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A comparison of muscle activation between back squats and belt squats

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ABSTRACT

A machine belt squat is a piece of equipment designed to allow the performance of squats while loading weight on the lifter's hips using a belt. The purpose of this investigation was to determine if belt squats differ from back squats in activation of the primary movers, and to determine the predictive capabilities of back squat load, training status, and anthropometric data on belt squat load. Thirty-one participants (16 males and 15 females) completed anthropometric measurements, a demographic questionnaire, a familiarization visit, and two testing visits, completing a 5 repetition maximum test for back squat and belt squat. Surface electromyography was used to measure muscle activation for the left and right vastus medialis (VMO), vastus lateralis (VLO), rectus femoris (RF), and gluteus maximus (GM). Comparison of muscle activation between the two exercises showed significant differences in the left GM (back squat: 0.84 ± 0.45, belt squat: 0.69 ± 0.22, *p*=0.015) and right GM (back squat: 0.86 ± 0.45, belt squat:

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0.71 ± 0.29, p=0.004). Regression analysis computed significant prediction equations for belt squat load for general population, males, females, and advanced lifters. Overall, results indicate that belt squats may significantly differ in GM activation from back squats. Back squat load, as well as other variables, may be effective in accurately estimating appropriate belt squat load. These findings may help to more appropriately program for training with machine belt squats as a back squat alternative.

KEY WORDS: Pit Shark®, Gluteus Maximus, Electromyography, Load Prediction

INTRODUCTION

Squats are one of the most frequently used exercises for lower body training (16). The closed-chain stance and coordinated recruitment of multiple large muscles make squats one of the best exercises for improving quality of life (9) and for rehabilitation purposes, including ACL strains, knee replacements, and patellar tendinopathy (14, 16, 18). They have also been associated with increased performance in components important to athletic performance, such as sprint speed, acceleration, and vertical jump (19, 22).

The effectiveness of back squats as a training tool have made them a common reference point for the assessment of other lower body exercises (8, 11, 12, 17, 20). Comparisons of muscle activation through electromyography (EMG) recording have been used to show some exercises, including front squats and box squats, may be as effective for muscle development

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(11, 12). Other exercises however (e.g. Smith machine squats) have been shown to be less effective in promoting muscle recruitment when compared to back squats (8, 17, 20). Both groups of exercises confirm that back squats are one the most effective exercises for training the lower body.

During a back squat, compressive forces on the lumbar spine reach 6 to 10 times body weight (5). It has also been noted that back squats can put the shoulders in a compromising position and may be contraindicated for certain populations with shoulder injuries or immobility (6). The load placed on the spine and stress to the shoulders during back squats have led to the investigation of exercises more suitable for populations with shoulder or spine ailments (8, 10, 20). Exercises including leg press, hack squat, and leg extensions put less load on the spine and keep the shoulders in a less compromising position, but have shown lower activation levels of the primary movers, quadriceps and gluteus maximus, than back squats, even at the same relative intensity (8, 20). This has led to the continued exploration of back squat alternatives.

Belt squats offer an alternative method of loading weight to back squats, which may be beneficial to individuals unable to perform traditional back squats due to some form of upper body limitation. Gulick et al. (10) studied muscle activation in free-weight belt squats compared to back squats. Results were promising, showing no significant differences in muscle activation between the two exercises. Machine belt squats are an alternative method for performing belt squats, and need separate assessment to assess if they are an effective substitute for back squats as free-weight belt squats are. **Figure 1** depicts the device used for machine belt squats in this study (Pit Shark®, Beachside Fitness Equipment, New Smyrna Beach, FL, USA), designed for

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belt squats, to which a lifter hooks the belt to one end opposite the pivot point (as shown in **Figure 2**), with the weight in the middle, giving the lift an advantage in leverage over the weight being moved. This set up causes the weight to move along a fixed track throughout a lifter's range of motion. Smith machine squats use the same motion as a back squat but move the weight along a fixed track, and have shown they may be less effective for muscle recruitment than back squats (17). While it has been shown that free-weight belt squats may be an effective alternative for lower body training to back squats (10), literature on belt squats is very limited, and therefore their effectiveness as a substitute for back squats is still uncertain. Additionally, different methods of belt squat, including various machines, need further assessment to determine if they are similarly effective.

