Original Article

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Squatting Posture Grading System for Screening of Limited Ankle Dorsiflexion

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Objective: To evaluate the effectiveness of a squatting posture grading system established to screen for limited ankle dorsiflexion.

Methods: The squat posture grading system categorizes subjects' squat posture into three grades. Grade 1 is defined as being able to maintain a squatting posture with heels on the ground in full ankle dorsiflexion without effort. Grade 2 is defined as being able to perform the same position, but unable to maintain the position for more than 5 seconds or requiring trunk and leg muscle efforts to maintain the position. Grade 3 is defined as being unable to maintain the same position and falling backwards immediately if attempted to touch the ground with heels. Next, subjects' ankle dorsiflexion angles were directly measured in knee flexed and extended position by goniometer.

Results: Out of the 92 total subjects, 35 were in grade 1, 18 were in grade 2, and 39 were in grade 3. The average ankle dorsiflexion angle with knee flexed position were 23.13° for grade 1, 16.03° for grade 2, and 9.31° for grade 3. The average ankle dorsiflexion angle with knee extended position were 15.16° for grade 1, 7.92° for grade 2, and 3.40° for grade 3. Ankle dorsiflexion angles showed a significant decrease from grade 1 to 3 ($p<0.05$).

Conclusion: The squatting posture grading system defined in this study effectively graded the subjects based on the difference in their average ankle dorsiflexion angle. This system could be used as a quick screening method for limited ankle dorsiflexion.

Keywords: Squatting posture, Ankle dorsiflexion

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INTRODUCTION

Limited dorsiflexion of the ankle joint is associated with a number of common clinically observed foot conditions and lower extremity injuries, including Achilles tendonitis [1], plantar fasciitis [2], chronic ankle instability [3], and tibial stress fracture [4]. In addition, insufficient dorsiflexion of the ankle joint induces unnecessary movement of the metatarsophalangeal joint, resulting in premature heel-off during gait, which can lead to strain in the midfoot and forefoot, which in turn contributes to foot and ankle injuries [5]. Therefore, grading the dorsiflexion angle of the ankle joint and screening for limitations in each grade could be useful for prevention and treatment of foot and ankle injuries. Assessing and preventing the potential for foot and ankle injuries is important not only in individual clinical assessments but also for sports medicine physicians who need to evaluate large groups before physical activities, such as competitions, in outdoor or gym settings. However, direct measurement of the dorsiflexion angle is time-consuming, labor-intensive, and requires adequate space and equipment. Therefore, direct measurement may be unsuitable as a screening test in situations like these. A simpler method that can be quickly administered to large groups in outdoor settings or similar environments may thus be necessary.

A squat requires full dorsiflexion of the ankle and full flexion of the knee and hip. Flexibility of the ankle joint and calf muscles in particular are important factors in performing and maintaining the position [6]. This posture requires full heel contact with the floor. Ankle dorsiflexion limitations can result in limited anterior tibial tilt, placing the center of gravity posteriorly, which can lead to poor postural stability and excessive effort to maintain the posture. Therefore, assessing squatting posture performance has the potential to be an indirect way to screen ankle dorsiflexion limitations and calf muscle flexibility. Furthermore, as a screening test, the squatting posture has the advantage of being easy to instruct and can be performed quickly in the context of a large-scale physical examination.

Previous studies have identified an association between squatting posture and ankle joint range of motion. Kasuyama et al. [6] found a significant difference in ankle dorsiflexion flexibility indirectly using the weight-bearing lunge between subjects who could and could not squat, but did not directly measure dorsiflexion angle of the ankle joint. Dill et al. [7] found an association between ankle joint range of motion measured in the weight-bearing lunge maneuver and the degree of dorsiflexion angle of the ankle joint in the squat. Rabin and Kozol [8] evaluated the usefulness of scoring performance of the overhead squat and forward arm squat positions to screen ankle dorsiflexion limitations.

However, the previous studies mentioned above all measured dorsiflexion angle of the ankle joint indirectly using a weight-bearing lunge, which is simpler and has higher inter-rater reliability, but only reflects ankle flexibility at knee flexed position and is potentially inaccurate compared to measurements using a goniometer. Actually, Hankemeier and Thrasher [9] found that angles measured using this method differed from those using a passive ankle dorsiflexion and goniometer by approximately 3-fold and showed only moderate correlation (r=0.621–0.681).

