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Original Article

Relationship between muscle-tendon length, range of motion, and resistance to passive movement in children with normal and increased tone

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Abstract. [Purpose] The aim of this study was to quantify the resistance to passive movement by measuring changes in muscle-tendon length and joint range of motion (ROM), before and after applying a standardized 5-kilogram tension force, and to correlate and compare these changes to muscle tone. [Subjects and Methods] Children with cerebral palsy (n=29) and typically developed children (n=12) participated in this observational study. The modified Ashworth scale (MAS) was used to assess tone in the right plantarflexor muscle. An ultrasound-imaging device was used to measure Δmuscle-tendon length in the right medial gastrocnemius muscle, and a goniometer was used to measure right ankle ΔROM. [Results] Compared with the MAS, the results showed that ΔROM had the highest construct validity (convergent and discriminant) followed by Δmuscle-tendon unit length. Therefore, these parameters may be better alternatives to the MAS for the quantitative assessment of resistance to passive movement in patients with increased tone. [Conclusion] This study demonstrated that measuring the change in the passive properties of the muscle-tendon unit, as well as the corresponding change in ROM, might provide better options for assessing resistance to passive movement or muscle tone.

Key words: Muscle-tendon length, Range of motion, Muscle tone

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INTRODUCTION

Cerebral palsy (CP) is defined as "a group of permanent disorders of the development of movement and posture causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain" (p9)[1)]. These movement and postural disorders can be divided into three categories: (1) spastic, (2) dyskinetic (dystonia or choreoathetosis), and (3) ataxic. However, some patients may demonstrate a mixture of these three categories[1)]. Movement abnormalities resulting from CP are usually associated with hypertonia, which is defined as an "abnormally increased resistance to externally imposed movement about a joint. It may be caused by spasticity, dystonia, rigidity, or a combination of features" (p91)[2)]. In contrast to hypertonia, spasticity is defined as "a velocity-dependent resistance of a muscle to stretch" (p91)[2)]. While these two terms have been used interchangeably in the literature, their definitions as described above suggest that they are not the same.

The clinical assessment of hypertonia and / or spasticity in patients with CP can be divided into four main categories:

Ashworth-like scales[3)]: this procedure involves passively moving the affected limb at one velocity, which is not specified, through its range of motion (ROM) and grading the resistance encountered on a 5-point ordinal scale (i.e., original Ashworth scale or AS), or a 6-point ordinal scale (i.e., modified Ashworth Scale or MAS − Bohannon). Other modifications include combining AS with MAS and grading it for severity of the spasticity (i.e., MAS − Peacock), as well as combining AS with a

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fast velocity stretch (i.e., New York University Tone scale)[3].

Tardieu-like scales[3]: this procedure involves passively moving the joint at three specified velocities and grading the intensity and duration of the muscle reaction to stretch, at the point where the muscle reaction is initially felt, on a 5-point ordinal scale (i.e., Tardieu scale), or alternatively, this procedure may be simplified by grading the muscle reaction to stretch at the moment the muscle "catches" during fast passive stretch (i.e., modified Tardieu scale).

Other clinical grading scales[3]: although not commonly used in clinical practice, these may include the spasticity grading scale, modified composite spasticity index, the Duncan Ely test, and the Hypertonia Assessment Tool[4].

Instrumented methods: these may include dynamometers to measure torque, and electromyography to measure muscle activity[5–7]. These instrumented methods are not usually used clinically due to unavailability of equipment, or the lack in expertise.

The severity of hypertonia may be measured by using these ordinal scales even though they are limited in their ability to distinguish among what causes it, i.e., as a result of spasticity, dystonia or rigidity[4]. Nevertheless, Sanger et al. argues that "they may still be useful, once a category (i.e., spasticity, dystonia or rigidity,) has been assigned" (p94)[2]. Because the MAS is simple and convenient, it is widely used in the assessment of hypertonia and / or spasticity in clinical practice and research[7, 8].

