



Original Article

Lumbar lordosis angle and trunk and lower-limb electromyographic activity comparison in hip neutral position and external rotation during back squats

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Abstract. [Purpose] To compare the lumbar lordosis angle and electromyographic activities of the trunk and lower-limb muscles in the hip neutral position and external rotation during back squats. [Subjects and Methods] Ten healthy males without severe low back pain or lower-limb injury participated in this study. The lumbar lordosis angle and electromyographic activities were measured using three-dimensional motion-capture systems and surface electrodes during four back squats: parallel back squats in the hip neutral position and external rotation and full back squats in the hip neutral position and external rotation. A paired t-test was used to compare parallel and full back squats measurements in the hip neutral position and external rotation, respectively. [Results] During parallel back squats, the average lumbar lordosis angle was significantly larger in hip external rotation than in the hip neutral position. During full back squats, lumbar erector spinae and multifidus activities were significantly lower in hip external rotation than in the hip neutral position, whereas gluteus maximus activity was significantly higher in hip external rotation than in the hip neutral position. [Conclusion] The back squat in hip external rotation induced improvement of lumbar kyphosis, an increasing of the gluteus maximus activity and a decrease of both lumbar erector spinae and multifidus activities.

Key words: Back squat, Lumbar lordosis, Electromyography

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INTRODUCTION

Squat exercise (SQ) is a typical lower-limb training performed by many athletes. During SQ which is the simple exercise on sagittal plane, athletes need to keep their posture properly. As one of the proper sagittal posture during SQ, maintenance of neutral zone¹⁾ by a slight pelvic anteroposterior tilt is required. The maintenance of neutral zone prevents from lumbar kyphosis and low back pain (LBP) caused by the increases of compressive load on lumbar intervertebral disc^{2, 3)}. Furthermore, considering the previous study⁴⁾ that reported lumbar erector spinae (LES) during SQ works for prevention from lumbar kyphosis, the more lumbar kyphosis causes excessive LES activity and myofascial LBP. Therefore, the maintenance of proper sagittal posture without lumbar kyphosis and excessive LES activity is important to prevent LBP.

As a means of preventing from lumbar kyphosis, improving hip joint flexion mobility is a good way because the cause of lumbar kyphosis during SQ is a decrease of hip joint flexion mobility^{5, 6)}. McKean et al.⁶⁾ compared lumbar motion between men and women during SQ and reported that women with less pelvic posterior tilt show less lumbar kyphosis than did men. This report indicated that women with higher joint mobility⁶⁾ have a small degree of pelvic posterior tilt during hip joint flexion, which makes it easy to maintain lumbar lordosis.

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Moreover, Myer et al.⁵⁾ reported that tightness of the iliotibial band posterior fiber is a considerable reason of occurrence of both pelvic posterior tilt and lumbar kyphosis before hip joint flexion of 120° during SQ. Under the circumstance that hip joint is deeply flexed, pelvic is likely to be pulled posteriorly via the gluteus maximus by the iliotibial band posterior fiber. From this theory, as a method to facilitate pelvic anterior tilt and lumbar lordosis during SQ, an externally rotated hip joint may lower the tension of the iliotibial band posterior fiber by shortening the distance between its origin and its insertion. A previous study of SQ compared weight position^{7, 8)}, stance width^{9, 10)}, and depth¹¹⁾; however, no study to date has verified the differences in hip joint rotational position. Moreover, the influence on the lumbar lordosis–kyphosis angle and muscle activity in the trunk and hip region by differences in hip joint rotational positions during SQ has not been clarified. Therefore, this study aimed to clarify the influence of the hip joint in external rotation during SQ on the lumbar lordosis–kyphosis angle and muscle activities in the trunk and hip region.

SUBJECTS AND METHODS

Ten healthy males (average height, 175.6 ± 7.2 cm; body mass, 88.9 ± 15.0 kg; age, 20 ± 2 years) participated in this study. Participants were excluded if they had low back pain or suffered lower-limb injuries in the past 6 months. They have resistance training habits of back squat (BSQ) exercise more than three times a week. Each participant provided written informed consent. This study was approved by the Waseda University ethics committee (2016-246).