In this study, we defined the squatting posture grading system and aimed to prove the its usefulness for screening calf muscle flexibility by directly measuring the dorsiflexion angle of the ankle joint using a goniometer, including not only the knee flexed position but also the knee extended position.

METHODS

Subjects

A total of 92 adolescents and adults participated in this study. Twenty-five subjects were healthy volunteers, sixty-seven subjects were athletes with intellectual disabilities who participated in Special Olympics Game. During the recruitment process, participants with musculoskeletal disorders in the last 6 months, surgical history, pain, or stiffness were excluded through screening, including medical interviews and physical examinations. All participants had a level of functionality that allowed them to perform daily activities as well as exercises such as running and jumping. This study was approved by Institutional Review Board of Gachon University Gil Hospital (No. GFIRB2023-141). In accordance with the hospital's ethical guidelines, the participants were provided with verbal information, which included the purpose and procedures of the study, before inclusion in this study. When fully understood, an informed consent to participate in the study was obtained from all subjects.

Definition of squatting posture and grading system

Squatting posture is defined as follows: standing barefoot, feet shoulder-width apart and next to each other, heels touching the ground, hips lowered so that the femur is tilted below the parallel line, hips and knees in full flexion [10]. The upper limbs should not touch the body, the ground, or any other objects.

The grading system defined in this study categorizes subjects' squatting posture into three grades. Grade 1 was designed to identify candidates with sufficient flexibility, which is defined as being able to maintain a squatting posture with heels on the ground in full ankle dorsiflexion in a comfortable relaxed state without effort. Grade 2 was designed to identify candidates with partially limited flexibility, defined as those who can achieve a position but are unable to maintain it for more than 5 seconds or require excessive effort from body and leg muscles, such as excessive contraction of the abdominal or pre-tibial muscles, to keep the body's center of gravity in the middle of the foot. Grade 3 was designed to identify candidates with severely limited flexibility. Grade 3 corresponds to limited flexibility, which is defined as being unable to maintain the same position and falling backwards immediately if attempted to touch the ground with heels (Fig. 1).

Fig. 1. Examples of squat posture for grade 1 and 3. (A) Examples of squatting posture for grade 1, with heels on the ground in full ankle dorsiflexion. (B) A representative example of a failed squatting posture for grade 3-the heel is not touching the ground. (C) Another example of a failed squatting posture for grade 3-the hip is not in full flexion and the femur is not tilted below the parallel line.

Procedure

All subjects performed the squatting posture as defined above, following the examiner's demonstration of the movement, and were categorized according to the above grading system. Next, the subjects' dorsiflexion angle of the ankle joint was measured. With the subject lying supine, one examiner manually immobilized the subject's ankle in maximum dorsiflexion, and the other examiner measured the dorsiflexion angle of the ankle joint using a goniometer. The bilateral dorsiflexion angle of the ankle joint was first measured with the hip and knee flexed to 90°, and measured again with the knee and hip fully extended. To prevent bias, the evaluator who assigned grades and the person who measured the angles were different individuals, and they were blinded to each other's results during the evaluation process.

The dorsiflexion angle of the ankle joint was measured by a single examiner using a goniometer with the axis at the intersection of the fibula and the extension line at the 5th metatarsal bone. The stationary arm was fixed parallel to the fibula and the moving arm was parallel to the 5th metatarsal bone line (Fig. 2).

In addition, a tripod sign was checked to determine if the subjects had hamstring tightness. This is a test in which the examiner extends the subject's knee to full extension in a seated position, and the subject's pelvis and trunk extend backward in response to the shortening of the hamstring, if subjects have hamstring tightness [11]. It was recorded positive when at least one of the left and right sides showed a positive sign (Figs. 3, 4).

Statistical analysis

The demographic data of the continuous parameters is described by the mean±standard deviation. A chi-square test and one-way ANOVA were used for group analysis of sex/age/height/weight/body mass index (BMI). ANOVA and t-tests were conducted to analyze the association between dorsiflexion angle of the ankle joint, the grade, and the presence of tripod sign. A chi-square test was used to compare the positive rate for the tripod sign of the subjects in each grade. The significance level of all statistical analyses was set at $p<0.05$ and analyzed using SPSS version 29.0.1.0. for Windows (IBM Corp.).

