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ORIGINAL ARTICLE

Activity of quadriceps muscles at different trunk tilt angles while squatting

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ABSTRACT

This study aimed to clarify the relationship between different trunk inclination angles and knee joint positions while squatting and the activity of the vastus medialis obliquus (VMO). The participants were 24 healthy young males and females. The task was performed in the squatting position with the knee joint in 60° flexion. Group F (knee forward group) allowed the apex of the knee to move over the toes in the forward direction, and group B (knee backward group) allowed it to be aligned. Furthermore, group F was set to 0° forward tilt (F0), 20° forward tilt (F20), and 40° forward tilt (F40) of the trunk, whereas group B was set to 20° forward tilt (B20) and 40° forward tilt (B40). Surface electromyography (sEMG) was used to detect action potentials from the VMO, vastus medialis longus (VML), and rectus femoris (RF). sEMG analysis showed that the vertical trunk position was significantly higher than the anterior trunk position in all muscles ($p < .05$). F0 had the smallest displacement of the anterior-posterior centre of pressure. F0 with knee flexion of around 60° and body supported by both upper limbs is a suitable squatting limb for quadriceps training, particularly in the VMO.

Keywords: Sport health, Vastus medialis obliquus muscle, Surface electromyography, Anterior-posterior centre of pressure, Muscle atrophy.

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INTRODUCTION

To achieve a sustainable society, it is necessary to address the various challenges of an ageing society. The prevention and treatment of musculoskeletal diseases and maintaining mobility are important for extending healthy life expectancy and reducing long-term care demands (Nakamura & Ogata, 2016). Preventing muscle weakness in the lower limbs due to sarcopenia is crucial in extending healthy life expectancy. Sarcopenia is an age-related loss of muscle mass and strength; type II fibre atrophy is more predominant than inactive muscle atrophy, and the muscle fibres not only atrophy but also decrease in number (Rosenberg, 1997; Ezaki, 2012). The vastus medialis obliquus (VMO) has a higher percentage of type II fibres than of type I fibres (Travnik et al.,1995). Resistance training increases the number and size of type II fibres; therefore, it is a method for sarcopenia prevention (Charette et al.,1991).

One method of strengthening the quadriceps muscles, which are significantly affected by sarcopenia, is squatting exercises. Numerous studies have examined the relationship between lower-limb muscle activity and the knee joint angle, knee joint position (i.e., whether the knee joint is placed in front of the toes), trunk tilt angle, and centre of gravity (COG) during squatting exercises (Nakamura & Ogata, 2016; Fry et al., 2003; Gullett et al., 2009). However, the characteristics of quadriceps activity at different trunk tilt angles during squatting have not been fully investigated.

In this study, we aimed to evaluate the relationship between the trunk tilt angle and knee joint position while squatting and the quadriceps activity. We also aimed to determine the squatting position suitable for patients with sarcopenia with selective atrophy of the VMO, which has a high percentage of type II fibres that are predominantly atrophic in sarcopenia.

METHODS

Participants

This study was approved by the Kibi International University Research Ethics Review Committee (Approval No. 17-19). The purpose of this study was explained to the participants, and their consent was obtained before the study was conducted.

The participants were 24 healthy young males and females (18 males and 6 females; mean age, 21.7 ± 1.0 years, body mass index 22.1 ± 3.1%) who did not report back or knee pain at the time of evaluation.

Squat measurement position

The squatting measurement positions were set with the knee joint at 60° flexion using two factors: the position of the knee joint (i.e., the tip of the knee was either in front of the toes or aligned with the toes) and the tilt angle of the trunk. The knee joint was set at 60° flexion because the squat was performed in a mildly flexed position, which is easy for olde adult patients prone to sarcopenia to perform, and the flexion angle for the maximum total compressive load at the tibiofemoral joint was not reached (approximate maximum range: 70°–110°) (Mündermann et al., 2008).