In the trials, parallel BSQ (P-BSQ) with a weight of 80% 1RM and full BSQ (F-BSQ) with 60% 1RM were performed randomly, with changes in the hip joint rotational positions (neutral position and external rotation). The stance width during each trial was adjusted to the participants' acromion and heel width. With respect to hip joint rotational position, the participants were instructed to direct their patella and toe to the front in the hip neutral position and to rotate their patella and toes 45° around their heel in hip external rotation. Each participant was instructed to squat until their thighs were parallel to the ground during P-BSQ and squat maximally during F-BSQ.

Before the trials, the examiner attached reflective markers (QPM190, Qualysis AB, Sweden) to the bilateral acromion, spinous processes of Th12/L3/S1, anterior/posterior superior iliac spine, greater trochanter, medial/lateral femoral epicondyle, medial/lateral malleolus, and barbell end except the spinous processes of Th12/L3/S1. All trials were photographed using seven three-dimensional (3D) motion-capture cameras (OQUS, Qualysis AB) at a sampling rate of 200 Hz; the cameras were synchronized with a versatile telemetry electromyography (EMG) system and wireless EMG sensors (m-BioLog2 DL-5000, S&ME Co., Ltd., Japan).

From the markers attached to the spinous processes of Th12/L3/S1, we calculated lumbar lordosis angle during BSQ. It was defined as the angle formed by the line connecting the markers of the Th12/L3 spinous processes and the line connecting the markers of the L3/S1 spinous processes. Lumbar lordosis was increased as its angle increased. From the markers attached to the barbell end, BSQ was divided into four phases (former eccentric, latter eccentric, former concentric, and latter concentric). With respect to the Z coordinate indicating the height of the 3D coordinate, the maximum to minimum value of the barbell-end Z coordinate is defined as the eccentric phase and the minimum to maximum value of the barbell-end Z coordinate is defined as the concentric phase. Each phase was divided into two (former and latter) by the middle value between the maximum and minimum values of the barbell-end Z coordinate. The lumbar lordosis angle data in each phase were converted from percentiles into 100 data points since the number of data points differed among phases and participants. Thereafter, the average lumbar lordosis angle was calculated from 100 data points in each phase.

Measurements were taken using surface electrodes (BlueSensor N-00-S, METS Co., Japan). The target muscles were the rectus abdominis (RA), external oblique (EO), internal oblique (IO), LES, MF, gluteus maximus (GMax), gluteus medius (GMed), rectus femoris (RF), and biceps femoris (BF). The surface electrodes were placed perpendicular to the muscle fibers.

EMG activity was examined using biological information analysis software (BIMUTAS-Video, Kissei Comtec Co., Ltd., Japan) and sampled at 1,000 Hz. The bandpass filter for the surface electrodes was 20–500 Hz. EMG activity was represented as percent maximum voluntary contraction (%MVC), which was calculated from the root mean square (RMS) amplitude and normalized by the RMS of the MVC. For measuring the RA MVC¹²⁾, the participants performed a partial sit-up with their knees flexed and manual resistance applied to the anterior aspect of the shoulder. For the EO and IO MVC¹²⁾, the participant was in a supine position with the knees flexed, hands behind the head, and trunk flexed and rotated. Resistance was applied at the shoulders in trunk extension and rotation to the opposite directions. For the LES and MF MVC measurements¹²⁾, the participants performed the exercise in prone trunk extension with resistance applied to the upper thoracic area in the direction of trunk flexion. For the GMax MVC, the participants performed the exercises in prone hip extension with resistance applied to the thigh in the direction of hip flexion. For the GMed MVC, the participants performed the exercise in side-lying hip abduction with resistance applied to the thigh in the direction of hip adduction. For the RF MVC, the participants performed the exercise in a seated position with knee extension, and resistance was applied to the lower leg in the direction of knee flexion. For the BF MVC, the participants performed the exercise with prone knee flexion and resistance applied to the lower leg in the direction of knee extension.

Normally distributed data were examined for lumbar lordosis angle and muscle activity, and a paired t-test was used to compare P-BSQ and F-BSQ measurements in hip joint rotational positions (neutral position and external rotation), respectively. The significance level was set at an alpha value of <0.05.