RESULTS

General characteristics

A total of 92 subjects participated, and their baseline characteristics are summarized in Table 1. Seventy-six were male and 16 were female, with age of 26.0±9.7 years, height of 169.6±12.0 cm, and weight of 70.0±15.9 kg. In the case of height, grade 2 was significantly higher than grade 1 and grade 3 ($p=0.01$), but there were no significant differences in other variables.

Squatting posture grade and dorsiflexion angle of the ankle joint

All participants attempted the specified squatting posture as defined above, and during this process, no pain or noticeable stiffness in the hip or knee joints was observed. Consequently,

Fig. 2. Schematic presentation of measurement of dorsiflexion angle. (A) Measurements with hip and knee flexed to 90°. (B) Measurements with hip and knee fully extended. (C) Measurements using a goniometer.

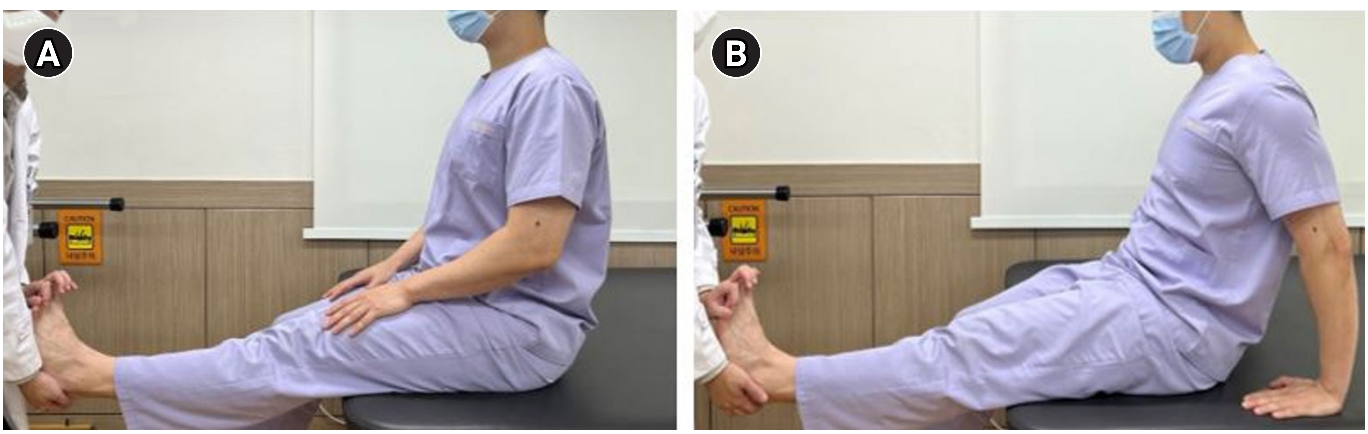

Fig. 3. Schematic presentation of tripod sign. (A) Negative tripod sign. (B) Positive tripod sign.

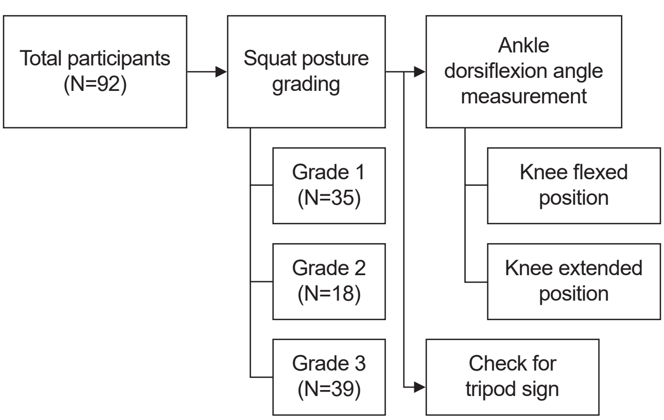

Fig. 4. Flow of the study.

of the 92 total subjects, 35 were in grade 1, 18 were in grade 2, and 39 were in grade 3. The left, right and average dorsiflexion angles of the ankle joint measured in the knee flexed and fully extended positions for subjects in each grade are shown in Table 2. The dorsiflexion angle of the ankle joint in knee flexed position was 23.13°±6.02° for grade 1, 16.03°±4.44° for grade 2, and 9.31°±6.11° for grade 3. The left, right, and average dorsiflexion angles of the ankle joint were all significantly different for each grade ($p<0.005$) and decreased towards grade 3.

