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ORIGINAL

Analysis of Lower Extremity Joint Moment and Power during Squat in Female Patients with Genu Varum

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Objective: The aim of this study was to analyze the net joint moment and joint power of the lower extremity during squat in female patients with genu varum.

Method: Eight female patients with genu varum were asked to do regular squats, and their net joint moment and joint power were compared to those of another eight female participants with straight legs. Their video recordings and ground reaction force data were analyzed to be used as a theoretical evidence of squatting effectively for female patients with genu varum.

Results: Squats had a higher impact on internal knee joint rotation and ankle joint flexion moments in the genu varum group than in the straight leg group due to their weak and short hip joint muscles.

Conclusion: There is a need to develop a squat movement that is appropriate for women with genu varum in order to distribute overload efficiently among the hip, knee, and ankle joints and to strengthen the muscles in a balanced way.

Keywords: Female genu varum, Squat, Net joint moment, Joint power

INTRODUCTION

Genu varum is a condition where the center of the knee joint is bent outward on a straight line that connects from the centers of the hip joint to that of the knee joint like an archer's bow (Mansfield & Neumann, 2009). Genu varum is divided into different levels, depending on the size of the gap measured when a person stands with the legs closed; Level I is diagnosed when the gap is <2.5 cm, while Level 2 is between 2.5 and 5.0 cm, Level 3 between 5.0 and 7.5 cm, and Level 4 >7.5 cm (Yang, 2013). Genu varum causes fatigue and deformity by increasing the instability of the lower extremity, which overloads the hip, knee, and ankle joints and accelerates the decline of body functions and degeneration of the joints (Wegener, Kisner, & Nichols, 1997). As a result, the vastus medialis and gluteus medius in the quadriceps, hamstring, and tibialis anterior grow weak, while the lower extremity loses its normal function as the tensor fasciae latae and soleus become short, making the joints swollen and causing pain (Cook, Burton, Kiesel, Rose, & Bryant, 2010). In addition, it also affects walking abilities as the patella is not in the normal position (Fry, Smith, & Schilling, 2003).

There have been a few exercise programs developed to correct genu varum; stretching, band exercise, sling exercise, and muscle resistive exercise have been reported to correct genu varum (Jacobon & Speechley, 1990; Smith, 1994). Clinically, there has been much effort to correct genu varum by combining various exercises together, and in particular, much attention is being paid to strengthening of the quadriceps and hamstring that contribute to the stability of the knee joint (Wayne & Susan, 2001).

Squat exercise is a multi-joint exercise that is the most well-known to strengthen the quadriceps and hamstring while flexing the hip, knee, and ankle joints simultaneously and developing the muscles of the lower extremity needed to correct genu varum (Palmitier & Scott, 1991). There are three types of squat exercise according to squat depth, including quarter squat, half squat, and full squat, and according to the knee angle, it can be further divided into semi squatting (40°), half squatting (70~100°), and deep squatting (≥100°) (Escamilla, 2001). Squat exercise is good in training the muscles of the lower extremity; therefore, a correct position is required. With a wrong squatting position, the lower back and the knee can get injured (Fry, 1993; O'Shea, 1985; Williams, 1980); hence, a correct position to prevent this should be taught in performing the exercise.

Squat exercise is the most representative exercise that strengthens the muscles of the lower extremity and develops the muscles needed to correct genu varum. As such, it is essential for women with genu varum to perform such exercise to not only correct genu varum but also develop the needed muscles. However, most of the previous studies where the squat exercise was the variable focused on people without genu varum or athletes, while there have been almost no objective data or research conducted on women with genu varum. Therefore, the present study aims to investigate the difference in the mechanics of the lower extremity joints among 16 women in their twenties with (eight patients) and without genu varum (eight patients) while they perform the squat exercise upon comparing and analyzing their squat positions.

METHODS

1. Participants

A total of 16 subjects were included in the present study: eight women in their twenties with genu varum but without any severe musculoskeletal injury of the lower extremity whose knee gaps were between 5.0~7.5 cm (age: 24.5±2.6 y, height: 163.6±7.6 cm, weight: 58.0±5.6 kg) and eight women in their twenties with straight legs without severe musculoskeletal injury of the lower extremity (age: 22.5±3.1 y, height: 165.4±5.9 cm, weight: 58.1±6.2 kg).