In the forward knee group (group F), the tip of the knee was allowed to go in front of the toes; the three positions were 0° forward inclination (F0), 20° forward inclination (F20), and 40° forward inclination (F40), where the line connecting the acromion and greater trochanter was in front of the vertical line. In the backward knee group (group B), the knee apex and toes were aligned, and the line connecting the acromion and greater trochanter was inclined 20° anterior to the vertical line (B20) or 40° anterior to the vertical line (B40) (Figure 1).

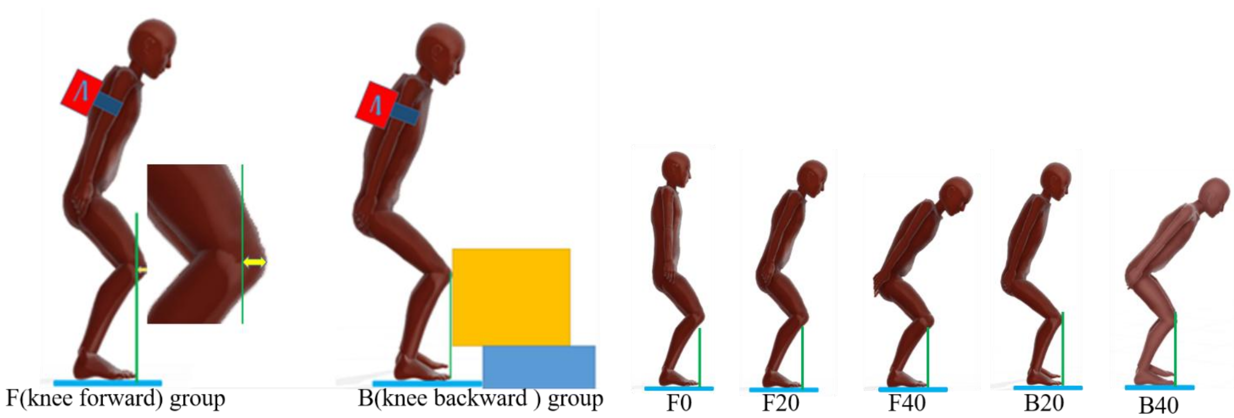


Figure 1. Limb positions during measurements.

In group F (knee forward group), the tip of the knee was allowed to go in front of the toes; the three positions were 0° trunk forward inclination (F0), 20° trunk forward inclination (F20), or 40° trunk forward inclination (F40). In group B (knee backward group), the kneecap and toes were aligned and inclined 20° trunk forward (B20) or 40° trunk forward (B40). Arrows (⇔) indicate the distance from the toe to the point where the front surface of the knee joint is projected onto the floor (group F).

Measurement of trunk tilt and knee joint angles
The angle of trunk inclination was measured with a homemade angle meter attached to the right upper arm (Figure 2). The upper arm was positioned such that the middle of the wrist joint was at the greater trochanter when the upper limb was aligned with the body during elbow extension. The knee joint flexion angle was measured using a goniometer (Tokyo University).