The dorsiflexion angles of the ankle joint in knee extended position were 15.16°±5.45° for grade 1, 7.92°±4.41° for grade 2, and 3.40°±5.72° for grade 3. The left, right, and average dorsiflexion angles of the ankle joint were all significantly different for each grade ($p<0.005$) and decreased towards grade 3, which is the same result as the knee flexed position. There was no

Table 1. Baseline characteristics of study groups

	Total	Grade 1	Grade 2	Grade 3	p-value
Number	92	35	18	39	
Sex, male/female	76/16	28/7	15/3	33/6	0.87
Age (yr)	26.0±9.7	27.0±11.3	25.0±5.1	25.0±10.1	0.84
Height (cm)	169.6±12.0	167.3±14.0	178.2±6.4	168.0±10.1	0.02*
Weight (kg)	70.0±15.9	68.2±17.7	72.2±13.2	70.0±15.1	0.78
BMI (kg/cm^2)	24.6±5.7	24.5±6.9	24.0±3.1	25.0±5.0	0.93

Values are presented as number only or mean±standard deviation.
BMI, body mass index.
*Significant difference (p<0.05).

Table 2. Mean and standard deviation of ankle dorsiflexion angles of study groups

		Knee flexed position (°)		p-value	Knee extended position (°)		p-value
Grade 1	Right ankle	23.34±5.70	23.13±6.02	<0.005*	15.29±5.49	15.16±5.45	<0.005*
	Left ankle	22.91±6.31			15.03±5.42		
Grade 2	Right ankle	16.17±4.72	16.03±4.44		8.17±4.31	7.92±4.41	
	Left ankle	15.89±4.15			7.67±4.50		
Grade 3	Right ankle	9.15±6.44	9.31±6.11		3.28±5.61	3.40±5.72	
	Left ankle	9.46±5.77			3.51±5.82		

Values are presented as mean±standard deviation.
*Significant difference (p<0.05).

significant difference between left and right dorsiflexion angles of the ankle joint in knee flexed position, knee extended position and each grade. The dorsiflexion angle of the ankle joint measured in knee flexed position were significantly higher than when measured in knee flexed position for all grades (p<0.005).

For each grade, the maximum, minimum, and median of the dorsiflexion angle of the ankle joint measured in knee flexion and knee extension is plotted (Fig. 5). In knee flexion, grade 1 had a maximum of 41.0°, a minimum of 16.0°, and a median of 21.5°; grade 2 had a maximum of 25.0°, a minimum of 11.0°, and a median of 14.8°; and grade 3 had a maximum of 21.5°, a minimum of -4.5°, and a median of 10.0°. In knee extension, grade 1 had a maximum of 30.0°, a minimum of 6.5°, and a median of 15.0°; grade 2 had a maximum of 16.5°, a minimum of 3.0°, and a median of 6.3°; and grade 3 had a maximum of 15.5°, a minimum of -7.5°, and a median of 4.5°.

The results of calculating the sensitivity and specificity for limited ankle dorsiflexion to verify the performance of the grading system as a screening test are summarized in Table 3. Limited ankle dorsiflexion was defined based on the actual measured dorsiflexion angle of the ankle joint, with cut-off values set at less than 18.5° in the knee flexed position and less than 11.5° in the knee extended position [12]. Grade 1 was considered negative, and grades 2 and 3 were considered positive for the screening test. In the knee flexed position, the sensitivity was 91.0% and the specificity was 81.1%. In the knee extended position, the sensitivity and specificity were 86.2% and 79.4%, respectively.

Tripod sign

The percentage of positive tripod sign in each grade is summarized in Table 3. The positive rate was 17% in grade 1, 28% in grade 2, and 64% in grade 3, respectively, and showed a significant difference when comparing the three groups simultaneously (p<0.005). When comparing between the two groups, there was no significant difference between grade 1 and 2, but grade 3 showed a significantly higher tripod sign than grade 1 and 2 (p<0.005).