In patients with CP, hypertonia (i.e., resistance to passive movement) may be due to neural mechanisms such as the hyperactive stretch reflex (i.e., spasticity), or secondary changes to the passive properties of the muscle-tendon unit (i.e., changes in muscle morphology or architecture resulting in tissue stiffness), or both[2]. Pierce et al.[9] reported that tissue stiffness, rather than spasticity, may play a greater role in increased passive resistance to movement in children with spastic diplegic CP particularly as they grow older. Yang et al.[10] suggested that changes in muscle architecture parameters were more sensitive than the Ashworth-like scales in evaluating spasticity. They stated that when the Ashworth-like scales were combined with measurements of muscle architecture parameters, the objectivity and accuracy of MAS to assess muscle tone could be greatly increased[10]. However, despite these suggestions, clinicians and researchers have continued to use the Ashworth-like scales exclusively to assess muscle tone and spasticity, particularly in children with cerebral palsy[3, 7, 8].

The validity and reliability of the Ashworth-like scales are not without controversy. With regards to its construct validity, Scholtes et al.[3] argues that the Ashworth-like scales do not assess the velocity-dependent increase in muscle tone, and hence may be inappropriate as a measure of spasticity. Pandyan et al.[11] suggested that the Ashworth-like scales, by the nature of its procedure, might be more correctly used as a measure of hypertonia (i.e., resistance to passive movement), rather than spasticity. With regards to its discriminant validity, while studies have reported that the Ashworth scale was able to detect the presence of spasticity (percentage exact agreement 81.5%, κ=0.24, p=0.057)[10], it was unable to identify the severity of the spasticity[7, 12]. This limitation was supported by Pandyan et al.[13] who reported that MAS could not discriminate between grades 1, 1+ and 2. They even suggested that fewer grades (by merging 1, 1+ and 2 into a single grade) might improve its discriminant validity[13]. With regards to its reliability, several studies have reported that the reliability of the Ashworth-like scales was not very high[14, 15]. It may also be possible that having fewer grades, as suggested by Pandyan et al.[13], might help to increase its reliability. Nevertheless, until these issues are addressed, the results from these types of assessments should be interpreted with care.

As an alternative to the Ashworth-like scales, some authors have developed custom-made devices to quantitatively measure the resistance to passive movement in children with cerebral palsy[16, 17]. Fonseca et al. used a portable device to measure the angle-moment of the ankle joint and their results demonstrated a negative correlation between the device and MAS, that is, as spasticity increased, the moment-angle decreased[16]. Pandyan et al.[17] investigated the use of a custom-made mechanical device to measure the resistance to passive movement at the elbow in patients with acute cerebrovascular accidents. They suggested that while MAS may still be able to provide a crude qualitative measure of hypertonia, their mechanical device, in comparison, was able to provide a more reliable and quantitative measure of resistance to passive movement[17]. However, these custom-made devices may not be readily available and therefore, their usefulness may be limited. Nevertheless, there is a need for a simple quantitative method to assess resistance to passive movement in view of all the problems associated with a qualitative method such as the Ashworth-like ordinal scales.

One possible method is to explore the relationship between increased resistance to passive movement with changes in its muscle morphology or architecture (such as muscle-tendon length, pennation angle, muscle thickness, fascicle length) and its corresponding change in joint ROM. For example, when tension is applied to a hypertonic muscle, resistance to movement occurs. This resistance to movement can be measured by changes in the muscle morphology or architecture (e.g. muscle-tendon length) and joint ROM. Willerslev-Olsen et al. reported that resistance to passive movement in a hypertonic muscle can be attributed to neural mechanisms (i.e., spasticity) and passive properties of the muscle-tendon unit (e.g., mechanical and / or morphological changes) which results in increased tissue stiffness[18]. They also suggested that when assessing the resistance to passive movement with techniques such as the MAS, it is not possible to distinguish between neural mechanisms or passive properties of the muscle-tendon unit. In addition, ultrasound imaging have been used in previous studies to investigate the effects of static stretching on the gastrocnemius muscle length in children with cerebral palsy[19] and healthy adults[20]. Therefore, while MAS may be able to qualitatively assess the resistance to passive movement, ultrasound imaging can also be used to quantitatively assess the passive properties of the muscle-tendon unit in a similar manner to these previous studies[19, 20].