Figure 1

Figure 2

Back squats have also been frequently used to test maximal lower body strength. Percentages based on one-repetition maximums (1RM), or estimates of 1RMs, can be used to determine appropriate loads for various repetition ranges, which can be very beneficial in designing training programs. Benefits in program design, and the ability to transition smoothly between different lower body exercises, led several researchers to investigate the ability to use back squat testing to determine appropriate training loads for various other exercises, including deadlifts, leg press, leg extensions, and lunges (7, 21). Currently, research comparing back squat load to belt squats is very limited.

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A machine belt squat allows for the performance of squats with the load located at the hips, decreasing the stress on the spine and shoulders. The purpose of this study was to determine if a machine belt squat produces the same level of muscle activation in the primary movers, vastus medialis (VMO), vastus lateralis (VLO), rectus femoris (RF), and gluteus maximus (GM), as a back squat if performed at the same relative intensity. A secondary purpose of this study was to determine a prediction equation that would allow for the seamless transition between these two exercises.

METHODS

Experimental Approach to the Problem

This study was designed with a repeated-measures approach to investigate the effects on muscle activation and compare the loads for each exercise. Participants completed a testing protocol to determine their 5 repetition maximum (5RM) for both belt squat and back squat, allowing the loads to be compared as a given percentage of the 1 repetition maximum (1RM) for each exercise. Muscle activation was compared using surface electromyography (EMG) of the gluteus maximus, vastus medialis, rectus femoris, and vastus lateralis during each 5RM test. The order of testing was randomized for the first participant of each sex, then balanced.

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Subjects

Thirty-one men and women, 20 to 30 y, (mean ± SD age = 23.1 ± 2.4 y, height = 172.6 ± 7.6 cm, body mass = 75.8 ± 13.2 kg) with various levels of training experience, categorized by the National Strength and Conditioning Association's (NSCA) Resistance Training Status standards as either Beginner, Intermediate, or Advanced Lifters, volunteered to participate. Participants were disqualified if they were unable to perform either high bar back squats or belt squats, monitored by an NSCA Certified Strength & Conditioning Specialist (CSCS) coach, to a depth of 90 degrees. All procedures were approved by the Kennesaw State University Institutional Review Board and all participants signed informed consent forms before testing. Participants were asked to refrain from resistance training for the 48 hours before each session and to come in fasted for their body composition measurements.

Procedures

5 Repetition Maximum Testing Protocol and Experimental Procedure

All participants completed three sessions, a familiarization session and two testing sessions, separated by a minimum of 48 hours, but no more than 120 hours. Participants fasted for 12 hours, and refrained from exercise and alcohol consumption for at least 24 hours, prior to each session. On their first visit, the familiarization session, participants read and signed an informed consent form, followed by the completion of a body competition assessment using dual x-ray absorptiometry (iDXA, General Electric, Fairfield, CT). After their anthropometric measurements, participants were familiarized with the protocol for EMG electrode attachments.

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Participants then completed a standardized warm up designed to optimize performance (2), consisting of 5 minutes of low to moderate intensity on a cycle ergometer to raise muscle temperature, a dynamic warm up consisting of 5 good mornings, 5 wide-leg good mornings, 5 summo squats, 3 inchworms, 5 quadruped hip circles, 5 kick backs, 10 glute bridges, 10 push ups, 10 press ups, 5 scorpions, 5 body weight squats, and 5 squat jumps to prepare the joints and muscle for squatting, and a specific warm up for each exercise, back squat and belt squat. Finally, participants were familiarized with the back squat and belt squat technique and equipment, recording set up for each participant to ensure reproducibility and consistency between exercises. Proper squat form was considered maintaining a flat back, knees in line with the toes for the full duration of the movement, and reaching a depth in which the top of their thighs were parallel with the floor (shown in **Figure 2**). For back squat, high bar technique was used, and all form was assessed by a Certified Strength & Conditioning Specialist (CSCS) Coach. Finally, participants were familiarized with the 5-repetition maximum (5RM) protocol (23).

