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ORIGINAL ARTICLES

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The Journal of Asian Rehabilitation Science

Original Article

Elongation training decreases spinal excitability in healthy human soleus muscle

JUNYA MIYAZAKI,RPT, PhD[1)] RYUTO YURUGI, RPT[2)] HINAKO OGAWA, RPT[3)]
KOJI NONAKA, RPT, PhD[4)] AZUSA UEMATSU, PhD[5)]

1) Kyoto Tachibana University (34 Yamada-cho Oyake, Yamashina-ku, Kyoto 607-8175, Japan)
2) Clinic of The Second Kyoto City Child Well-being Center
3) Harajuku Rehabilitation Hospital
4) Naragakuen University
5) Dokkyo Medical University

Abstract. [Purpose] The purpose of this study was to determine the effect of elongation training (ELT) on spinal excitability in healthy human soleus muscle. [Participants and Methods] Twenty-six healthy young male participants were randomly assigned to ELT (n = 13) and control group (n = 13). We measured the H-reflex and M-wave from participants' right soleus muscle for baseline, 1 min and 30 min after intervention (ELT or 5 min rest). [Results] H-max/M-max was similar level between both groups at baseline. Only in ELT group, H-max/M-max decreased 20% for 1 min and 30 min after intervention. [Conclusion] These results suggested that ELT depresses the spinal excitability and this after-effect lasts at least for 30 min.

Key words: elongation training, spinal excitability, H-max/M-max

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1. INTRODUCTION

Static stretching of the muscle is generally used for improving human health and preventing motor disfunction. Main benefits of static stretching are increase in range of joint motion and decrease in muscle tone[1, 2)]. However, previous studies reported that static stretching does not affect[3)] or decrease muscle power output[4, 5)], suggesting that static stretching only should not expect improve muscle strength. Further, static stretching decreases the spinal excitability in the target muscle[6)].

In the recent clinical practice for rehabilitation, a new training method called "Elongation Training (ELT)" was developed for increasing both range of joint motion and muscle strength. ELT uses elastic fabric band ("Elongation Band") during training exercise. Elongation band can progressively add a load with safe depending on participant's body position and voluntary effort. Main concepts in ELT are antagonist muscle stretching based on reciprocal inhibition and strength training based on moderate to maximal voluntary muscle contraction. Therefore, ELT theoretically can include benefits for both of stretching and strength training. We have reported that ELT increases a range of motion in the target muscle[7)]. However, there is still no neurophysiological data for expectable benefit of ELT. Previous study reported the spinal excitability was decreased by antagonist muscle contraction[8)], suggesting that ELT also have a possibility of an effect to decrease the spinal excitability in the target muscle. Thus, the purpose of this study was whether ELT acutely decreases spinal excitability in soleus muscle.

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*Corresponding author: JUNYA MIYAZAKI (j-miyazaki@tachibana-u.ac.jp)

2. SUBJECTS AND METHODS

Twenty-six healthy young males (age: 20.9 ±0.6 years, weight: 65.2 ±11.2 kg, height: 170.9 ±5.4 cm) participated in the experiment. Participants were randomly assigned to ELT group and control group. Participants gave written informed consent prior to the experiment. The University Ethics Committee approved the study protocol which was conducted according to Declaration of Helsinki (17-37).

Surface electromyography (EMG) from the right soleus muscle (SOL) was recorded with Ag/AgCl surface electrode (electrode diameter: 1 cm, center-to-center electrode distance: 2 cm). EMG signal was amplified, band-pass filtered (low-cut: 20 Hz, high-cut: 3 kHz) to attenuate low and high-frequency noise from EMG signal, A/D converted at sampling rate of 10 kHz, and recorded on hard-disk (MEB－9400, Nihon Kohden Japan).

Single percutaneous electrical stimulation (duration: 1 ms, rate: 1 Hz, MEB-9400, Nihon Kohden Japan) to the posterior tibial nerve was delivered to evoke the maximal H-reflex (H-max) and M-wave (M-max) from soleus muscle. The stimulating electrode (interelectrode distance: 2 cm) was placed at the popliteal fossa of the right leg. Participants laid prone on the bed while recording H-max and M-max. Before starting baseline recording, participants positioned laying prone at rest for 10 min as a familiarization to the testing condition. Testing of H-max and M-max was executed 1 min and 30 min after the intervention (ELT or 5 min rest). H-max/M-max were used to evaluate the spinal excitability[6].