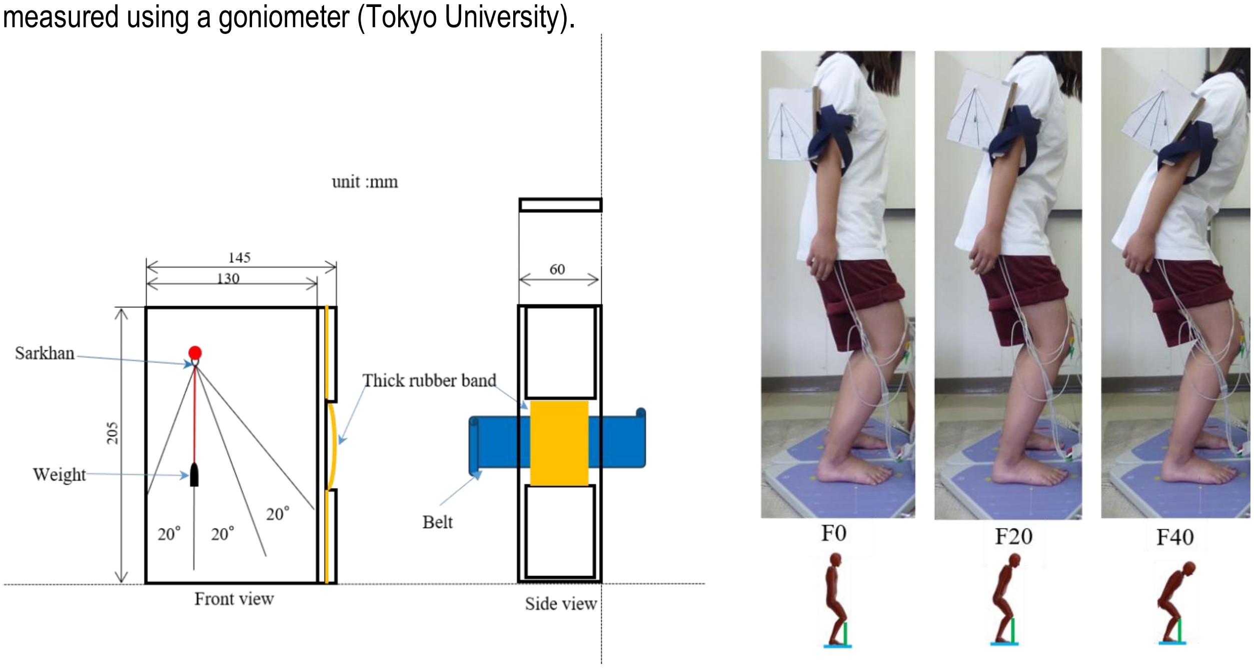


Figure 2. Angle meter for measuring the trunk tilt angle.

A weight is attached to the thread and a board with an attached angle scale. The trunk tilt angle is measured at 0°, 20°, and 40° forward tilt.

Setting the knee joint position while squatting

The distance between two points (from the toe to the point where the front surface of the knee joint is projected onto the floor) was measured in ImageJ. The distance was measured from images taken from the side (Figures 1and 2). For the squatting position in which the knee was positioned in front of the toes (group F), the patient was instructed to "*assume the squatting position with the knee forward*". For the squatting position in which the knee did not come forward in front of the toes (group B), a box placed at the toe position on the table was shown, and the participant was instructed to "*Please get into the squatting position so that your knee does not touch the box in front of you*". The position of the knee joint on the coronal plane was maintained in the middle position to avoid moving the knee in and out.

Measurement of anterior-posterior (A-P) centre of pressure (COP) of the fifth metatarsal as the origin

As the centre of gravity (COG)and COP are approximated in static standing posture (Fujiwara and Ikegami, 1981). COP was therefore used as an evaluation parameter. The A-P COP was measured using a Gravicorder G-620 (Anima, Tokyo) and captured on a PC at a sampling frequency of 20 Hz.

Two force plates were placed side by side on either side to measure A-P COP. The left and right feet were spaced such that the width of the medial margin of the bilateral anterior superior iliac spine and the width of the centre of the left and right calcanei viewed posteriorly coincided. The feet were symmetrically positioned, and the feet were oriented such that the lines connecting the medial edges of both heels and the medial edges of both first metatarsophalangeal joints were parallel. The feet were placed symmetrically such that the centre of the fifth metatarsals was aligned with the central transverse line of the detector. A 10-s measurement was taken after confirming that the measuring limb position had been taken. A-P COP was expressed as %foot length, with the posterior end of the heel to the apex of the toe representing 100%, the centre of the fifth metatarsal representing the origin, positive values representing the anterior positions, and negative values representing the posterior positions (Figure 3).