Hypothetically, as resistance to movement increases (i.e., as tone increases from normal to hypertonia), changes in muscle-tendon length and its corresponding joint ROM would decrease due to changes in the passive properties of the tissues, spasticity, or both[18]. However, in order to ensure that changes in muscle-tendon length is not being impeded by joint contractures, the tension applied to the muscle should not be excessive and should avoid encountering the end range of the movement. The adequate tension force used in this study was determined in a pilot study in a small ad-hoc sample of patients with CP attending the outpatient department. The results from this ad-hoc sample suggested that 5-kg was an adequate force to apply tension to the soft tissues without encountering the end of the ROM. Therefore, the aim of this study was to quantify the resistance to passive movement, by measuring changes in muscle-tendon length and joint ROM, and to correlate and compare these changes in length and ROM to muscle tone (from normal to hypertonia) in order to evaluate its construct (convergent and discriminant) validity.

SUBJECTS AND METHODS

This observational study employed a cohort design. CP subjects were recruited from the outpatient and inpatient departments, and typically developed (TD) children from staff members, at Shinano Handicapped Children's Hospital in Shimosuwa city, Japan, from July 2014 to February 2015 (Fig. 1). All subjects or their parents gave their written informed consent before participating in this study. The ethics committees of both Shinano Handicapped Children's Hospital (No. 25-3) and the Graduate School of Medicine, Shinshu University (No. 2772) approved this study.

All available volunteers for the study determined the sample size. The inclusion criteria consisted of subjects with diagnosis of CP and typically developed children from ages of 5 to 18 years old. Subjects with normal tone (TD children of staff members) consisted of 12 children (6 males, 6 females), mean age of 10.8 (± 4.3) years. Subjects with hypertonia consisted of 29 children with CP (12 males, 17 females) aged between 5 and 18 years, mean age of 13.1 (± 4.3) years. Subjects with CP were excluded if passive movement of the joint was not possible (e.g., MAS 4 where limb movement was not possible because of rigidity), or if they had lengthening surgery within 1 year (which may result in changes to the viscoelastic properties of the muscle-tendon unit), or if they were treated with Botulinum toxin (Type A) within the past 6 months (which may result in temporary changes in their muscle tone). In addition, they were excluded if they have uncontrolled epilepsy and if they were unable to tolerate getting into a prone position comfortably.

The same researcher (AM), with 9 years experience as a pediatric physical therapist, performed all measurements on the TD and CP subjects. For the assessment of the right plantarflexor muscle tone, the MAS (Bohannon Method) was used. Subjects were graded as "0" indicating no resistance to passive movement, and "1" to "3" according to their increased resistance to passive movement.

For the assessment of muscle-tendon length and ankle ROM, subjects were positioned in prone on a plinth with their feet hanging off the edge (Fig. 2). Measurements were performed twice: initially at rest position (without tension), and after the application of a 5-kg tension force (Fig. 3). With the ankle at rest, the angle of the right ankle joint was measured with a goniometer (neutral position was the ankle joint in anatomical position, positive values were for plantarflexion and negative values were for dorsiflexion). The right medial gastrocnemius (MG) muscle belly and tendon lengths were measured using the Venue 40 ultrasound-imaging device (GE Healthcare, Milwaukee, Wisconsin 53201, USA) with a 12L-SC linear array transducer (4–13 MHz) in B-mode as follows: (1) the MG musculotendinous junction (MTJ), the distal tendon insertion point (TIP) at the calcaneus and the proximal muscle insertion point at the medial femoral condyle were identified using the ultrasound imaging device and marked on the skin surface with an anatomical marker; (2) using a tape measure, the MG muscle length was measured from the MTJ to the medial femoral condyle, and the MG tendon length was measured from the MTJ to the TIP (Fig. 2). Next, a 5-kg tension force, using a spring scale, was applied to the foot via a strap in the direction of ankle dorsiflexion (Fig. 3). The angle of the ankle joint in this position was measured with a goniometer, and the MG muscle and tendon lengths were measured in the same manner as described above.