Table 1. Average lumbar lordosis angle during four squats

Phase	P-BSQ N	P-BSQ ER	F-BSQ N	F-BSQ ER
Former eccentric	191.0 ± 5.3	191.3 ± 3.6	190.7 ± 5.1	190.2 ± 4.6
Latter eccentric	185.4 ± 4.7	186.0 ± 5.1	183.1 ± 4.1	183.4 ± 4.0
Former concentric	184.4 ± 4.8*	186.1 ± 5.4	181.7 ± 4.5	182.9 ± 4.0
Latter concentric	188.4 ± 5.5	188.6 ± 4.9	186.1 ± 4.9	186.3 ± 4.3

Values are expressed as average ± SD ° (degrees).

P-BSQ N: parallel back squat in the hip neutral position; P-BSQ ER: parallel back squat in hip external rotation; F-BSQ N: full back squat in the hip neutral position; F-BSQ ER: full back squat in hip external rotation.

*Significant difference corresponding to hip joint rotational position (p<0.05).

Table 2. Average of 5 trunk muscles EMG activities during four squats

	Phase	P-BSQ N	P-BSQ ER	F-BSQ N	F-BSQ ER
RA	Former eccentric	18.2 ± 35.3	14.3 ± 21.0	14.1 ± 22.3	21.7 ± 32.6
	Latter eccentric	17.8 ± 29.7	24.5 ± 53.0	18.7 ± 16.9	12.2 ± 9.0
	Former concentric	11.9 ± 14.9	22.9 ± 48.4	28.3 ± 29.6	37.1 ± 53.9
	Latter concentric	13.0 ± 13.0	11.5 ± 10.6	24.3 ± 38.8	10.7 ± 10.1
EO	Former eccentric	32.6 ± 21.6	35.6 ± 29.7	28.5 ± 13.0	25.8 ± 17.2
	Latter eccentric	36.2 ± 33.3	20.3 ± 5.4	43.2 ± 22.5	32.7 ± 12.5
	Former concentric	20.5 ± 5.7	26.7 ± 25.6	34.8 ± 19.0	30.9 ± 12.7
	Latter concentric	31.7 ± 32.1	31.9 ± 31.4	54.8 ± 55.0	33.0 ± 39.2
IO	Former eccentric	35.5 ± 17.2	29.0 ± 12.2	39.4 ± 14.9	36.7 ± 19.4
	Latter eccentric	65.2 ± 37.3	60.2 ± 31.9	73.2 ± 39.8	68.2 ± 31.5
	Former concentric	53.1 ± 20.6	52.3 ± 26.4	62.6 ± 21.0	65.7 ± 18.6
	Latter concentric	45.6 ± 33.9	37.2 ± 19.7	51.7 ± 24.8	42.6 ± 18.6
LES	Former eccentric	51.2 ± 26.1	40.2 ± 22.0	42.4 ± 17.6	45.8 ± 35.2
	Latter eccentric	71.2 ± 24.8	57.7 ± 22.5	72.1 ± 36.9*	60.8 ± 26.4
	Former concentric	90.4 ± 39.8	80.1 ± 31.6	99.5 ± 43.0*	90.4 ± 35.6
	Latter concentric	59.1 ± 32.8	45.2 ± 19.4	53.5 ± 19.2	51.2 ± 19.3
MF	Former eccentric	59.4 ± 20.8	46.6 ± 13.7	53.9 ± 16.2	46.8 ± 14.1
	Latter eccentric	80.6 ± 28.3	69.2 ± 22.5	77.3 ± 41.7	60.1 ± 22.0
	Former concentric	99.3 ± 33.2	88.0 ± 27.1	108.6 ± 44.6*	86.1 ± 29.9
	Latter concentric	83.8 ± 28.2	76.4 ± 27.7	84.7 ± 33.7	77.2 ± 25.3

Values are expressed as average ± SD %MVC.