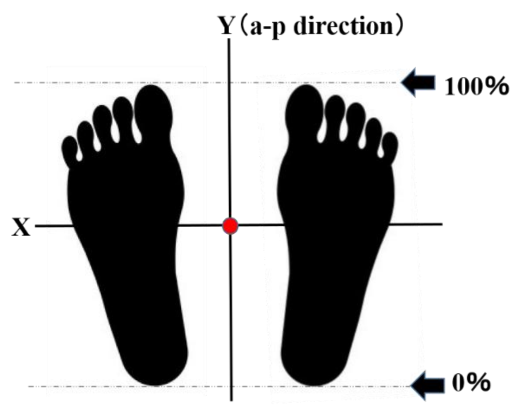


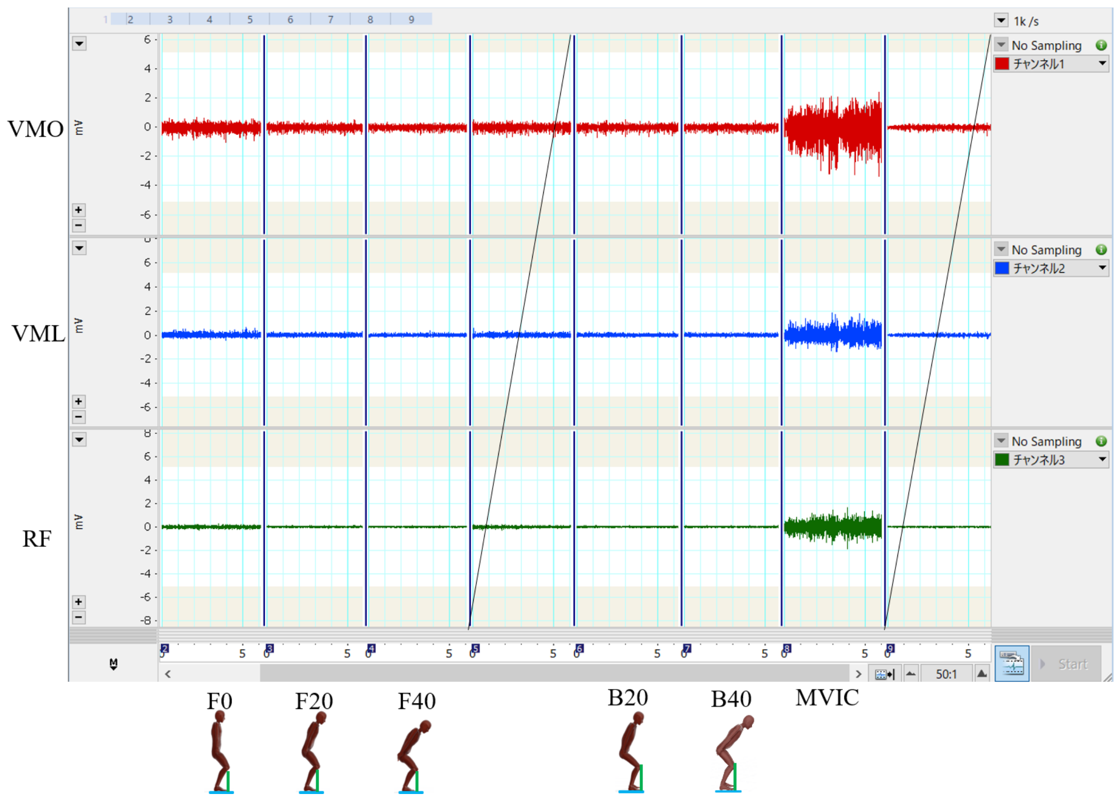
Figure 3. Measurement of anterior-posterior (A-P) centre of pressure (COP) ● Centre of pressure (red circle): %foot length.

Surface electromyography (sEMG) assessment

sEMG was used to measure muscle activity, and data were collected and analysed using the Power Lab system. The sampling frequency was 1 kHz, and the bandpass filter was set from 20 Hz to 1 kHz.