On the subsequent testing days, participants were fitted with the EMG electrodes and then completed their warm up. Following the warm up, participants completed a series of Maximum Voluntary Isometric Contractions (MVICs) in order to normalize the data recorded during each exercise. MVICs consisted of participants squeezing certain muscles as hard as they could for three seconds in a static position. The MVICs were performed in the same position at the same joint angles (15), measured by goniometer, in order to ensure reproducibility. Following the MVICs, participants completed the 5RM testing protocol for the exercise they were assigned that day, belt squat or back squat. Participants started with a set of 10 repetitions

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at relatively light weight, 30-50% estimated 5RM, followed by incremental jumps of 40-80kgs, for 1 to 3 repetitions, until their estimated 5RM. Subjects were given 1 to 2 minutes rest between each warm-up set. Once the estimated 5RM was reached, participants completed 5 repetitions for each set increasing weight 10 to 20% until 5 repetitions could no longer be completed. If participants could not complete 5 repetitions, weight was decreased 5 to 10%. Participants were given 2 to 4 minutes rest between each 5RM attempt, and 5RM testing was completed within 3 to 5 attempts (23). Belt squat weight was recorded as the weight added to the machine.

Electromography

Electromyography data were collected during both of the testing visits. Participants' skin was prepared prior to electrode placement by shaving, abrading, and cleaning the attachment sites. Electrode data were collected and stored on a personal computer (Latitude D810, Dell, Round Rock, TX, USA). Eight separate bipolar (2.0-cm center-to-center) surface electrodes (Dual Electrodes #272S, Noraxon, Scottsdale, AZ, USA) were placed over the right and left gluteus maximus, rectus femoris, vastus medialis, and vastus lateralis muscles (www.seniam.com), with the reference electrode placed on the superomedial border of the patella (3). Electrodes for the gluteus maximus were placed midway on the line between the sacral vertebrae and the greater trochanter. Electrodes for the rectus femoris were placed halfway between the anterior superior iliac spine (ASIS) and the superior border of the patella. Electrodes for the vastus medialis were placed three quarters of the way down the line from the ASIS to the joint space in front of the anterior side of the medial ligament. Finally, the electrodes for the vastus lateralis were placed two thirds of the way down the line from the ASIS to the lateral

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border of the patella. The EMG signals were preamplified (gain, 1000x) using a differential amplifier (MS1400A, Noraxon, Scottsdale, AZ, USA).

Signal Processing

The EMG signals were band-pass filtered (fourth-order Butterworth) at 20-500Hz. Amplitudes of the signals were expressed as root mean square values. All analyses were performed with MyoResearch XP Master Edition 1.07.09 (Noraxon, Scottsdale, AZ, USA). The EMG data recorded from the 5RM set of each exercise were recorded and normalized using the MVIC's from that testing session. A 0.5 second sliding-window average was used to determine the peak amplitude for each MVIC, and data recorded from each exercise were recorded as a proportion of the MVIC for that session to allow for comparison between sessions on different days.

Statistical Analysis

Peak and mean amplitudes for each muscle during the two lifts were compared using one-way analysis of variance (ANOVA) to assess correlations in muscle activation between the two lifts and to determine if any significant differences existed. Stepwise regression analysis was used to determine significant predictor variables with belt squat load as the dependent variable. An alpha level of 0.05 was used to determine statistical significance. IBM SPSS Statistics 21 (IBM Corporation, Somers, NY, USA) was used to perform all statistical analyses.

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RESULTS

Pearson correlations between lifts showed peak and mean values for the right VMO, VLO, and RF all had moderate correlations (r>0.60, p<0.01), and all other values had high correlations (r>0.80, p<0.01). Means, standard deviations, and correlations for peak and mean amplitudes, as a proportion of MVIC, are shown in **Table 1.**

Table 1

No significant differences (p>0.05) were found in either VMO, VLO, or RF for either peak amplitude (shown in **Figure 3**) or mean amplitude (shown in **Figure 4**). However, significant differences (p<0.05) were found in both the right and left GM for both peak and mean amplitudes (shown in **Figure 5**).

Figure 3

Figure 4

Figure 5

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Stepwise regression analysis was performed with belt squat 5RM (Pit_5RM) as the dependent variable and back squat 5RM, training status, sex, body composition (body fat %), age, height, and weight as the dependent variables. Back squat 5RM (R^2=0.821, p<0.001), back squat 5RM and age (R^2=0.850, p<0.001), and back squat 5RM, age, and training status (R^2=0.871, p<0.001) were all found to be significant in predicting machine belt squat 5RM. Back squat 5RM alone was found to be a significant predictor variable (β=2.329, p<0.001), but the constant was not found to be a significant predictor (p>0.05). All of the variables in the second and third equations (shown in **Tables 2** and **3**) were found to be significant (p<0.05).