Therefore, to investigate the influence of hamstring tightness, groups were segregated based on the presence of the tripod sign, and additional analysis was performed to explore the relationship between grade and dorsiflexion angle of the ankle joint. In the group showing a negative tripod sign, the dorsiflexion angles of the ankle joint in the knee-flexed position were 23.52°±6.00° for grade 1, 16.38°±4.86° for grade 2, and 10.88°±5.70° for grade 3, with an overall average of 18.85°±7.76°. While in the knee-extended position, they were 15.64°±5.23° for grade 1, 9.19°±4.34° for grade 2, and 4.92°±5.14° for grade 3, with an overall average

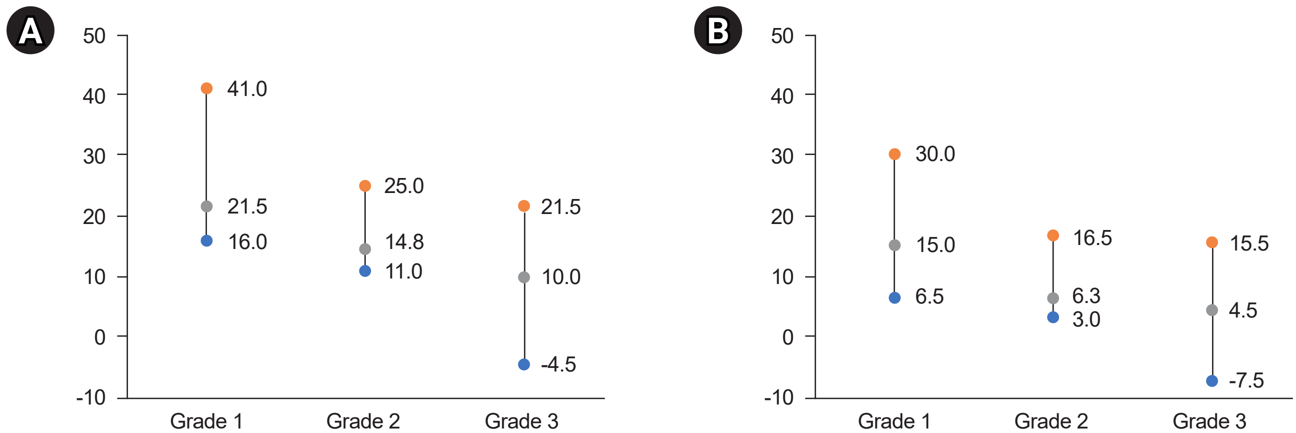

Fig. 5. Maximum, minimum and median of ankle dorsiflexion angle. (A) Maximum, minimum, and median of ankle dorsiflexion angle in knee flexed position. (B) Maximum, minimum, and median of ankle dorsiflexion angle in knee extended position. Orange, maximum; gray, median; blue, minimum.

Table 3. Confusion matrix with sensitivity and specificity

	Knee flexed position		Knee extended position	
	DF angle<18.5°	DF angle≥18.5°	DF angle<11.5°	DF angle≥11.5°
Grade 2 or 3	TP=50	FP=7	TP=50	FP=7
Grade 1	FN=5	TN=30	FN=8	TN=27
Sensitivity (%)	91.0		86.2	
Specificity (%)	81.1		79.4	

Values are presented as number only.
DF, dorsiflexion; TP, true positive; FP, false positive; FN, false negative; TN, true negative.

of 11.58°±6.76°. In the group exhibiting a positive tripod sign, dorsiflexion angles of the ankle joint in the knee-flexed position were 21.25°±4.40° for grade 1, 15.10°±2.06° for grade 2, and 8.52°±5.98° for grade 3, averaging 11.47°±7.23° overall. In the knee-extended position, these angles were 12.83°±4.64° for grade 1, 4.60°±1.46° for grade 2, and 2.63°±5.60° for grade 3, totaling 4.56°±6.29° across all grades. In each group divided by the presence of the tripod sign, similar to the overall findings, dorsiflexion angles of the ankle joint varied significantly across grades, decreasing progressively with grade 3 ($p<0.005$; Table 4).

Furthermore, a regression analysis was conducted to determine which variable, between limited ankle dorsiflexion and the presence of hamstring tightness, has a greater influence on the determination of the squatting posture grade. Limited ankle dorsiflexion was defined based on the actual measured dorsiflexion angle of the ankle joint, with cut-off values as same as above. The results are shown in Table 5, indicating that the limited ankle dorsiflexion contributes more significantly to grade determination in both postures.

Subgroup analysis of a group with intellectual disabilities

The group with intellectual disabilities had a slightly higher proportion of grade 3 at 43.3% compared to the normal group's 40.0%, but the difference was not significant. The average dorsiflexion angles of the ankle joint in the knee-flexed position and knee-extended position were 15.28° and 8.19°, respectively, which were smaller than the normal group's 17.48° and 10.26°, but again, the difference was not significant.