To perform ELT for right soleus muscle, participants fixed their left fingers and right toes to the end of the elongation band (Fig. 1). ELT was consisted of 8 sec voluntary exercise and 10 sec rest. The voluntary exercise included maximal flexion of left shoulder with fully extended left elbow and maximal extension of right hip joint with fully extended right knee joint and dorsiflexed the right ankle joint.

Participants performed ELT in the right-side-up lateral position while hold their pelvis with right hand and flexed their left hip and knee joint for 90°. ELT was repeated 5 times.

All data were presented as the mean ± SD. Main analysis was time (baseline, 1 min after, 30 min after) by intervention (ELT, 5 min rest) two-way repeated-measures ANOVA. When significant interaction or main effect was found, we used Bonferroni's multiple comparison as a post-hoc test. For executing all statistical tests, the SPSS (for windows, version 23.0, IBM) was used. The level of significance was set at $p<0.05$.

Fig.1: The elongation training for the right soleus muscle

3. RESULTS

Table 1 represents H-max/M-max data in both ELT and control groups. There was a Time by intervention interaction ($p<0.05$). Post-hoc test revealed that comparing with baseline, H-max/M-max decreased 1 min after and 30 min after in ELT group, but no significant changes in control group.

Table 1. H-max/M-max (unitless) data for before and after the intervention.

Intervention	Baseline	1-min after	30-min after
ELT	0.20 ± 0.14	0.16 ± 0.13*	0.16 ± 0.10*
Control (5-min rest)	0.21 ± 0.12	0.24 ± 0.13	0.24 ± 0.16

Values are represented as mean ± SD.ELT: elongation training
1-min after: a time point indicates 1 min after the intervention
30-min after: a time point indicates 30 min after the intervention
*: lower than baseline value (all $p<0.05$)

4. DISCUSSION

We examined the effects of ELT on soleus muscle spinal excitability. Main finding was that the H-max/M-max decreased after ELT for at least 30 min.

H-reflex is induced by electric stimulation of Ia afferents9), and magnitude of H-reflex amplitude represents total spinal excitability10), suggesting that H-reflex potentially presents an underlying neural mechanism of the muscle tone. Indeed, H-max/M-max is higher in the tone-increased muscle in patients with muscle spasticity11). In this experiment, participants kept ankle dorsiflexed position by contracting ankle dorsiflexors while performing ELT targeting on the soleus. Therefore, inhibitory effects on the spinal excitability of right soleus by muscle stretching and reciprocal inhibitory inputs derived from ankle dorsiflexor voluntary contraction may play a key role of long-lasting decrease in H-max/M-max after ELT.

Mizuno et al. (2013) reported that range of motion for ankle dorsiflexion increased after 5 time repetitions of 1 min static stretching and it lasts for 30 min12). We did not test participants' range of motion for ankle dorsiflexion, but there is a possibility that ELT for soleus increases soleus flexibility because H-max/M-max still decreased for 30 min after ELT. We showed that ELT decreases the spinal excitability which is a potential underlying neural mechanism of the muscle tone, suggesting ELT can inhibit muscle hyper-tone. Because ELT also includes muscle voluntary contraction, we speculate that ELT activates weak-tone muscle and fix an imbalance of muscle hyper- and weak-tone. Future studies need to examine clinical effects of ELT on muscle condition. Limitations of this study was that we compared only between ELT and control groups and examined only for soleus muscle, thus effects of ELT should be compared with other muscle stretching techniques and examine for other muscles.

In conclusion, ELT decreased the spinal excitability of the soleus muscle in the healthy young adults and it lasted at least 30 min. Thus, ELT can be an useful method to decrease participant's muscle tone. Also, it is expectable that performing voluntary contraction included in ELT will increase participant's amount of physical activity.

Funding and Conflict of interest

No funding was provided for this study. The author declares no conflict of interest.