2. Measurements

Prior to the start of the experiment, all subjects were informed of the purpose and method of the experiment and shown how to perform a squat exercise with a detailed explanation of precautions. Most subjects had adequate training to familiarize themselves with the correct squat position, such as the knee angle and feet position since they were not used to the exercise. As a warm-up, the subjects performed PT jumps 20 times to stretch the muscles of the lower extremity needed for the squat exercise and increase the muscle temperature.

According to the method of the experiment, three successful squat movements of the same position were collected. As a way of preventing movement of the upper extremity, the subjects controlled the movement as much as possible by crossing their arms over the chest while looking straight ahead (Escamilla, 2001). The squat exercise performed in the present study was a half squat exercise, where the knees were bent at an angle of 70~100°, and the horizontal plane angle of the feet was 0°. On the basis of the videos where successful squat movements were recorded, the knee angles were calculated, and the squat movements with knee angles of 85~95° were processed into data. Videos were recorded, and data on the ground reaction forces were collected while the subjects performed the squat exercise. The experimental set up is shown (Figure 1).

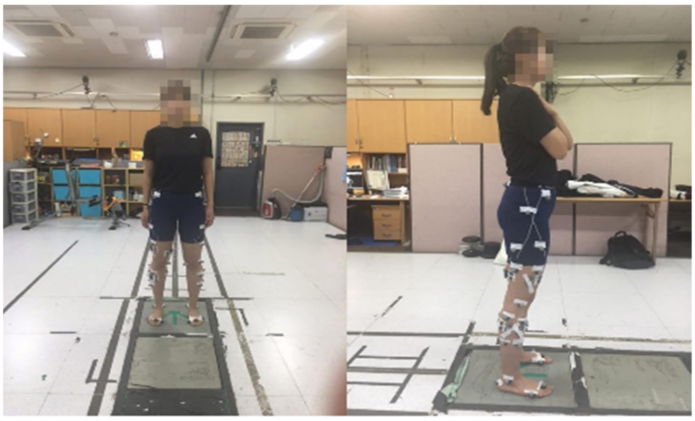

Figure 1. Experimental setup

3. Data processing

1) Movement analysis

To record the squat movements, an imaging equipment (Qualisys Oqus 500, Qualisys, USA) was used to record the movements of the hip, knee, and ankle joints. The moment and power of the lower extremity joints were calculated along with the data on ground reaction forces taken from a force place (AMTI OR6-7, AMTI, USA).

2) Ground reaction forces

Data on ground reaction forces were collected at 2,000 Hz using a ground reaction force system (AMTI OR6-7, AMTI, USA). For the three-dimensional space, the anterior-posterior direction was set on the X axis, while the medial-lateral and the vertical directions were set on the Y and Z axes, respectively. The data on the ground reaction forces and the image data were used to calculate the moment and power of the joints (Lee & Lim, 2014; Lim, Ryu & Kim, 2013; Winter, 1980).

3) Setting of events and phases

Three events and two phases were set in the present study.

① Event 1: where a half squat (70~100°) movement begins

② Event 2: where the knee joint is bent at a minimum angle

③ Event 3: where the knee joint is flexed at a maximum angle

④ Flexion phase: from the ready position of the half-squat exercise (70~100°) where the knee joint starts flexing (Event 1) to the time when the knee joint is bent at a minimum angle (Event 2)

⑤ Extension phase: From the time when the knee joint is bent at a minimum angle (Event 2) to the time when the knee joint is flexed at a maximum angle (Event 3)

4. Statistical analysis

Statistical data in the present study were processed using the SPSS program (Version 23.0). To investigate the statistical difference in the joint moment and power between the experimental group (women with genu varum) and the control group (women with straight legs), an independent sample *t*-test was conducted, and the level of significance was set at α=.05.

RESULTS

1. Net joint moment

The first research topic of the present study was to compare the difference in the joint moment during squat movements between the groups. To investigate this, average measurement values for the sagittal, frontal, and transverse planes of the hip, knee, and ankle joints during the flexion and extension phases were calculated.