A subgroup analysis was conducted on the subjects with intellectual disabilities, who constitute the majority of the study population. Among the total of 67 individuals, 26 were grade 1, 12 were grade 2, and 29 were grade 3. The dorsiflexion angles of the ankle joint in knee flexed position was 23.56°±6.92° for grade 1, 15.79°±4.22° for grade 2, and 7.66°±5.62° for grade 3. The dorsiflexion angles of the ankle joint in knee extended position were 14.88°±6.30° for grade 1, 8.58°±4.10° for grade 2, and 2.03°±5.62° for grade 3. The average dorsiflexion angles of the ankle joint were all significantly different for each grade ($p<0.005$) and decreased towards grade 3 in both positions. A

Table 4. Mean and standard deviation of ankle dorsiflexion angles by presence of tripod sign and grades

Tripod sign	Grade	No.	Knee flexed position (°)	p-value	Knee extended position (°)	p-value
Negative	Grade 1	29	23.52±6.00		15.64±5.23	
	Grade 2	13	16.38±4.86	<0.005*	9.19±4.34	<0.005*
	Grade 3	13	10.88±5.70		4.92±5.14	
	Total	55	18.85±7.76		11.58±6.76	
Positive	Grade 1	6	21.25±4.40		12.83±4.64	
	Grade 2	5	15.10±2.06	<0.005*	4.60±1.46	<0.005*
	Grade 3	26	8.52±5.98		2.63±5.60	
	Total	37	11.47±7.23		4.56±6.29	

Values are presented as mean±standard deviation.
*Significant difference (p<0.05).

Table 5. Multiple linear regression analysis for the association between presence of ankle dorsiflexion angles, tripod sign and grades

Position	Variable	β	t	p-value	F	Adjusted R^2
Knee-flexed	Limited ankle dorsiflexion	1.20	8.62	<0.005*	58.45*	0.56
	Tripod sign	0.35	2.52	0.01*		
Knee-extended	Limited ankle dorsiflexion	1.07	6.73	<0.005*	40.21*	0.46
	Tripod sign	0.36	2.32	0.02*		

*Significant difference (p<0.05).

similar analysis was performed based on the presence or absence of the tripod sign. The results are shown in Supplementary Table S1. Regardless of the presence or absence of the tripod sign, there were significant differences in the dorsiflexion angle of the ankle joint for each grade, which decreased progressively towards grade 3.

DISCUSSION

This study aimed to demonstrate the effectiveness of our newly developed squatting posture grading system for evaluation of limited ankle dorsiflexion and calf muscle flexibility. Grade 1 corresponds with sufficient flexibility, grade 2 means partially limited flexibility, and grade 3 indicates a severely limited flexibility of dorsiflexion angle of the ankle joint of the subjects in our grading system. In this study, the dorsiflexion angle of the ankle joint decreased stepwise as the squatting posture grade increased from 1 to 3. Furthermore, a significant difference was observed in the mean dorsiflexion angles of the ankle joint among the groups in each grade. This statistical significance was also observed in the subgroup with intellectual disabilities.

We also found that the squatting postures were easy to perform for all subjects, even including those with intellectual disabilities. The subjects followed the instructions and demonstrations easily, and their grades were assessed promptly. These characteristics make this grading system appropriate for screening test for ankle and calf muscle flexibility.

The dorsiflexion angle of the ankle joint depends on the flexibility of the soleus and gastrocnemius. The limitation of ankle dorsiflexion in the knee extended position results from decreased flexibility of the soleus and gastrocnemius, while the limitation of dorsiflexion in the knee-flexed position results from decreased flexibility of the soleus [13]. Measuring the dorsiflexion angle of the ankle joint in knee flexed position is a way to evaluate the tightness of the soleus alone in which the position the gastrocnemius is relaxed [14].

Considering that the squatting posture used in this study is performed with the knees fully flexed, it was thought that the performance of this posture would have less to do with tightness of the gastrocnemius and more to do with tightness of the soleus. Based on the above paragraph, theoretically, subjects with isolated gastrocnemius tightness should perform well in the squatting posture with this system and would have limitations in ankle dorsiflexion in the knee extended position, but no limitations should be observed in the knee flexed position. However, in this study, a group with this characteristic was not clearly observed. Also, the actual dorsiflexion angle of the ankle joint measured in this study showed a decreasing pattern toward grade 3 in both the knee flexed and knee extended positions and the influence of soleus tightness cannot be excluded in both positions. Therefore, a caution should be taken when interpreting the results of applying this grading system to subjects with isolated gastrocnemius tightness which was not validated in this study. However, it is clear that tightness in soleus sufficiently causes limited ankle dorsiflexion and decreased flexibility in the calf muscles, so this system could still be considered a valid screening method.