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Original Article

Validity of mixed use of measurement units for hip joint rotation range of motion: Simulation using equivalence and non-inferiority trials

HEONSOO HAN PT PhD1), AKIRA KUBO PT PhD1), MASAHIRO ISHIZAKA PT PhD1),
HITOSHI MARUYAMA PT PhD2)

1) Department of Physical Therapy, International University of Health and Welfare
(2600-1 Kitakanemaru, Ohtawara, Tochigi 324-8501, Japan)
2) Department of Physical Therapy, School of Graduate School, International University of Health and Welfare

Abstract. [Purpose] To investigate the validity of the mixed use of 1- and 5-degree measurement units for hip joint rotation range of motion (ROM). [Participants and Methods] This study included 152 legs of physical therapy students. The ROM of internal rotation and external rotation of the hip joints were measured in 1-degree units. The measured values were converted from 1-degree units to 5-degree units. The 5-degree units were compared to the 1-degree units as the measured values of one time (trial 1), the average value of two times (trial 2), and the average value of three times (trial 3). A paired t-test was conducted to determine the differences between the 1- and 5-degree units. To investigate the relevance of criterion-related validity related to 1-degree-unit measurement values, correlation coefficients and equivalence and non-inferiority trials were compared to those of the 5-degree units. Determinations of equivalence and non-inferiority trials were performed using the confidence intervals of the average value. [Results] No significant differences were observed in any of the three trials for internal rotation or external rotation in t-test. Significant differences were found in all correlation coefficients. The results of the equivalence and non-inferiority trials were judged as non-inferior in all three trials of internal rotation and external rotation. [Conclusion] No inferiority was seen between 1- and 5-degree units in the measurement of hip joint rotation ROM. Thus, the measurement units are appropriate, suggesting the possibility of their mixed use.

Key words: hip rotational ROM, mixed measurement units, validity

(This article was submitted September.3, 2019, and was accepted November.2, 2019)

1. INTRODUCTION

In the field of clinical physical therapy, assessments of joint range of motion (ROM) are important evaluation tools for understanding motor function abnormalities. In motor dysfunction, evaluation of the joint ROM is important to discern the degree of dysfunction or change in motor function [1].

Limiting factors for joint ROM includes joint structures such as dislocations, osteophytes, intra-articular loose bodies, and those caused by functional factors such as rigidity, shortening by soft tissue around the joints, contractures, spasticity, and pain. Limited joint ROM often occurs in combination with these factors, and an evaluation of joint ROM is an important means of determining the state of the joint before and after intervention[1].

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*Corresponding author: HEONSOO HAN (han@iuhw.ac.jp)

The purpose of measuring ROM is mainly to detect factors that inhibit joint movement, determine the degree of injury, plan treatment, and assess the treatment effect [1]. The use of tools such as an inclinometer [2], goniometer [3], [4], photo [5], and three-dimensional motion analyzer [6] has been widely reported as a measurement method of joint ROM. Goniometers are mainly used to measure ROM in educational and clinical settings, and measurement values in 5-degree units are used [7], [8], [9] in physical therapy in Japan.

This study focused on the existence of both 1- and 5-degree units of hip rotation ROM measurements. Hip rotation ROM limitations are reportedly associated with osteoarthritis [10]. Cibulka et al. suggested that asymmetrical hip rotation may be related to patellofemoral joint pain in a case report[11], and was important for the evaluation of chronic low back pain [12]. In the clinical practice of physical therapy, hip rotation ROM is used as a useful tool to evaluate low back pain and knee pain. In various research reports, the hip rotation ROM exists in both 1-degree[13] and 5-degree units [8], [9]. Five-degree units are generally used; however, the use of 1-degree units may ensure more precise measurement accuracy because the scale is finer despite the potential for increased variability and reduced accuracy.

Thus, there may be a demand for additional units of measure for example 1- and 5-degree units for determining hip rotation ROM. If both 1-degree and 5-degree units can be used, we can exchange values obtained using different measurement units. However, the lack of validity regarding mixed use makes it difficult for this exchange to occur between the different measured values.

There are situations in which mixed use is difficult, such as incompatibility between measurements due to different measurement units. However, no studies have examined the validity of the mixed use of 1- and 5-degree measurement units in hip rotation ROM. This study was based on the hypothesis that 5-degree units are equal or non-inferior to 1-degree units because of the difficulty guaranteeing accuracy of the latter for measuring joint ROM. This study aimed to examine and clarify the validity of the mixed use of 1- and 5-degree measurement units for hip joint rotation ROM.

2. SUBJECTS AND METHODS

The participants were 152 legs of 76 students (mean age, 19.9 ± 3.1 years; 46 males, 19.5 ± 1.0 years; 30 females, 20.6 ± 4.7 years) enrolled in the Department of Physical Therapy at the International University of Health and Welfare. The measurements were made between April and July 2014 (Table 1).

