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Original Article

The relationship between the deep squat movement and the hip, knee and ankle range of motion and muscle strength

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Abstract. [Purpose] We examined and clarified the relationship between the maximum squat depth and the range of motion of the ankle, knee, and hip joints, and the knee and hip muscle strength. [Participants and Methods] Nine healthy males participated in this study and performed a deep squat with the upper extremities raised; the movement was analyzed by two-dimensional motion analysis. We measured the ankle dorsiflexion, hip flexion, and knee flexion ranges of motion, as well as the knee extension and hip flexion muscle strengths and analyzed the relationship between the squatting motion, the range of motion, and the muscle strength of each joint. [Results] The right ankle dorsiflexion range of motion was a significant predictor of the ankle dorsiflexion angle on both sides. The right knee flexion range of motion was a significant predictor of the knee flexion angle, and the left knee flexion range of motion was a significant predictor of the trunk anterior tilt angle on both sides. The right ankle dorsiflexion range of motion was a significant predictor of the right hip flexion angle and vice versa. [Conclusion] This study reveals that movement on one side affects contralateral movement, which is important when evaluating the deep squat motion as a functional test.

Key words: Squat, Functional movement, Motion analysis

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INTRODUCTION

Squats are often used as a strength training or motion improvement exercise[1)]. Recently, they have also been used to assess dynamic motor control in the lower extremities[2, 3)]. Based on the squatting motion of bilateral legs, the movements of the hip, knee, and ankle joints have been analyzed[4)], and the muscle activity of the lower extremities was reported as a result[5, 6)]. Single leg squat analysis has also been performed to assess stability during dynamic motion[7, 8)]. Associations between squatting ability, anterior cruciate ligament injury[9)], and hip disorders (e.g., femoroacetabular impingement)[3)] have also been reported. Deep squats are used to evaluate athletes' functional movement, as shown in FMS by Cook[10)]. According to Cook, ankle dorsiflexion, range of hip flexion, and trunk mobility are motion-related functions[10)]. The motion of a deep squat, which is a closed kinetic chain, is affected by the motion of each joint; the movement of each joint is easily affected by the inhibition of another joint. During movement evaluation, many athletes perform asymmetrical squats due to compensatory movements, including internal and external rotation of the hip joint, pelvic tilt, trunk rotation, and lateral bending, even though the squatting movement overall is basically symmetrical. However, most past movement analyses focused on the sagittal plane on one side, and the influence of the movement on this side and its relationship with movement on the contralateral side are not clear. Clarifying how the range of motion (ROM) of one lower limb affects the movement of the opposite limb will help to predict functional impairment based on the evaluation of a deep squat.

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The purpose of this study was to examine and clarify the relationships among the maximum squat depth; ROM of the ankle, knee, and hip joints; and muscle strength of the knee and hip.

PARTICIPANTS AND METHODS

Nine healthy males participated in this study (age: 18.3 ± 0.5 years, height: 171.8 ± 6.3 cm, weight: 66.2 ± 6.2 kg). All participants provided a voluntary signed informed consent form; this study was approved by the ethical committee of the Sendai Seiyo Gakuin College (Approval No.3007) in accordance with the Declaration of Helsinki.

Each participant performed a deep squat with the upper extremities raised while being recorded by a digital video camera (HC-V480MS, Panasonic, 30fps, Osaka, Japan) from the left and right. Two-dimensional motion analysis was then performed using motion analysis software (Kinovea, 0.8.27, Boston, MA, USA). Reflective markers were attached to the left and right acromion, superior anterior iliac spine, superior posterior iliac spine, seventh cervical spinous process, fifth lumbar spinous process, greater trochanter, lateral epicondyle of the femur, fibula head, lateral malleolus, base of the fifth metatarsal bone, and head of the fifth metatarsal bone. The angles of ankle dorsiflexion, knee flexion, hip flexion, pelvic posterior tilt, and trunk anterior tilt at maximum squat depth were calculated. Ankle dorsiflexion was measured as the angle between the line connecting the fibula head and the calcaneus and the line connecting the base and head of the fifth metatarsal bone. Knee flexion was measured as the angle between the line connecting the greater trochanter and the lateral epicondyle of the femur and the line connecting the fibula head and the lateral malleolus. Hip flexion was measured as the angle between the line perpendicular to the line connecting the superior anterior iliac spine and superior posterior iliac spine and the line connecting the greater trochanter and the lateral epicondyle of the femur. Pelvic posterior tilt was measured as the angle between the line connecting the superior anterior iliac spine and the superior posterior iliac spine and an imaginary line parallel to the floor. Trunk anterior tilt was measured as the angle between the line connecting the seventh cervical spinous process and the fifth lumbar spinous process and an imaginary line perpendicular to the floor.