In general, the average dorsiflexion angle of the ankle joint is known to range from 8° to 26° in various positions, with the dorsiflexion angle of the ankle joint being greater when the knee is flexed than when the knee is extended [15]. In previous studies measuring passive dorsiflexion angle of the ankle joint during knee flexion and extension, Kim et al. [16] reported an average passive dorsiflexion angle of the ankle joint of 11° during knee extension and 17° during flexion in a supine position. DiGiovanni et al. [17] reported a passive dorsiflexion angle of the ankle joint of 13° during knee extension and 22° during flexion in a supine position. In our study, the average dorsiflexion angle of the ankle joint was 8.7° in the knee extended position and 15.8° in the knee flexed position, which is within a similar range to the previous studies mentioned above.

Meanwhile, several studies have shown that limitations in dorsiflexion angle of the ankle joint are associated with a variety of foot and ankle injuries, but the criteria for such limitations vary in the literature. In a study linking ankle dorsiflexion restriction to forefoot and midfoot pain, DiGiovanni et al. [17] defined the restriction as an dorsiflexion angle of the ankle joint measuring less than 5° with the knee extended and less than 10° with the knee flexed. Tabrizi et al. [18] found that in a group of children and adolescents with ankle fractures or sprains, the mean dorsiflexion angle of the ankle joint was 5.7° with the knee extended position and 11.2° with the knee flexed position, compared to 12.8° with the knee extended position and 21.5° with the knee flexed position measured in the control group. In a study analyzing the correlation between Achilles tendinitis and heel cord tightness, Kaufman et al. [12] defined heel cord tightness as a dorsiflexion angle of the ankle joint measuring less than 11.5° with the knee extended and less than 18.5° with the knee flexed.

In this study, the average dorsiflexion angle of the ankle joint was 23.13° in knee flexed position and 15.16° in knee extended position for grade 1, 9.31° in knee flexed position and 3.40° in knee extended position for grade 3, respectively, which is in a similar range to the cut-off values in the above studies, suggesting that our squatting posture grading system has the potential to replace direct dorsiflexion angle of the ankle joint measurement and, by extension, screening groups with foot and ankle injuries or pain.

Additionally, based on Kaufman et al. [12], the cut-off values for dorsiflexion angle of the ankle joint to determine the presence of heel cord tightness in the study population were set at 18.5° in the knee-flexed position and 11.5° in the knee-extended position. Accordingly, the sensitivity and specificity were calculated, revealing a sensitivity of 91.0% in the knee-flexed position and 86.2% in the knee-extended position. These values were significantly considerable, indicating the effectiveness of the screening test.

Similar to this study, Rabin scored performance of the overhead squat and forward arm squat positions to analyze the relationship between squatting posture and dorsiflexion angle of the ankle joint. However, all subjects in study of Rabin were able to perform the overhead squat and forward arm squat positions, which are more difficult than the squatting posture in this study. The mean dorsiflexion angle of the ankle joint was 27.9° measured using a weight-bearing lunge, which is similar to the dorsiflexion angle of the ankle joint in squatting posture grade 1 in this study. It is suggested that Rabin and Kozol [8] included only subjects with a normal level of calf muscle flexibility. Contrary to Rabin and Kozol [8], we used a relatively easy squatting posture, including a large number of subjects with low to high calf muscle flexibility, and categorized calf muscle flexibility into three grades.