Table 2

Table 3

One way ANOVA was performed to determine if any significant differences existed between groups for muscle activation and belt squat to back squat ratio, separating groups by sex, body fat percentage categorization (normal versus overweight) (1), and training status (beginner, intermediate, or advanced). No significant differences were found between any groups for muscle activation (p>0.05) and no significant differences were found between body composition groups for belt squat to back squat ratio (p>0.05). Significant differences in belt squat to back squat ratio were seen between males and females (p=0.037) and between beginners and advanced lifters (p=0.018).

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DISCUSSION

The purpose of the research was to determine if a machine belt squat elicits the same amount of muscle activation in the primary movers at the same relative intensity as back squats, as well as to determine the predictive capabilities of multiple variables, including back squat load, on belt squat load.

Previous research, by Gulick et al. (10), has shown that free-weight belt squats may not significantly differ from back squats in muscle activation of the primary movers. While this study showed promising results, certain areas needed further investigation. All of the participants were trained, which leaves questions about the effect of training status on the use and effectiveness of belt squats. The number of female participants was relatively low, 4 females compared to 9 males, leaving the possibility that sex differences may been found with a greater female population. The muscles grouped under quadriceps, VMO, VLO, RF, have, in previous squat alternative studies, shown that one muscle may have a significant difference even if the other two do not (20). Use of root mean square alone, without normalization through MVICs, to analyze EMG data makes it difficult to compare results to previous studies. Finally, the SquatMax-MD hip belt squat platform, used by Gulick et al. for performing hip belt squats, is one of many different pieces of equipment designed for hip belt squats. Other pieces of equipment load the weight differently and some move the weight along a fixed track or about a fixed pivot point, therefore more research is necessary to determine if these are as effective for training as back squats. (10)

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The lack of significant differences between belt squat and back squat for right or left VMO, VLO, and RF activation are similar to previous research (10). However, significant differences in both peak and mean amplitude for the left and right GM between belt squat and back squat differs from previous research (4). This difference may be the result of the weight moving along a fixed track during a machine belt squat, unlike a free-weight belt squat. Previous studies have shown exercises in which the weight moves along a fixed track, like Smith machine squats and leg press, have significantly less muscle activation than back squats (8, 17, 20). Additionally, because the weight rotates about a pivot point, rather than a vertical load, the difference in muscle activation may be a result of a variation in the angle of resistance. Either way, if using the machine belt squat as a replacement for back squat in a training program, it may be beneficial to supplement with additional exercises focused on GM activation.

No significant differences were found between males and females in muscle activation for any of the muscles observed, which supports previous research which only found a significant difference in the gastrocnemius (10), and no significant differences were found between beginner, intermediate, or advanced groups for muscle activation. These results indicate that muscle activation during both of these lifts, as a proportion of their overall activation capabilities, may not differ between sexes or with additional training.

Significant differences were found between males and females, as well as between beginner and advanced lifters in belt squat to back squat ratios ($p<0.05$). These results suggest that there may be differences in the relationship between belt squat load and back squat load for

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males and females, as well as for beginner and advanced weight lifters. This difference showed that it may be beneficial to examine the relationship between belt squat and back squat for these groups individually.

Back squat 5RM only, back squat 5RM and training status, and back squat 5RM, training status, and age were capable of predicting machine belt squat 5RM. Variance explained by each equation increased with each additional variable, 82.1%, 85%, and 87.1% respectively, ($p<0.01$), which indicated more accurate estimates of appropriate load for machine belt squats may be achieved if training status and age are known. This differed from previous research on the use of multiple repetition maximums to predict one-repetition maximums for back squat, which found no anthropometric measures to be significant predictor variables (13). Possible reasons for this difference in results were the use of multiple exercise modalities, which may limit the predictive capabilities of multiple repetition maximums alone, and the inclusion of training status as a variable.

Significant differences were found in belt squat to back squat ratios between males and females and between beginner and advanced lifters. This difference indicates it may be beneficial to examine predictive capabilities of the independent variables within each group.

Needs for further research include assessment of the role of sex within different training levels. Also, the effect of training status within each sex should be assessed. The differences found in GM activation between this study and previous research on free-weight belt squats (10) suggest that further research is required on similar forms of squat alternative devices to

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determine their effectiveness. Finally, because of the role of the moment arm of resistance on force requirement for a machine belt squat, future research is needed to determine the relationship between back squat load and belt squat load using different attachment sites.