The activities of the VMO, vastus medialis longus (VML), and rectus femoris (RF) were measured. The VMO conductor was placed approximately 2 cm medial to the superior patella along the course of the muscle fibres, with a slope of approximately 55°. The VML conductor was placed on the muscle belly, the width of four fingers from the superior border of the patella. The RF conductor was placed in the muscular belly approximately in the middle of the line connecting the superior anterior iliac spine and the knee joint.

The EMG potentials were measured for 6 s at each limb measurement position, and the middle 3 s of the stabilized EMG potentials were integrated after rectification to obtain an integrated EMG (IEMG) value. The MVIC of the quadriceps was measured in the sitting posture with the trunk tilted 30° posterior to the vertical line and the knee joint flexed at 40°. Resistance was applied at the distal surface of the front lower leg to extend the knee joint. The EMG integral value of the maximum voluntary isometric contraction (MVIC) of each muscle was determined, and the IEMG of each muscle was divided by the MVIC to obtain the %MVIC (Figure 4).



VMO: vastus medialis obliquus; VML: vastus medialis longus; RF: rectus femoris; MVIC: maximum voluntary isometric contraction. In group F (knee forward group), the tip of the knee was allowed to go in front of the toes; the three positions were 0° trunk forward inclination (F0), 20° trunk forward inclination (F20), or 40° trunk forward inclination (F40). In group B (knee backward group), the kneecap and toes were aligned and inclined 20° trunk forward (B20) or 40° trunk forward (B40).

Figure 4. Representative example showing electromyograms for each limb position.

Procedures

Measurements were taken at F0, F20, F40, B20, and B40, in that order. Before measuring A-P COP, the 60°flexion position of the knee joint was confirmed with a goniometer and the knee joint position was photographed. A-P COP measurements were performed for 10 s. sEMG measurements were performed for 6 s during A-P COP measurements. MVIC measurements were taken after A-P COP measurements were completed. Rest breaks were taken as needed.

Statistical analysis

One-way analysis of variance and multiple comparison tests with repeated measures (Bonferroni method) were performed for muscle activity, A-P COP and knee position while squatting according to trunk tilt angle. Statistical analyses were performed using IBM SPSS Statistics Base for Windows (Version 24,29 for Windows; IBM, Armonk, NY, USA). For all statistical tests, $p < .05$ was considered significant.

RESULTS

The VMO activity on sEMG was significantly higher for F0 than for F20, F40, B20, or B40. The VML %MVIC was significantly higher for F0 than for B40. No significant differences were observed between the other groups. The RF activity was significantly higher for F0 than for F20, F40, B20, or B40 (Table 1).

Table 1. Comparison of muscular activity (%MVIC) according to trunk tilt.

Variable	Comparison target		Mean	Standard deviation	Standard error	*p*-value	95%CI
	Trunk tilt vs Trunk tilt						Lower – Upper
VMO%MVIC (%)	F0	F0	21.23	11.24	2.30	–	16.49 – 25.98
		F20	17.05	9.73	1.99	<.001*	12.94 – 21.16
		F40	15.89	9.31	1.90	.005*	11.96 – 19.83
		B20	17.13	9.70	1.98	.001*	13.04 – 21.22
		B40	16.14	8.40	1.72	.012*	12.59 – 19.69
VML%MVIC (%)	F0	F0	19.21	12.65	2.58	–	13.87 – 24.56
		F20	16.16	12.33	2.52	.43	10.96 – 21.37
		F40	14.43	10.11	2.07	.24	10.16 – 18.70
		B20	15.82	10.54	2.15	.69	11.37 – 20.28
		B40	14.04	8.40	1.71	.04*	10.49 – 17.59
RF%MVIC (%)	F0	F0	13.91	7.6	1.55	–	10.71 – 17.11
		F20	9.21	5.5	1.11	<.001*	6.91 – 11.52
		F40	8.33	5.2	1.05	.002*	6.15 – 10.51
		B20	9.88	6.3	1.29	.003*	7.21 – 12.56
		B40	8.76	5.4	1.11	.003*	6.47 – 11.06

*Note. *: p < .05 (vs F0).*

The A-P displacement of the COP was significantly more posterior in B20 than in F20, F40, and B40 (Table 2). F0 was the value with the smallest displacement of the COP in the A-P direction.