Previous studies have shown an association between limited range of motion of ankle and hamstring tightness, which is thought to be due to tight hamstrings causing an overall contraction of the posterior leg musculature [19]. In this study, the percentage of hamstring tightness identified by the tripod sign was 17% in grade 1, 28% in grade 2, and 64% in grade 3, with no significant difference between grade 1 and grade 2, but a significant difference between grade 1 and grade 3 and also between grade 2 and grade 3. The relationship between hamstring tightness and the performance of the squatting posture, as defined in this study, remains unclear. In cases of hamstring tightness, flexion of the lumbar spine may accompany the squat exercise due to the tension exerted on the ischial tuberosity [20]. However, this aspect was not included as an evaluation factor in the squatting posture grading system used in this study. Moreover, the length of the hamstrings did not change significantly throughout the squat performance, which is likely attributable to the bi-articular structure characteristic of this muscle [21]. Additionally, considering the possibility that hamstring tightness could act as a confounding variable, additional analyses were conducted based on its presence or absence. In both cases, a significant difference in the dorsiflexion angle of the ankle joint according to the grade was confirmed. Considering the previously mentioned evidence and results, hamstring tightness, under the individual characteristic of overall posterior leg musculature flexibility deficiency, is associated with limited ankle dorsiflexion. However, it is unlikely to be significantly related to the performance and grading of the squatting posture.

The majority of the subjects were people with intellectual disabilities in this study. It is known that people with intellectual disabilities have higher rates of abnormal foot conditions such as limited ankle range of motion and flat feet [22]. Since this study was aimed to compare groups with and without decreased calf muscle flexibility rather than determining the proportion in the overall population, we included a larger number of subjects with intellectual disability than the number of subjects with normal cognition to ensure that we had a sufficient number of subjects with limited dorsiflexion angle of the ankle joint. In addition, subjects with intellectual disabilities were able to follow the postures presented in this study without difficulty despite their cognitive function. This can also be regarded as a necessary characteristic for quick and general screening method. However, in this study, the group consisting of the subjects tended to have smaller dorsiflexion angles of the ankle joint compared to the group of normal subjects, although the difference was not significant. This is presumed to be due to the fact that the participants in this study were athletes with relatively high athletic abilities, as they participated in the Special Olympics Games, and exclusions were made during the recruitment process based on prior medical history through interviews.

The height was significantly higher in grade 2 than in grades 1 and 3. However, the total number of subjects in this study was not large, especially the number of subjects in grade 2 was small (N=18), hence it is possible that the subjects in this group were taller than the other groups by chance. However, according to Kasuyama et al. [6], unlike our study, significant differences in body weight were observed between the possible squatting and impossible squatting groups. Nevertheless, in the additional discriminant analysis and discussion conducted in that study, body weight showed significance, yet the strength of its association was very weak. Similarly to our study, BMI, which is strongly correlated with weight, did not demonstrate significant differences.

Furthermore, following the classification method used in Kasuyama et al. [6], we categorized our study population into groups that could be considered as the "possible squatting group," corresponding to grade 1, and the "impossible squatting group," corresponding to grades 2 and 3. We did not observe significant differences in height between the reclassified groups. While the difference in weight did not reach statistical significance, with respective means of 66.08 and 70.64 kg and a p-value of 0.12, there was a possibility of some degree of difference. Therefore, further research is needed to determine how exactly body weight influences squat posture and to what extent.

This study has several limitations. First, there is heterogeneity in the overall population. However, it is important to consider that this study initially included many individuals with intellectual disabilities to secure a large number of subjects with heel cord tightness. In addition, there was a lack of evaluation of other joints such as the hip and knee, which are related to the performance of the squatting posture. Lastly, due to the limitations of the testing environment, it was not possible to secure more than one evaluator, thereby preventing the assessment of interrater reliability. Nevertheless, considering the simplicity of the evaluation method and the clear distinctions between grading levels, it is presumed that there will not be significant differences between evaluators or in repeated measurements.

Conclusion

The squatting posture grading system defined in this study effectively graded the subjects based on the difference in their average dorsiflexion angle of the ankle joint. Grade 1 corresponds with sufficient flexibility, grade 2 corresponds with partially limited flexibility, and grade 3 corresponds with severely limited flexibility of dorsiflexion angle of the ankle joint of the subjects. In addition, the squatting postures in this system were easy to perform and could be graded quickly, suggesting that this grading system has the potential to be an effective screening method for limitations in ankle dorsiflexion and decreased calf muscle flexibility.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTION

Conceptualization: Lee JK. Data curation: Kim JY, Na H. Methodology: Lee JK. Formal analysis: Kim JY. Investigation: Kim JY, Na H. Project administration: Lee JK. Software: Park KD. Resources: Lim OK. Visualization: Na H. Supervision: Lee JK. Validation: Kim JY, Lee JK. Writing – original draft: Kim JY. Writing – review and editing: Lee JK. Approval of final manuscript: all authors.

SUPPLEMENTARY MATERIALS

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