(Table 1) shows the result of the analysis to determine whether there is a difference in the joint moment between the groups during the flexion phase. According to the result, there was no statistically significant difference in the measurement values for the sagittal, frontal, and transverse planes of the hip joint between the groups ($p > .05$). During the flexion phase, the knee joint did not show any statistically significant differences in the measurement values for the sagittal and frontal planes of the knee joint between the groups ($p > .05$).

Table 1. Differences in net joint moment in the knee flexion phase

(unit: Nm/kg)

Joint	Plane	Group	M ± SD	*t*	*p*-value
Hip	Sagittal (x)	Exp	21.04±7.22	.013	.990
		Con	21.00±8.45		
	Frontal (y)	Exp	36.59±17.75	.474	.646
		Con	32.89±13.14		
	Transverse (z)	Exp	16.52±11.92	.634	.540
		Con	13.50±6.32		
Knee	Sagittal (x)	Exp	40.48±11.42	-1.74	.104
		Con	48.91±7.56		
	Frontal (y)	Exp	15.84±11.53	1.31	.215
		Con	9.45±7.57		
	Transverse (z)	Exp	-1.41±1.55	-2.68	.024*
		Con	2.22±3.50		
Ankle	Sagittal (x)	Exp	-8.26±1.76	-4.60	.001*
		Con	-.48±4.45		
	Frontal (y)	Exp	7.45±4.45	1.75	.103
		Con	3.63±4.30		
	Transverse (z)	Exp	.32±2.48	-.33	.747
		Con	.70±2.04		

Note: Sagittal (flexion: -, extension: +), Frontal (adduction: -, abduction: +), Transverse (internal: -, external: +)
Asterisk indicates a statistical difference between the groups ($p < .05$).
Exp, experimental; Con, control; M ± SD, mean ± standard deviation

However, there was a statistically significant difference in the transverse plane of the knee joint between the groups ($p < .05$). This, in turn, indicates that the experimental group had an internal knee rotation moment, while the control group had an external knee rotation moment.

During the flexion phase, there was a statistically significant difference in the measurement value for the sagittal plane of the ankle joint between the groups ($p < .05$) (Figure 2). This indicates that no difference in the internal knee rotation moment was observed between the groups. Moreover, no statistically significant difference in the frontal and transverse planes of the knee joint was found between the groups ($p > .05$).

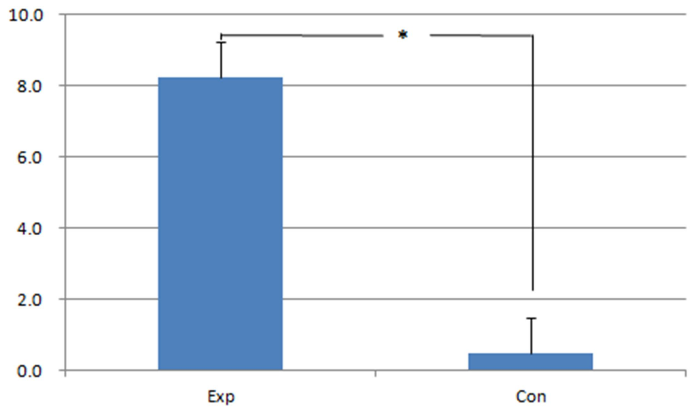

Figure 2. Differences in the ankle net joint moment in the knee flexion phase between the two groups (unit: Nm/kg). Asterisk indicates a statistical difference between the groups ($p < .05$).

(Table 2) shows the result of the analysis to determine whether there is a difference in joint moment between the groups during the extension phase. According to the result, there were no statistically significant differences in the sagittal, frontal, and transverse planes of the hip joint during the extension phase between the groups ($p > .05$).

During the extension phase, there was no statistically significant difference in the sagittal and frontal planes of the knee joint between the groups ($p > .05$). However, there was a statistically significant difference in the transverse plane of the knee joint between the groups ($p < .05$).

This indicates that the experimental group had an internal rotation moment, while the control group had an external rotation moment. In addition, both groups did not show any statistically significant differences in the sagittal, frontal, and transverse planes of the ankle joint during the extension phase ($p > .05$).