P-BSQ N: parallel back squat in the hip neutral position; P-BSQ ER: parallel back squat in hip external rotation; F-BSQ N: full back squat in the hip neutral position; F-BSQ ER: full back squat in hip external rotation; RA: rectus abdominis; EO: external oblique; IO: internal oblique; LES: lumbar erector spinae; MF: multifidus.

*Significant difference corresponding to hip joint rotational position (p<0.05).

RESULTS

The average lumbar lordosis angle in each phase during BSQ is shown in Table 1. In the former concentric phase of P-BSQ, the average lumbar lordosis angle in hip external rotation (186.1 ± 5.4°) was significantly larger than that in the hip neutral position (184.4 ± 4.8°) (p=0.028). In other P-BSQ phases, the average lumbar lordosis angle was not significantly different by hip joint rotational position. The muscle activities in each phase during BSQ are shown in Tables 2 and 3. Regarding each muscle activity in each phase during P-BSQ, there were no significant differences by hip joint rotational position.

The average lumbar lordosis angle in each phase during F-BSQ was not significantly different by hip joint rotational position. In the latter eccentric and former concentric phase of F-BSQ, LES activity in hip external rotation (60.8 ± 26.4%MVC, 90.4 ± 35.6%MVC) was significantly lower than that in the hip neutral position (72.1 ± 36.9%MVC, 99.5 ± 43.0%MVC) (p=0.046, 0.035). On the other hand, the GMax activity in hip external rotation (34.2 ± 18.0%MVC, 40.4 ± 19.2%MVC) was significantly higher than that in the hip neutral position (19.4 ± 9.3%MVC, 31.5 ± 14.6%MVC) (p=0.006, 0.033). In the

Table 3. Average of 4 lower limb muscles EMG activities during four squats

Phase		P-BSQ N	P-BSQ ER	F-BSQ N	F-BSQ ER
GMax	Former eccentric	16.7 ± 9.6	17.5 ± 7.8	16.9 ± 10.0	19.8 ± 10.7
	Latter eccentric	15.2 ± 6.9	22.4 ± 9.9	19.4 ± 9.3*	34.2 ± 18.0
	Former concentric	27.9 ± 13.0	32.1 ± 15.9	31.5 ± 14.6*	40.4 ± 19.2
	Latter concentric	38.2 ± 14.6	37.3 ± 14.6	39.1 ± 16.3	42.8 ± 23.4
GMed	Former eccentric	18.1 ± 8.7	16.8 ± 7.9	16.1 ± 6.5	17.5 ± 6.0
	Latter eccentric	17.4 ± 8.3	19.9 ± 9.5	22.2 ± 10.6	26.5 ± 18.6
	Former concentric	18.8 ± 12.8	18.7 ± 13.1	19.3 ± 10.9	22.1 ± 15.2
	Latter concentric	29.4 ± 15.0	27.5 ± 15.5	33.6 ± 18.2	29.3 ± 11.6
RF	Former eccentric	41.7 ± 21.8	36.2 ± 22.1	34.4 ± 14.6	36.3 ± 18.8
	Latter eccentric	80.7 ± 39.6	66.3 ± 37.2	61.1 ± 34.8	60.2 ± 36.0
	Former concentric	85.8 ± 34.4	75.3 ± 28.8	66.7 ± 32.4	79.4 ± 34.4
	Latter concentric	31.4 ± 18.4	28.6 ± 15.1	31.5 ± 13.8	35.6 ± 17.8
BF	Former eccentric	14.3 ± 6.4	12.9 ± 6.8	14.0 ± 8.2	14.6 ± 7.7
	Latter eccentric	14.4 ± 11.6	16.9 ± 11.3	22.3 ± 18.5	24.1 ± 16.5
	Former concentric	19.1 ± 15.3	20.7 ± 13.7	25.0 ± 18.4	28.2 ± 18.2
	Latter concentric	28.4 ± 18.0	34.3 ± 25.7	29.3 ± 18.7	29.9 ± 17.3

Values are expressed as average ± SD %MVC.

P-BSQ N: parallel back squat in the hip neutral position; P-BSQ ER: parallel back squat in hip external rotation; F-BSQ N: full back squat in the hip neutral position; F-BSQ ER: full back squat in hip external rotation; GMax: gluteus maximus; GMed: gluteus medius; RF: rectus femoris; BF: biceps femoris.