Table 2. Comparison of A-P COP according to trunk tilt.

Variable	Comparison target		Mean	Standard deviation	Standard error	*p*-value	95%CI
	Trunk tilt vs Trunk tilt						Lower – Upper
A-P COP (%)	B20	F0	-0.04	2.22	0.45	.07	-0.98 – 0.90
		F20	0.36	2.66	0.54	.005*	-0.77 – 1.48
		F40	0.66	2.61	0.53	.002*	-0.44 – 1.76
		B20	-2.04	2.36	0.48	–	-3.04 – -1.04
		B40	-0.82	2.25	0.46	.006*	-1.77 – 0.13

*Note. *: p < .05 (vs B20).*

The distance from the toe to the point of the knee apex projected onto the floor was significantly more anterior for F0 than for F20 and F40 (Table 3).

Table 3. Comparison of Knee position according to trunk tilt.

Variable	**Comparison target**		**Mean**	**Standard deviation**	**Standard error**	***p*-value**	**95%CI**
	Trunk tilt vs Trunk tilt						Lower－Upper
Knee position (cm)	F0	F0	5.78	1.85	.38	－	5.00－6.57
		F20	2.85	3.03	.62	<.001*	1.58－4.13
		F40	2.05	2.21	.45	<.001*	1.11－2.98

*Note. *: p < .05 (vs F0).*

Tables 1-3. n = 24 for each group. Statistical analysis: Bonferroni method. 95% CI: 95% confidence interval values. In group F (knee forward group), the tip of the knee was allowed to go in front of the toes; the three positions were 0° trunk forward inclination (F0), 20° trunk forward inclination (F20), or 40° trunk forward inclination (F40). In group B (knee backward group), the kneecap and toes were aligned and inclined 20° trunk forward (B20) or 40° trunk forward (B40).

DISCUSSION

The %MVIC values for the VMO and RF were significantly greater for F0 than for F20, F40, B20, or B40. The %MVIC value of the VML was significantly greater for F0 than for B40. This is thought to be because the vertical distance between the COG and the centre of rotation of the knee joint (moment arm) is longer in the vertical trunk position than in the anterior trunk leaning position, resulting in a larger knee extension moment.

At B20, where the knee is in line with the toes, the COP is significantly posterior than in F20, F40, and B40. This may be due to the fact that B20 is a limb position with a small anterior tilt angle between the lower leg and trunk, causing the COG to move backwards. The posture of an older adult person in a stationary standing position has a COG that is shifted backward compared to the position of the centre of foot pressure, owing to kyphosis of the thoracolumbar spine and backward tilt of the pelvis (Elble et al.,1997). Squatting, which involves a small forward trunk tilt angle and does not allow the tip of the knee to go beyond the toes, is an exercise that increases the risk of falling backward.

This study had some limitations. The trunk tilt angle in this study was not a direct measure of spinal alignment. Therefore, cases in which the trunk tilt angle was compensated for by flexion and extension of the thoracolumbar spine were judged from the images and excluded from the measurement data.

CONCLUSION

The vertical trunk position is a significant source of muscle activity for the VMO and other quadriceps muscles in squats with the knee joint flexed 60º.

COP at F0 was the limb position with the smallest A-P displacement. However, due to reasons such as the tendency of the COG of older people to move backwards, squatting with both upper limbs supporting the body is a better way to avoid the risk of falls.

AUTHOR CONTRIBUTIONS

Tetsuo Imano: Study design, data analysis, manuscript preparation. Masaaki Nakajima: Study design, data analysis.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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ETHICS STATEMENT

The experiments completed in this study comply with the current laws of the country in which they were performed.

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