PRACTICAL APPLICATIONS

Analysis of muscle activation in the primary movers between machine belt squat and back squat showed significant differences in the activation levels of the gluteus maximus for both the right and left sides. This information may be valuable in designing a resistance training program using machine belt squats or for switching an athlete from back squats to machine belt squats for any reason, including acute injury to the shoulders. If using machine belt squats, it may be beneficial to supplement with additional exercises that work the gluteus maximus, to avoid a loss of training stimulus. Use of variables including back squat load, training status, body composition, and age were able to develop prediction equations for machine belt squat loads, which may allow for a smoother transition between exercises, improving training effectiveness.

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Table 1

Table 1: Electromyography Data by Muscle (Proportion of MVIC)

	Mean	Std. Deviation	P-Value of Difference	Correlation
Rt GM Back Rt GM Belt	.992660 .862798	.4939156 .3484028	*.014	**.873
Mean Rt GM Back Mean Rt GM Belt	.862400 .713414	.4480712 .2942201	**.004	**.867
Lt GM Back Lt GM Belt	.981799 .839259	.5159906 .2498181	*.032	**.875
Mean Lt GM Back Mean Lt GM Belt	.842499 .690175	.4507504 .2185466	*.015	**.824
Rt VLO Back Rt VLO Pit Belt	1.607793 1.856990	.6188813 1.2992619	.213	**.624
Mean Rt VLO Back Mean Rt VLO Belt	1.424488 1.645101	.5239499 1.1390479	.209	**.627
Lt VLO Back Lt VLO Belt	1.962875 2.379881	.1.5131805 2.6563999	.112	**.921
Mean Lt VLO Back Mean Lt VLO Belt	1.716185 2.096667	1.2416607 2.3921402	.154	**.881
Rt RF Back Rt RF Belt	2.830952 2.821397	1.9601330 2.1158538	.976	**.656
Mean Rt RF Back Mean Rt RF Belt	2.452355 2.498428	1.7021496 1.9045922	.876	**.639
Lt RF Back Lt RF Belt	3.135345 3.439540	2.8898934 2.9368753	.081	**.948
Mean Lt RF Back Mean Lt RF Belt	2.699479 2.894827	2.3780931 2.4482751	.196	**.942
Rt VMO Back Rt VMO Belt	1.793955 1.960465	.7004692 1.0441577	.285	**.651
Mean Rt VMO Back Mean Rt VMO Belt	1.586095 1.737963	.5876229 .9461544	.288	**.639
Lt VMO Back Lt VMO Belt	2.134931 2.484488	2.1335404 2.3254316	.115	**.864
Mean Lt VMO Back Mean Lt VMO Belt	1.862062 2.109677	1.6709065 1.8663353	.213	**.824

* Denotes P<0.05
** Denotes P<0.01

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Table 2

Table 2: Regression Variables

Regression Variables[a]				
Model	β	Standard Error	Variable P-Value	R^2
**1st (Constant)	-22.848	20.195	.267	.821
Back Squat 5RM	**2.329	.202	.000	
**2nd (Constant)	-34.363	19.464	.088	.850
Back Squat 5RM	**1.857	.277	.000	
Training Status	*24.994	10.767	.028	
**3rd (Constant)	**-152.439	53.940	.009	.875
Back Squat 5RM	**1.788	.259	.000	
Training Status	*25.205	10.010	.018	
Age	*5.382	2.316	.028	

a. Dependent Variable: Pit Shark® Belt Squat 5RM

* Denotes P<0.05, ** Denotes P<0.01

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Table 3

Table 3: Regression Equations

Regression Equations[a]	
Model	Equation
**1st (Constant) Back Squat 5RM	= -22.848 + **2.329(Back Squat 5RM)
**2nd (Constant) Back Squat 5RM Training Status	= -34.363 + **1.857(Back Squat 5RM) + *24.994(Training Status)
**3rd (Constant) Back Squat 5RM Training Status Age	= **-152.439 + **1.788(Back Squat 5RM) + *25.205(Training Status) + *5.382(Age)

a. Dependent Variable: Pit Shark® Belt Squat 5RM

* Denotes P<0.05, ** Denotes P<0.01

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