*Significant difference corresponding to hip joint rotational position ($p < 0.05$).

former concentric phase of F-BSQ, MF activity in hip external rotation ($86.1 \pm 29.9\%$ MVC) was significantly lower than that in the hip neutral position ($108.6 \pm 44.6\%$ MVC) ($p = 0.049$). With regard to the other muscle activities in each phase during F-BSQ, there were no significant differences by hip joint rotational position.

DISCUSSION

In the former concentric phase of the P-BSQ, a high lumbar lordosis angle was noted in hip external rotation compared with the hip neutral position. The former concentric BSQ is the phase rising from the lowest point, and the load on the intervertebral disc is the highest because of ground reaction force and weight load^{2, 3}. P-BSQ in hip external rotation is thought to contribute to reducing the lumbar load on the intervertebral disc since lumbar kyphosis was decreased in the former concentric phase. Hip external rotation brings the attachment part of the iliotibial band posterior fiber and gluteus maximus closer to each other and lowers their tension as compared to that in the hip neutral position, which leads to increased hip joint flexion mobility. In other words, hip external rotation can avoid pelvic posterior tilt, a compensatory motion of the hip joint. As a result of the avoidance of the pelvic posterior tilt, lumbar can keep their original alignment during the deep flexion of the hip joint and therefore lumbar kyphosis was decreased. However, the lumbar lordosis angle during F-BSQ was not different between hip external rotation and the hip neutral position. It is surmised that lumbar kyphosis could not be decreased even in hip external rotation since the F-BSQ had a hip joint flexion angle greater than that of the P-BSQ, and pelvic posterior tilt of compensatory motion occurred.

The muscle activity in the trunk and hip region was not significantly different between the hip neutral position and hip external rotation during P-BSQ. However, the LES activity of the latter eccentric and former concentric phases and MF activity of the former concentric phase in hip external rotation were lower than those in hip neutral position during F-BSQ. The LES activity of former concentric phase showed 99.5%MVC in the hip neutral position and 90.4%MVC in hip external rotation during F-BSQ. Furthermore, in the study⁴) whose trials of high load BSQ and MVC are similar to this study, the LES activity of concentric phase showed 94.7%MVC during BSQ. As a reason for showing high LES activity in the concentric phase during high load BSQ, the LES may activate to maintain pelvic anterior tilt, lumbar lordosis and extension of upper trunk in order to resist weight load behind the shoulder. Consequently, the F-BSQ in hip external rotation resulted in lower LES and MF activities than the hip neutral position, and it was possible for the participants to maintain lumbar lordosis equivalent to that of the hip neutral position, which contributed to reducing the muscle activity related to lumbar region load.

Although the LES and MF activities decreased, the GMax activity of the latter eccentric and former concentric phases increased in hip external rotation during F-BSQ. Kang et al.¹³) reported that GMax activity increased in hip abduction during prone hip extension, and indicated that positioning the muscle fiber of GMax parallel to the femur makes its activity increase. This indication is also shown in this study, representing GMax activity during F-BSQ was increased when the hip joint was

in hip external rotation. Therefore, performing SQ with hip external rotation is a considerable exercise to accomplish the increased GMax activity.

The limitation of this study is that the markers attached to the anterior superior iliac spine (ASIS) were hidden by the participant's body at deep flexion of hip joint and could not be used to measure ASIS coordinate data. Therefore, it was impossible to calculate the pelvic anteroposterior tilt angle. Although we considered pelvic anteroposterior tilt, it was not possible to clarify the influence of pelvic anteroposterior tilt in hip external rotation during the BSQ.

In conclusion, BSQ in hip external rotation induced improvement of lumbar kyphosis, an increase of the GMax activity and a decrease of both LES and MF activities. On the other hand, BSQ in the hip neutral position might effectively improve excessive lumbar lordosis. Lastly, as clinical implications, since both BSQ in hip external rotation and one in hip neutral position have distinctive merit, hip joint rotational positions during BSQ should be individually selected with their own objectives.

Conflict of interest

None.

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