The ROM of ankle dorsiflexion, hip flexion, and knee flexion were measured in all participants. Ankle dorsiflexion was measured using a digital inclinometer to measure the maximum forward tilt of the lower leg in a standing position. To assess hip flexion, the maximum angle at which the hip joint was passively flexed in a supine position was measured, and to assess knee flexion, the maximum angle at which passive knee flexion was passively conducted in a prone position was measured using a goniometer.

Muscle strength of hip flexors were measured with the participant seated and hip and knees flexed at 90° and hand-held dynamometer (μ-tas, ANIMA, Tokyo, Japan) placed in the anterior of the thigh. Knee extensor were measured with the participant seated and hip and knee flexed at 90° and dynamometer placed on the anterior aspect of shank, proximal to the ankle joint. Both tests involved maximal voluntary isometric contraction. Dynamometer secured to treatment table with belt.

Using Spearman's rank correlation, we calculated bivariate correlations among the angles of joints at maximum squat depth; ROM of the ankle, knee, and hip joints; and muscle strength of knee extension and hip flexion. Statistical analysis was performed using EZR[11]), and a p-value of <0.05 was considered statistically significant in all analyses.

RESULTS

Results of ROM, strength, and angles of joints at maximum squat depth are shown in Table 1. During squatting, the ROM of ankle dorsiflexion and knee flexion were significantly positively correlated with knee flexion and hip flexion, respectively. On the left side, the ROM of ankle dorsiflexion and knee flexion were significantly negatively correlated with the pelvic tilt angle. In addition, the ROM of knee flexion was significantly correlated with the ankle dorsiflexion angle and trunk inclination angle (Table 2).

Regarding contralateral relationships, there was a significant correlation between the ROM of ankle dorsiflexion and the contralateral knee flexion angle, hip flexion angle, and pelvic posterior tilt angle on both sides. Only the ROM of right ankle

Table 1. Range of movement (ROM) of joints and angles of joints at maximum squat depth

		Rt	Lt
ROM (degrees)	Ankle dorsiflexion	54.1 ± 6.4	52.9 ± 6.8
	Hip flexion	143.3 ± 5.9	136.3 ± 8.3
	Knee flexion	145.9 ± 6.8	146.5 ± 7.5
Angle of deep squat motion (degrees)	Ankle dorsiflexion	25.9 ± 5.1	23.4 ± 5.9
	Hip flexion	124.6 ± 13.6	124.1 ± 25.1
	Knee flexion	125.2 ± 24.8	124.3 ± 14.5
	Pelvic posterior tilt	−4.1 ± 14.0	−5.6 ± 18.7
	Trunk anterior tilt	33.2 ± 8.3	32.6 ± 8.0

Table 2. Relationship between range of motion and angles of joints at maximum squat depth

			Range of motin			
			Ankle dorsi flexion		Knee fkexion	
			Rt	Lt	Rt	Lt
Angle of deep squat motion	Rt side	Ankle dorsi flexion				0.469 *
		Knee flexion	0.723 *	0.753 *	0.795 *	0.803 **
		Hip flexion	0.837 **	0.833 **	0.883 **	0.862 **
		Pelvic posterior tilt		−0.717 *		
		Trunk anterior tilt				−0.695 *
	Lt side	Ankle dorsi flexion	0.753 *		0.750 *	0.720 *
		Knee flexion	0.703 *	0.733 *	0.767 *	0.770 *
		Hip flexion	0.744 *	0.762 *	0.720 *	0.668 *
		Pelvic posterior tilt	−0.678 *	−0.767 *	−0.767 *	−0.762 *
		Trunk anterior tilt				−0.695 *

Spearman rank test, *p<0.05, **p<0.01.

dorsiflexion was significantly correlated with ankle dorsiflexion angle. The ROM of knee flexion was significant positively correlated with ankle dorsiflexion angle, knee flexion angle, and hip flexion angle on both sides. In addition, there was a significant correlation between the pelvic posterior tilt angle on the right side and the trunk anterior tilt angle on the left side (Table 2).