Table 2. Differences in net joint moment in the knee extension phase

(unit: Nm/kg)

Joint	Plane	Group	M ± SD	*t*	*p*-value
Hip	Sagittal (x)	Exp	19.03±8.37	-.47	.645
		Con	21.56±12.65		
	Frontal (y)	Exp	35.66±17.47	.140	.891
		Con	34.55±14.38		
	Transverse (z)	Exp	13.95±11.08	.819	.429
		Con	10.21±6.67		
Knee	Sagittal (x)	Exp	42.87±13.91	-1.53	.149
		Con	51.59±8.22		

Table 2. Differences in net joint moment in the knee extension phase (Continued) (unit: Nm/kg)

Joint	Plane	Group	M ± SD	*t*	*p*-value
Knee	Frontal (y)	Exp	14.86±1091	1.09	.296
		Con	9.01±10.67		
	Transverse (z)	Exp	-.39±1.91	-2.64	.019*
		Con	2.45±2.37		
Ankle	Sagittal (x)	Exp	-1.94±5.52	.260	.798
		Con	-2.70±6.16		
	Frontal (y)	Exp	7.08±4.49	1.62	.128
		Con	3.55±4.23		
	Transverse (z)	Exp	-.00±2.32	-.92	.371
		Con	.98±1.91		

Note: Sagittal (flexion: -, extension: +), Frontal (adduction: -, abduction: +), Transverse (internal: -, external: +)
Asterisk indicates a significance ($p<.05$).
Exp, experimental; Con, control; M ± SD, mean ± standard deviation

Table 3. Differences in joint power in the knee flexion phase (unit: Nm/s^2)

Joint	Plane	Group	M ± SD	*t*	*p*-value
Hip	Sagittal (x)	Exp	22.87±13.25	.176	.863
		Con	21.70±13.40		
	Frontal (y)	Exp	14.60±15.78	1.12	.283
		Con	8.05±5.11		
	Transverse (z)	Exp	5.54±3.97	1.04	.327
		Con	3.97±1.57		
Knee	Sagittal (x)	Exp	7.38±1.91	.845	.416
		Con	6.20±3.45		
	Frontal (y)	Exp	3.42±3.61	.754	.463
		Con	2.30±2.17		
	Transverse (z)	Exp	8.24±7.92	-.185	.856
		Con	9.27±13.59		
Ankle	Sagittal (x)	Exp	2.22±1.71	.893	.387
		Con	1.63±.72		
	Frontal (y)	Exp	.91±.96	.661	.520
		Con	.65±.56		
	Transverse (z)	Exp	.97±.64	-.713	.488
		Con	1.86±3.49		

Note: Sagittal (flexion: -, extension: +), Frontal (adduction: -, abduction: +), Transverse (internal: -, external: +)
Asterisk indicates a significance ($p<.05$).
Exp, experimental; Con, control; M ± SD, mean ± standard deviation

2. Joint power

The second research topic of the present study was to compare the difference in the joint power between the groups by measuring it during the squat movement. To investigate this, average measurement values for the sagittal, frontal, and transverse planes of the hip, knee, and ankle joints were calculated during the flexion and extension phases.

(Table 3) shows the result of the analysis to determine whether there is a difference in the joint power between the groups during the flexion phase. According to the result, there were no statistically significant differences in the power of the hip, knee, and ankle joints between the groups during the flexion phase ($p>.05$). This, in turn, indicates that the experimental group and the control group showed no difference in terms of the maximum power of energy absorption and expression.

(Table 4) shows the result of the analysis to determine whether there is a difference in the joint power between the groups during the extension phase. According to the result, there were no statistically significant differences in the power of the hip, knee, and ankle joints during the extension phase ($p>.05$). This means that the experimental group and the control group did not show any difference in the maximum power of energy absorption and expression.

