larger ROM in all the joints during the TBS. Trunk and hip flexion ROM values were considerably greater in the TBS than in the SMS. Although there were no significant differences between joint angles at MKF for the two types of squat techniques (See Figure 3), there was greater trunk flexion (ES = 1.49) during the TBS at MKF and less ankle dorsiflexion (ES = .54) during the SMS. Figure 4 shows the relationship between the bar and knee positions with respect to time during the squat motions. Because of the linear motion of the SMS the bar is restricted in the AP (anterior-posterior) direction (Figure 4 - Gray plane), whereas in the TBS the bar and the knee move forward during the descent phase. Figure 5 shows the horizontal distance of the bar relative to position of the knee. Although non-significant (ES =.50), the bar was positioned further back from the knee during the SMS at the instance of MKF. In the TBS the bar moved closer over the knee joint center.

DISCUSSION:

The SMS is a common weight training exercise because it is safer to perform, as it removes the necessity of balance and it can be done without spotters. It has been the assumption that the SMS has similar joint motions than the TBS, although some studies have shown that the SMS generates greater 1RM and different knee joint moments and forces than the TBS. There has not been a kinematic comparison of the two types of squats and there is some controversy regarding the knee kinetics. One study suggests that the SMS enhances the 1RM by reducing the knee torques due the position of the feet in front of the bar (Cotterman, Darby et al., 2005) which reduces the stress at the knee. This theory was supported by the biomechanical model presented by Abelbeck (2002) in which the knee moments decreased and the hip moments increased as the feet were positioned anterior to the hip joint (from the standing position), but contradicts the research by Jacobson (2003) in which the SMS generated greater compressive and AP forces. Our subjects had greater ROM at the joints when using the TBS. The joints ROM during the TBS were similar to those reported in previous studies (Escamilla, Fleisig et al., 1998; Robertson, Wilson et al., 2008). At the instance of MKF there was great deal of variability in the knee and hip joint angles, it was clear that there was less trunk flexion and less ankle dorsiflexion. To achieve the desired ROM in the SMS the subjects had to position the feet farther forward which increased the horizontal distance from the bar to the knee. In the TBS the bar moved forward as the trunk flexed forward to position the load closer to the knee joint. These kinematic changes can lead to more stress to knee joint during the SMS (Abelbeck, 2002; Jacobson, 2003) but further research is needed to confirm this hypothesis.

Figure 5. Horizontal Distance Between Bar and Knee Position at MKF



CONCLUSION:

The motions of the SMS are slightly different that the motions of the TBS. The restricted linear motion of the bar affects the ROM of the joints and alters the foot placement in relation to the bar. These changes may affect the kinetics of the lower extremity joints (Abelbeck, 2002; Jacobson, 2003). Knowledge of this information could be beneficial in testing, training, and rehabilitation programs and could have implications for prescribing exercise modalities. Caution should be used to assume that the SMS produces similar motions to the TBS.

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