Potential participants were recruited from among the university students by asking them if they agreed with the research purpose and wanted to participate in the study. The participants were students who were able to walk without aids at the time of the measurements and had no trouble in daily life. Exclusion criteria were current orthopedic treatment, because such treatment may affect the validity of the study measures and analyses, and presence of characteristics that cannot be easily measured within the context of this study (e.g., some neurological and unexpected problems). No students were excluded based on these criteria.

Table 1. Participants' characteristics

	Male (n=46)	Female (n=30)	Total (n=76)
Age, years	19.5±1.0	20.6±4.7	19.9±3.1
Height, cm	171.8±6.5	157.9±5.3	166.3±9.1
Weight, kg	63.8±9.0	53.6±6.4	59.8±9.5
BMI, kg/m^2	21.6±2.3	21.5±2.3	21.5±2.3

The participants were placed in a prone position on the treatment bed. We then measured the ROM values for both internal and external hip rotation, in both the left and right hips. In prone measurement, the measurement should be taken by holding the pelvis with one hand and moving the hip joint to the final region with the other hand to prevent the compensatory movement of the pelvis from floating. Such measurement is difficult even for an experienced physical therapist alone. Therefore, this time, we divided the measurement process into four roles.

With their designated roles, the students participated in the measurements, supervised by a physical therapist. Before the measurement, the physical therapy teaching staff provided them with the instructions. The participants remained blinded to the measurement values until the measurements were completed. As a blinding method, the measurement values were not shared until the measurement was completed by not verbalizing or showing the values. The roles in the measurement were divided into four parts as follows: the exerciser, who performed movements of the rotational range of the hip joint toward the final region; the goniometer operator; the recorder, and the observer. A physical therapist participated in a part of measurement roles during supervising.

The measurements orders were determined by lottery, and the record clerk notified the person in charge of the exercise of the order at the time of measurement. The observers and physical therapist ensured that the measurements were performed in accordance with the measurement method. The physical therapist supervised and directed all the measurements on site. Each hip rotation ROM was measured 3 times each in 1-degree units using a goniometer (University of Tokyo type).

To confirm the validity of the measurement, after subdivision into four roles, variable error was used to determine the internal consistency of within-subject measurements. The calculation formula of the variable error VE is

$$\mathrm{VE}(°) = \sqrt{\frac{\sum_{i=1}^{3}(x_i - M)^2}{3}}$$, where M is the average of three measurements.

The variable errors were calculated for each of the four measurement items, measured thrice in each subject. The mean and standard deviation of the variable error of left internal rotation, left external rotation, right internal rotation, and right external rotation were 2.8° ± 2.1°, 3.2° ± 1.7°, 2.5° ± 1.8°, and 3.0° ± 1.8°, respectively. Akazawa et al.[14)] reported that a minimal clinically important difference for hip flexion, obtained and measured with a digital camera was 3.1°.

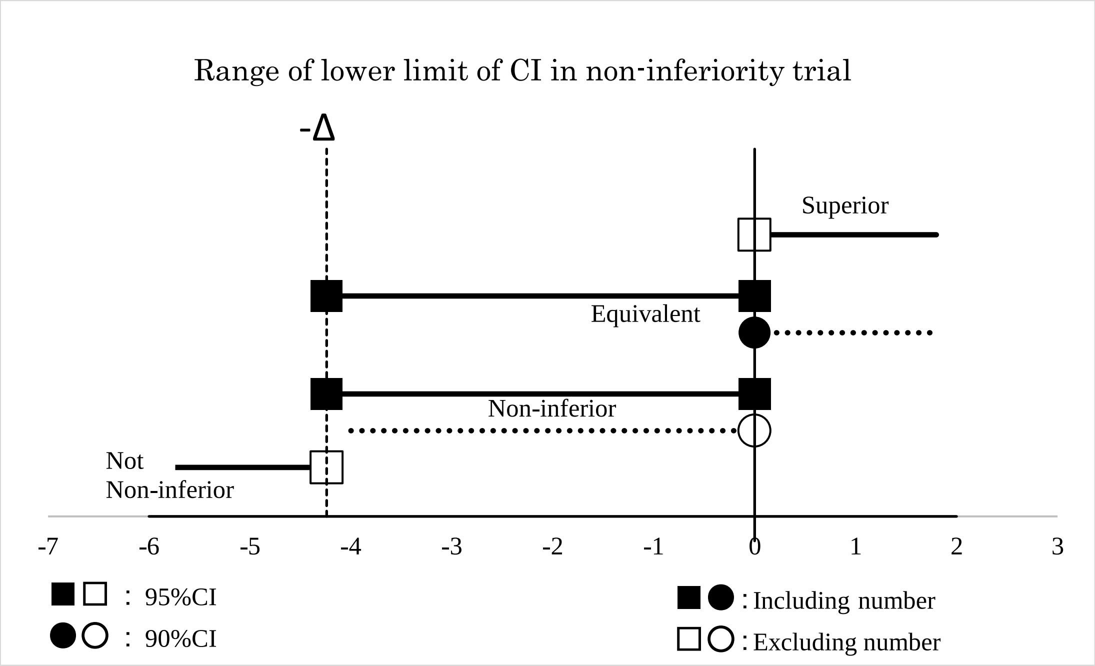
Converted values obtained by converting each hip joint ROM from the measured values in 1- to 5-degree units were used as comparison targets. Conversions from 1- to 5-degree units were performed on the assumption of the same process as in the actual measurement in 5-degree units.