Table 4. Differences in joint power in the knee extension phase (unit: Nm/s^2)

Joint	Plane	Group	M ± SD	*t*	*p*-value
Hip	Sagittal (x)	Exp	35.33±26.57	-.612	.550
		Con	42.43±19.23		
	Frontal (y)	Exp	10.35±8.70	-0.33	.974
		Con	10.51±10.47		
	Transverse (z)	Exp	5.72±3.05	.309	.762
		Con	5.26±2.96		
Knee	Sagittal (x)	Exp	50.60±26.73	-1.086	.296
		Con	63.86±21.88		
	Frontal (y)	Exp	6.15±5.63	.731	.477
		Con	3.99±6.22		
	Transverse (z)	Exp	6.18±5.48	.145	.887
		Con	5.71±7.28		
Ankle	Sagittal (x)	Exp	5.47±3.76	-.462	.651
		Con	6.56±5.55		
	Frontal (y)	Exp	1.36±2.20	.140	.890
		Con	1.21±1.83		
	Transverse (z)	Exp	.78±.40	.403	.693
		Con	.66±.72		

Note: Sagittal (flexion: -, extension: +), Frontal (adduction: -, abduction: +), Transverse (internal: -, external: +)
Asterisk indicates a statistical difference between the groups ($p<.05$).
Exp, experimental; Con, control; M ± SD, mean ± standard deviation

DISCUSSION

The present study aims to investigate the joint moment and power of the lower extremity by comparing and analyzing the squat movement of eight women in their twenties with genu varum and eight women in their twenties with straight legs. To this end, an independent sample *t*-test was conducted to find out the statistical difference in the measurement values between the groups. According to the research findings, the joint moment of the experimental group and the control group during squat movement was divided into the flexion and extension phases; during the flexion phase, the experimental group had an internal knee rotation moment in the transverse plane, while the control group had an external knee rotation moment; the experimental group experienced a greater flexion moment in the sagittal plane of the ankle joint than the control group. Even during the extension phase, the experimental group had an internal knee rotation moment in the transverse plane, while the control group had an external knee rotation moment. In addition, the experimental group had a decline in the ability to control posture during various physical activities which, in turn, affects their balancing strategies (Tsai, Yu, Mercer, & Gross, 2006). It changes the positions of the ground reaction forces and pressure center (Van Gheluwe, Kirby, & Hagman, 2005). Such changes resulted in the difference in the output of the joint moment in the control group.

In addition, it is thought that the experimental group must have had a longer knee joint moment as they had an internal knee rotation, but not an external ankle rotation to make up for the anterior tilt of the hip joint resulting from the weak and short hip joint muscles, a characteristic of bowed legs (Jeong, 2016). Therefore, the use of small equipment, such as a band should be considered by women with genu varum when performing squat movements to exert constant power while maintaining little tension outward to control the anterior tilt of the hip joint and reduce the internal knee rotation (Jeong, 2016).

When both groups performed the squat movements, no significant difference in the joint power was found between the groups during the flexion and extension phases. However, when comparing the flexion and extension phases, both groups showed the maximum power of energy absorption and expression during the extension phase. Consequently, the joint powers of both groups were not affected by the weak and short muscles, as well as the changes in the joint angles; this, in turn, is thought to be attributable to both groups being healthy women in their twenties with no pathological problems in the joints (Jeong, 2016).

As a result, the experimental group was thought to have not been able to distribute the overload effectively due to their weak and short hip joint muscles and deformities in the joints, compared to the control group (Jeong, 2016). Therefore, it is thought that the less active muscles of the experimental group should be developed in consideration of the characteristics of the muscle development found in the previous studies, which are influenced by muscle activities with different stance width and squat depth (Jeong, 2016).

CONCLUSION

In the present study, the joint moment and power of the eight women in their twenties with genu varum during squat movements were investigated by comparing and analyzing them with those of the eight women in their twenties with straight legs. The following conclusion has been drawn after analyzing the images and ground reaction forces to provide theoretical grounds for a squat exercise that is effective for women with genu varum. Since the experimental group had poorer and weaker hip joint muscles than the control group, they had a greater impact on the internal knee rotation moment and ankle flexion moment. To effectively distribute the overload among the hip, knee, and ankle joints and develop the muscles in a balanced manner, women with genu varum need to perform squat exercises with modified movements appropriate for them, rather than a general squat exercise.

Based on the present study, it is thought that various factors, including pre- and post-stretching tests centered on the poor and short muscles in women with genu varum, the angle and width of feet and knee control should be considered for future research to study the movements in detail; in turn, this will produce a meaningful outcome of narrowing the gap in the joint and muscle use between women with genu varum and women with straight legs during squat movements.

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