According to Portney and Watkins[21], "…the construct validity of a test could be evaluated in terms of how its measures relate to other tests of the same and different constructs" (p77) and "this determination is based on the concepts of convergence and discrimination" (p77). Convergent validity is defined as how "two measures believed to reflect the same underlying phenomenon will yield similar results or will correlate highly" (p77). Therefore, the use of correlational analysis was chosen to evaluate the convergent validity of muscle-tendon length and ROM changes with resistance to passive movement (as indicated by the MAS scores). Discriminant validity is defined as "different results are expected from measures that are believed to assess different characteristics" (p78), and this can be assessed by "analyzing the statistical difference between the two (*or more*) groups" (p77). Therefore, in order to evaluate if we could discriminate between normal, low, moderate and high resistance to passive movement (as indicated by the MAS scores) we used ANOVA to analyze the statistical difference among the four characteristics.

Data analysis was carried out on all 29 subjects with CP and 12 TD children. The four predictor variables were based on the calculated differences between 5-kg tension and rest positions of the ankle for the following: (1) Δnormalized muscle length; (2) Δnormalized tendon length; (3) Δ muscle-tendon unit length; (4) Δankle ROM. Normalization of muscle and tendon lengths was performed by dividing with the muscle-tendon unit length at rest. The criterion variable was resistance to passive movement based on the MAS 6-point ordinal scale. However, due to the fact that none of the subjects recruited were

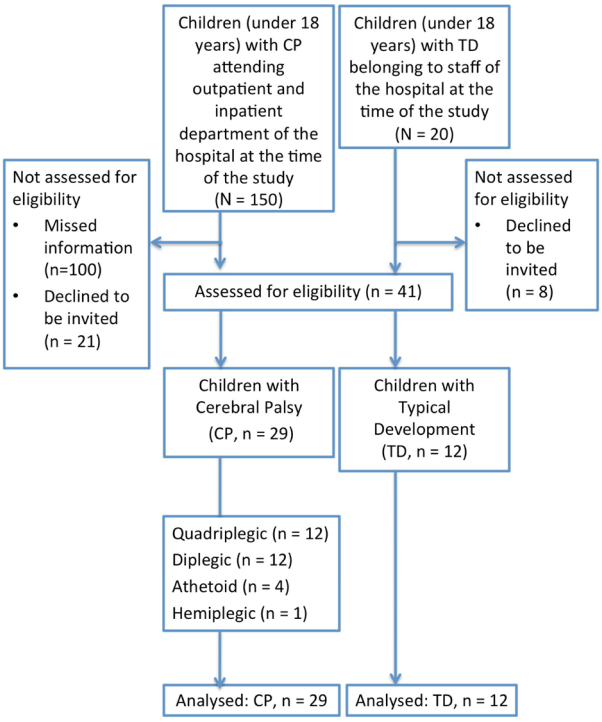

Fig. 1. Flow-chart for subject recruitment and analysis

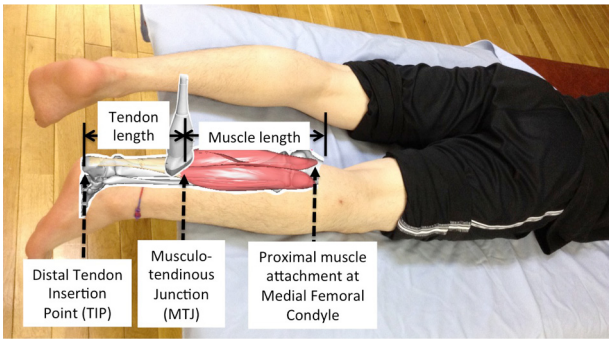

Fig. 2. Measurement of muscle length, tendon length and ROM in the resting position of the ankle