When the ROMs are measured with a goniometer in 5-degree units, the range ± 2 around 0 or 5 is read as the closer of the two numbers. For example, if the number to be read is in the range of 20 ± 2, it is considered 20, while if it is 25 ± 2, it is considered 25. Therefore, one digit of the measured values was rounded up from 8 or 9 to 0; 1 or 2 was rounded down to 0; 3 or 4 was rounded up to 5; and 6 or 7 was rounded down to 5.

Three comparisons were made between measured values in 1-degree units and converted values converted to 5-degree units (Table 2). For trial 1, a comparison was made between the first measured value in 1-degree units and the converted value obtained by converting the measured value into 5-degree units. Trial 2 compared the average value of the first and second measurement values with the average first and second measurement values converted to 5-degree units. For trial 3, the average of the first, second, and third measurement values were compared with the average values of the first, second, and third converted values.

Table 2. Average values for each trial of hip rotation range of motion

		Internal Rotation		External Rotation	
		Measured value (1° units)	Converted value (5° units)	Measured value (1° units)	Converted value (5° units)
Trial 1	Male (n = 92 legs)	41.8 ± 10.1	41.9 ± 10.3	57.3 ± 12.4	57.2 ± 12.5
	Female (n = 60 legs)	55.0 ± 12.1	54.8 ± 12.2	51.7 ± 12.3	51.8 ± 12.3
	Total (n = 152 legs)	47.0 ± 12.7	47.0 ± 12.8	55.1 ± 12.6	55.1 ± 12.6
Trial 2	Male	41.8 ± 9.8	41.8 ± 9.9	57.7 ± 12.4	57.6 ± 12.4
	Female	55.2 ± 12.1	55.2 ± 12.0	51.8 ± 12.4	51.9 ± 12.6
	Total	47.1 ± 12.6	47.1 ± 12.6	55.3 ± 12.7	55.4 ± 12.7
Trial 3	Male	41.9 ± 9.8	42.0 ± 9.9	57.9 ± 12.5	57.8 ± 12.4
	Female	55.6 ± 12.4	55.6 ± 12.4	51.4 ± 12.2	51.4 ± 12.4
	Total	47.3 ± 12.8	47.4 ± 12.8	55.3 ± 12.7	55.3 ± 12.8



CI, confidence interval

Fig. 1. Equivalence and non-inferiority trials of hip rotational range of motion using 95% and 90% CI lower limits between the 1- and 5-degree units. Created by HeonSoo Han based on ISHI H. [15]

To examine the criterion-related validity of the measured value of 1-degree units, the correlation with the converted value of 5-degree units and the equivalence and non-inferiority trials were examined. Paired t-tests were performed to determine the presence or absence of differences between 1- and 5-degree units ($p < 0.05$). IBM SPSS Statistics 25 was used to perform all analyses.

The determinations of equivalence and non-inferiority trials were performed using the confidence interval (CI) of the average value [15] (Fig. 1). The size of the non-inferiority margin is said to be 1/3 of the standard deviation of the two variables in the population[15]. The size of the non-inferiority margin was set to one-third of the average value by averaging the standard deviation of the measured value in 1-degree units and the converted value to 5-degree units.