There was no correlation among the knee extension strength, hip flexion strength, and the angles of joints at maximum squat depth (Table 2).

DISCUSSION

Squats are used to evaluate the stability of athletes' posture and motion[2, 3]. By analyzing the squatting motion, it is possible to evaluate symmetric motion and related functions. Cook suggested that the proper deep squat motion requires a large ROM of ankle dorsiflexion, knee flexion, hip flexion, and trunk mobility[10].

Muscle activity in the quadriceps and gluteal muscles is important and depends on the quality and quantity of movement[4, 6]. Hip and knee flexion angles during squatting may be low due to muscle fatigue and muscle weakness[9, 12]. In the present study, there was no correlation between knee extension strength, hip flexion strength, and maximum squat depth. Based on the results of the present study, muscle strength is related to the alignment of the frontal plane, but not to the maximum angle of the sagittal plane.

In biomechanic analyses of deep squats, hip, knee flexion and ankle dorsiflexion are performed at approximately the same time[13]. In the present study, average ankle dorsiflexion was 23.4–25.9°, average knee flexion was 124°, and average hip flexion was 124–125° in a deep squat, with no significant left–right differences. It was clear that the squatting motion is symmetrical.

By examining the relationship between the movements of the left and right side of the body and the ROM of various joints in a deep squat, it was found that there was a correlation between the side with the smaller ROM and the joint angle during movement. For example, in one participant, the ankle dorsiflexion angle was related to the ROM of right ankle dorsiflexion and right knee flexion, which were smaller than on the left side, and the ROM of right ankle dorsiflexion affected the knee flexion angle on both sides. It seems that the side with smaller ROM tends to hinder overall movement because the squatting motion is symmetrical by nature.

Knee flexion angle was related to the ROM of ankle dorsiflexion, and hip flexion angle was related to the ROM of ankle dorsiflexion and knee flexion. The mobility of lower joints may determine the ROM of joints during deep squats. The same phenomenon is observed in other motions; upper joint movement is limited by the movement of lower joints being limited[14, 15]. In addition, it was suggested in the present study that ankle dorsiflexion is an important factor that determines the ROM of deep squats, as indicated in previous studies.

In terms of contralateral relationships, the ROM of ankle dorsiflexion did not correlate with the ankle dorsiflexion angle on the same side, but did correlate with that on the contralateral side. Therefore, when motion is analyzed from one side, the fact that the limiting factor for movement may not the ROM of the observed side but rather that of the joints on the opposite side must not be overlooked.

The present study showed that the ankle dorsiflexion angle in a deep squat is smaller than the maximum ROM of ankle dorsiflexion. During the measurement position during weight-bearing standing, the feet were spread back and forth so that there was almost no influence from the ROM on the side where measurements were not made. However, during deep squats, it is necessary to perform ankle dorsiflexion, knee flexion, and hip flexion while keeping the center of gravity within the base of support made by the feet on both sides, and it is difficult to tilt the lower leg anteriorly to the maximum ROM. Limiting the ROM can hinder joint motion during deep squats, but it should be noted that full ROM is not necessary for motion.

One limitation of the present study is that motion analysis was not performed in 3D, so the neither the motion of the horizontal and frontal planes nor the process of motion could be analyzed. The relationships between the ROM of various joints could be analyzed in more detail by studying the displacement of each joint during motion in a posture change from a standing position. In addition to the items measured this time, it has been reported that the ankle dorsiflexor muscle strength was related to the medial knee displacement during squat[16]. However, in this study, the ankle dorsiflexion muscle strength was not measured because the hip and knee muscle strength were the main targets. Including this item may have provided more suggestions.

The idea that physical functions and movements are the same on both sides of the body is common, but it is clear from the present results that movement of a body part affects contralateral movement. By evaluating the deep squat as a functional test, we were able to provide new information that will aid in screening for movement dysfunctions.

Conflict of interest

The authors declare no conflicts of interest associated with this manuscript.

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