EFFECT OF DIFFERENT TIBIA ANGLES TO LOADING OF KNEE DURING SPLIT SQUAT

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The aim of this study was to investigate the difference of knee joint force and moment during split squats of different front tibia angles. Twelve healthy male college students performed six repetitions of four different split squat types with a standard additional load of 25% BW added using a barbell. Using 10 camera 3D motion capture system and a force plate to collect data. The peak force and moment of knee flexion (sagittal plane) were calculated by using self-designed MATLAB programs. One-way ANOVA test was undertaken using SPSS 20.0 statistical software. The analysis results of the study indicated that all kinetic parameters of the four types split squats were achieved high significant differences ($p<.000$). A better understanding of different loading in specific joints and correct exercise execution during training will help protecting practitioners from sport injury.

KEY WORDS: unilateral squat, loading, eccentric contraction.

INTRODUCTION: Various tests of lower body unilateral exercises such as lunge, step-up, split squat, and Bulgarian split squat are available to determine the baseline function and the effectiveness of a training program (McCurdy, Langford, Cline, Doscher, & Hoff, 2004). According to previous studies indicated that squat exercises have a multitude of benefits ranging from increasing in strength, hypertrophy, and muscular endurance (ACSM, 2009; Kraemer & Ratamess, 2005; Hooper et al., 2014).
However, Swiss researchers pointed out that incorrect exercise execution and weight overload was the highest risk of injury during strength training, especially split squat, in fitness centers (Müller, 1999). One study found that when performing forward lunges, if changed trunk position was able to significantly affect the biomechanics of the lower extremities (Farrokhi et al., 2008). Although several split squat studies have been described, it is still unclear that how influences the joint loading in different tibia angles during split squat. Therefore，the aim of this study was to investigate the difference of knee joint force and moment during split squats of different front tibia angles.

METHODS: In this study, twelve healthy male college students with at least 2 times a week resistance training habit, and no lower extremity musculoskeletal injured within six months were recruited as subjects (average of 23.2 ± 1.17 years of age, 179.8 ± 5.74 cm in height, and 81.8 ± 8.91 kgw in weight). All subjects performed six repetitions (2-3s for each repetition) of four different split squat types with a standard additional load of 25% BW added using a barbell. Used 85% of leg length as step lengths and evaluated tibia angles of 60°, 75°, 90° and 105° effect on knee joint (Schütz et al., 2014) (Figure 1). The experimental equipment in this study using ten-camera, three-dimensional motion capture system (T40, Vicon Motion System Ltd., UK) to collect three-dimensional position data (kinematic) from a reflective marker set consisted of 16 skin markers for legs. And a force plate (Kistler type 9287A, Kistler AG, Winterthur, Switzerland) for dominant leg was used to measure the ground reaction forces (kinetic). The kinematic and kinetic data were recorded simultaneously at 200 Hz and 2000 Hz, respectively. Experimental data included the kinematic and kinetic were analyzed using self-designed computer programs written in MATLAB (Version 7.6.0.324, MathWorks, Inc., USA) to calculate the flexion (eccentric contraction) peak force and moment (Sagittal plane) of the knee joint. One-way ANOVA test was undertaken using SPSS 20.0 statistical software. The statistical significance level was set at $p < .05$.

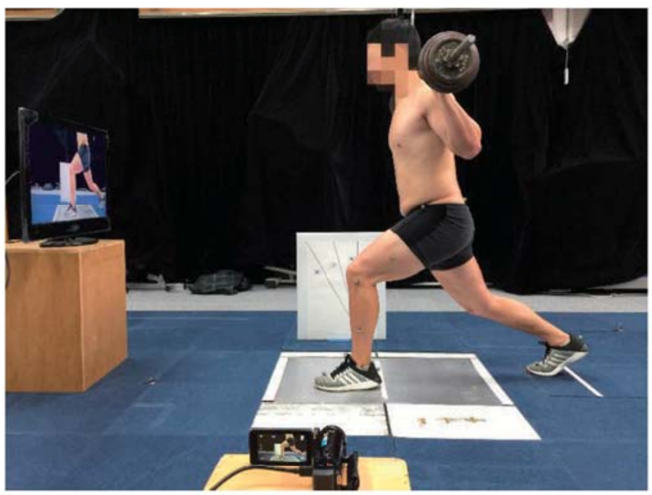

Figure 1: The measurement setup for split squats.

RESULTS: The kinetic parameters of the four split squat types (tibia angles of 60°, 75°, 90° and 105°) are presented in Table 1. Results showed that when subjects performed four split squat types, the maximal forces_{peak} and moments_{peak} of the front knee joint was observed for a tibia angle of 60°. The forces_{peak} of the front knee joint achieved high significant differences ($F = 322.323$, $p^a = .000$). The moments_{peak} of the front knee joint also achieved high significant differences ($F = 236.476$, $p^a = .000$).

Table 1

Comparison of peak joint force and moment among tibia angles with 60°, 75°, 90° and 105°

	60°	75°	90°	105°	F	p^a
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
Joint force	5.17 (0.74)^{c,d,e}	3.91 (0.40)^{b,d,e}	2.53 (0.23)^{b,c,e}	1.60 (0.13)^{b,c,d}	322.323	.000
Joint moment	1.41 (0.18)^{c,d,e}	1.14 (0.08)^{b,d,e}	0.92 (0.10)^{b,c,e}	0.64 (0.05)^{b,c,d}	236.476	.000

Joint force: N/kg; Joint moment: mN/kg; [a]Analysis of variance, Welch statistic; [b]Significantly different from 60° (Games-Howell post-hoc test); [c]Significantly different from 75° (Games-Howell post-hoc test); [d]Significantly different from 90° (Games-Howell post-hoc test); [e]Significantly different from 105° (Games-Howell post-hoc test).

DISCUSSION: The results of this study indicated that all kinetic parameters of the four split squat types were achieved high significant differences. The highest value of load ($force_{peak}$ and $moment_{peak}$) was observed when using 60° of tibia angle during split squat. And the smallest value was observed when using 105° of tibia angle during split squat. It can clearly be observed that as the tibia angle increased, the force and moment decreased in the knee joint. The $force_{peak}$ of the knee joint sequentially increased by 32.2% (75° to 60°), 54.5% (90° to 75°) and 58.1% (105° to 90°), respectively. The $moment_{peak}$ of the knee joint sequentially increased by 23.7% (75° to 60°), 23.9% (90° to 75°) and 43.8% (105° to 90°), respectively. However, when the distance between knee and toes begin to increase, knee joint loading is obviously rise in our study is still lower than the joint force and moment during running or jumping (Kobayashi et al., 2010; Devita et al., 2016), indicated that this loading of the front knee is safe for healthy adults. According to the common guideline, appropriate joint loading may requires the knees move slightly over the toes or keep the shank as vertical as possible during squatting (McLaughlin, Lardner, & Dillman, 1978; Fry, Smith, & Schilling, 2003; Schütz et al., 2014). This might make cruciate ligament at the risk of injury. For future studies, we'll focus on the factors of lower extremity injury above different kind of split squats.

CONCLUSION: Weight-bearing exercises, such as squat, is performed for three purposes, increasing the hip and thigh musculature, improving muscle endurance and getting better working capability. But it may cause injuries due to the incorrect exercise execution. Therefore, understanding the factors of knee injury caused by different kinds of split squat is the most important issue that the sports scientists and trainers need to be concerned.

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