The difference in standard deviation in the population was estimated. The lower limits of 95% and 90% were used as CI in the determination of equivalence and non-inferiority trials. The lower limit value of each CI was compared with the value ($-\Delta$) with the non-inferiority margin taken on the negative side. Judgements of equivalence and non-inferiority trials were determined from four items of non-inferiority cannot be said, non-inferiority can be said, equality can be said, or superiority can be said. When the lower limit of 95% CI was smaller than $-\Delta$, non-inferiority cannot be said. Moreover, when it is greater than 0, superiority can be said. When the lower limit of 95% CI is in the range of $-\Delta$ or more and 0 or less ($-\Delta \leq$ 95% CI lower limit ≤ 0) is a common range of “non-inferiority can be said” and “equality can be said.” The range of the lower limit of 90% CI differs between cases. The former is less than 0, while the latter is 0 or more.

Participants were given an explanation of the study content and purpose, and each provided written informed consent. This study was approved by the International University of Health and Welfare Ethics Review Board (approval number: 18-Io-42).

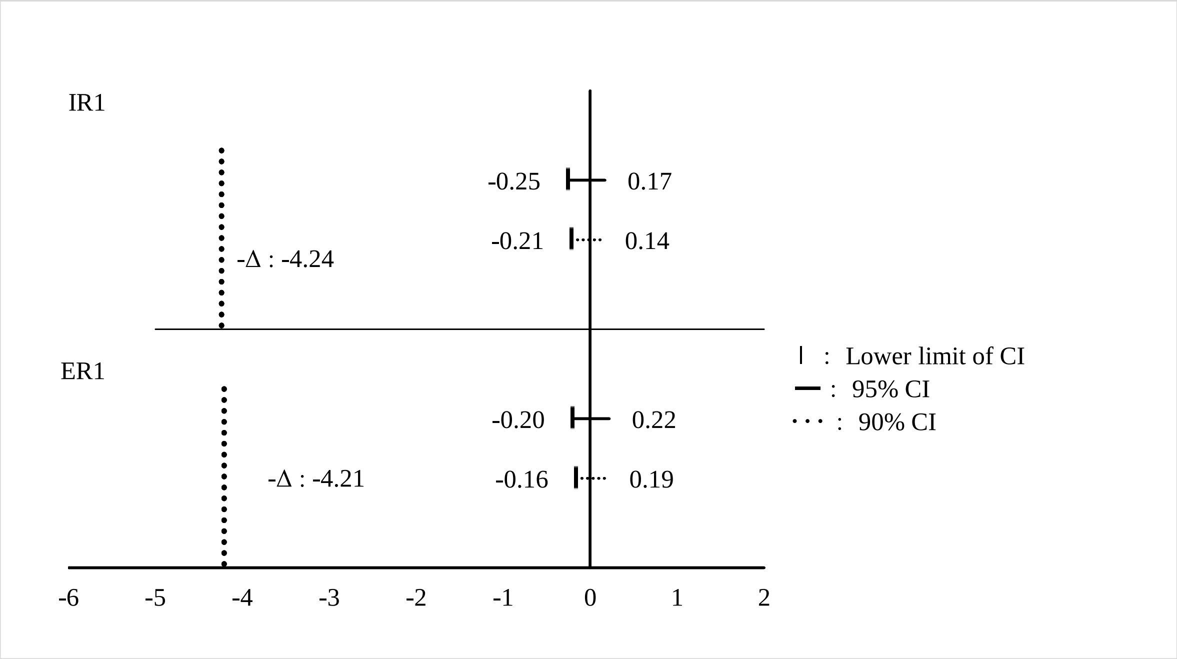
3. RESULTS

The t-test results were not significantly different because of all of the p values were greater than 0.05 for all items of internal and external rotation comparing the measured and converted values, the average of two measured values with the average of two converted values, and the average value of three measured values with the average of the converted value (Table 3). The correlations were very high and significant ($p < 0.001$) in all items of all three trials of internal and external rotations (Table 3).

Table 3. p-values and correlation coefficients between measurement values and converted values

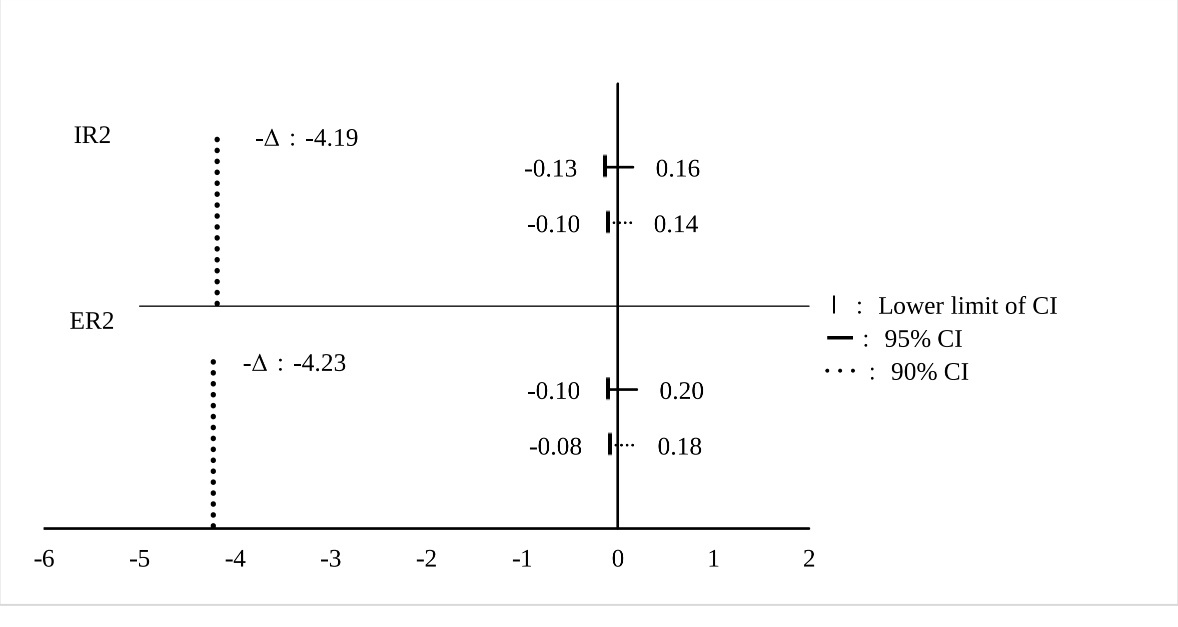
	Internal Rotation		External Rotation	
	P value	Correlation coefficient	P value	Correlation coefficient
Trial 1	0.71	0.995	0.90	0.995
Trial 2	0.79	0.997	0.52	0.997
Trial 3	0.25	0.998	0.97	0.998

Judgement results of equivalence and non-inferiority trials “can be said to be non-inferior” judgements in both internal and external rotation in trial 1(Fig.2), trial 2(Fig.3), and trial 3(Fig.4) of internal and external rotation, respectively. Because the lower limits of 95% and 90% CI for all six items of external rotation and internal rotation of trials 1, 2, and 3 are located between $-\Delta$ and 0, the judgements “can be said to be non-inferior.”



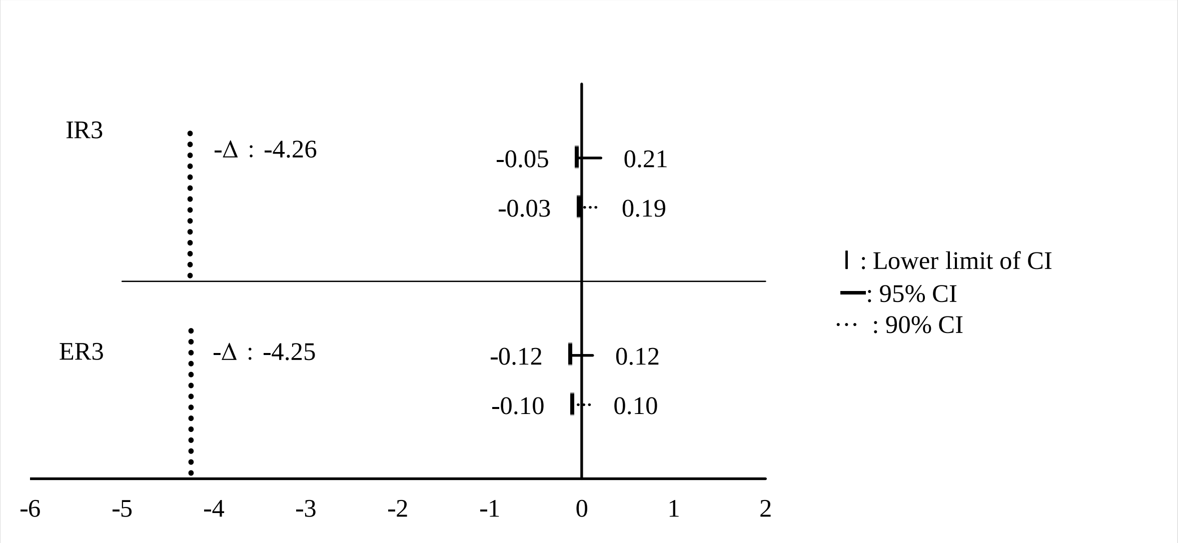
IR, internal rotation; ER, external rotation; CI, confidence interval

Fig. 2. Equivalence and non-inferiority trials of hip joint rotational range of motion 1 batch data using lower limits of 95% CI and 90% CI (trial 1)



IR, internal rotation; ER, external rotation; CI, confidence interval

Fig. 3. Equivalence and non-inferiority trials of hip joint rotational range of motion 2 batch data using lower limits of 95% CI and 90% CI (trial 2)



IR, internal rotation, ER, external rotation; CI, confidence interval
Fig. 4. Equivalence and non-inferiority trials of hip joint rotational range of motion 3 batch data using lower limits of 95% CI and 90% CI (trial 3)

4. DISCUSSION

We hypothesized that the converted value in 5-degree units is equal or non-inferior to the measured value in 1-degree units, while the ROM can be measured using 1-degree and 5-degree units. Then, the validity of the mixed use of measured values in 1-degree units and converted values in 5-degree units was examined using the measurement of hip joint rotation ROM.

Converted values were prepared by converting the value measured in 1-degree units of hip rotation ROM into 5-degree units using the same logical process as in actual measurement in 5-degree units, and the measured and converted values were compared. The t-test showed no significant differences in any trial in internal or external rotation. This result demonstrated that there are no differences between the measured values (1-degree units) and converted values (5-degree units).

Furthermore, in the examination of equivalence and non-inferiority trials, the converted value of 5-degree units is non-inferior to the measured value of 1-degree units and the correlation is extremely high; thus, the criterion-related validity is considered appropriate.

The measurement of joint ROM is currently performed using 5-degree units, a method of The Japanese Orthopaedic Association and The Japanese Association of Rehabilitation Medicine. The Japanese Physical Therapy Association proposes methods [16] to supplement those methods as follows. The measurement is based on 5-degree increments, but if necessary, 1-degree increments are considered. When it is necessary to verify a change of less than 5 degrees in the determination of the treatment effect, measurements should be performed using an instrument capable of measuring with an accuracy of 5 degrees or less.

Akazawa et al. [14] reported that the clinically relevant minimum difference in hip flexion angle in healthy adult men is 3.1 degrees. The reference ROM of the hip flexion used in their study is 125 degrees, while the hip joint rotation used in our study is 45 degrees of internal rotation and external rotation, respectively. Hip flexion and hip joint rotation are different from each other with respect to the type of joint movement as well as the range of motion. However, to detect the minimum difference, use of the 1-degree unit makes sense. Although the accuracy of the measurement needs to be guaranteed, this is often difficult in clinical practice. The reason for this is that there are many factors that impede joint movement measurement accuracy. These include: 1) patient factors such as joint structure, soft tissue around the joint, and central nervous diseases, which can be considered limiting factors [1);

2) measurement, e.g. errors due to the strength and adjustment of the load of the measurer when determining the final ROM and goniometer placement. It seems difficult to achieve measurement accuracy using the 1-degree unit while completely controlling the influence of the measurement factor.

It should be noted that the mixed use of 1- and 5-degree units of measurement is inappropriate if a case requires a change of less than 5 degrees. If a clinical comparison is required in the mixed-use condition, the accuracy of the comparison must be adjusted to the 5-degree unit.

This study was limited to the rotational ROM of the hip joint, but it is expected that the result will be obtained if the same process as this simulation is used, even in the ROM measurement of other joints using a goniometer. Therefore, it seems useful even if the measurement units coexist when measured by goniometer. The possibility of mixed use of both units is broadened and may be useful even when integrating research reports from different researchers in clinical situations and meta-analyses.

This study had several limitations. First, we did not consider inter- and intra-rater reliability. Second, the 5-degree unit values were not actual measured values; rather, they were logically converted from actual measured values of 1-degree unit values. In order to address the present limitation, future studies should compare the measured values, not the converted values, to confirm the validity of the mixed use of measurement units. Furthermore, the selection of measurers and recruitment of participants should be considered in future studies.

In conclusion, 5-degree unit measures of hip joint rotation ROM are not inferior to 1-degree unit measures, and their mixed use is a statistically valid approach for assessing hip rotation ROM in young healthy Japanese students.

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