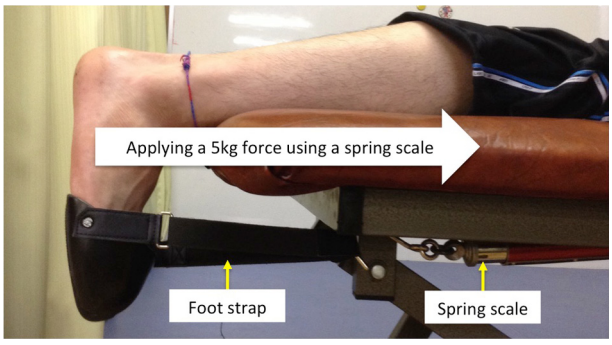

Fig. 3. Application of a 5-kg tension force in the direction of dorsiflexion

Table 1. Subjects' characteristics

Characteristics	TD	CP (MAS 1+)	CP (MAS 2)	CP (MAS 3)
n	12	4	8	17
Gender, female, n	6	0	6	11
Age (yrs), X (SD)	10.8 (4.3)	10.9 (4.6)	11.2 (4.9)	14.5 (3.5)
Body weight (kg), X (SD)	33.9 (14.3)	20.8 (2.6)	29.3 (9.2)	38.8 (11.4)
Height (cm), X (SD)	139.0 (21.8)	121.0 (17.0)	128.1 (14.2)	143.3 (16.8)

graded as "MAS 1", and "MAS 4" was intentionally excluded from the study, this was reduced to a 4-point ordinal scale for resistance to passive movement as follows: "MAS 0" for "normal resistance", "MAS 1+" for "low resistance", "MAS 2" for "medium resistance", and "MAS 3" for "high resistance". An additional analysis was performed based on a 3-point ordinal scale as recommended by Pandyan et al.[13] i.e., "MAS 0" for "normal resistance", "combined MAS 1+ and 2" for "combined low resistance" and "MAS 3" for "high resistance". The Shapiro-Wilk test of normality was carried out to check the distribution of the four predictor variables and the appropriate descriptive statistics were calculated for all variables. Convergent validity was assessed using the Spearman's correlation coefficient, and discriminant validity was assessed using the one-way ANOVA with a Tukey's post-hoc test. All statistical analyses were carried out using IBM SPSS version 22.0 (IBM Corporation, Armonk, NY, USA). The level of significance was set at $p<0.05$.

RESULTS

The subject characteristics for children with CP (n=29) and TD (n=12) are shown in Table 1. Children with CP were further subdivided into their respective MAS scores (MAS 1+, n=4; MAS 2, n=8; MAS 3, n=17). There was no statistically significant difference in age, body weight and height between TD and CP subjects. The Shapiro-Wilk tests showed that all four predictor variables were normally distributed and their means, SDs and 95% CI of the mean (upper and lower limits)

Table 2. Descriptive statistics for (1) Δnormalized muscle length; (2) Δnormalized tendon length; (3) Δ muscle-tendon unit length; and (4) Δankle ROM according to resistance to passive movement (normal, low, medium, combined low, high)

Resistance to Passive Movement	(1) Δnormalized muscle length	(2) Δnormalized tendon length	(3) Δ muscle-tendon unit length (cm)	(4) Δankle ROM (degrees)
Normal (TD)				
X (SD)	0.048 (0.245)	0.003 (0.010)	0.051 (0.018)	27.2 (5.3)
95% CI Lower	0.033	−0.003	0.040	23.8
Upper	0.064	0.010	0.063	30.6
Low (MAS 1+)				
X (SD)	0.035 (0.036)	0.025 (0.053)	0.060 (0.040)	27.3 (7.8)
95% CI Lower	−0.022	−0.060	−0.005	15.0
Upper	0.093	0.110	0.124	39.5
Medium (MAS 2)				
X (SD)	0.049 (0.023)	0.015 (0.022)	0.064 (0.025)	31.0 (8.1)
95% CI Lower	0.029	−0.003	0.043	24.3
Upper	0.068	0.033	0.085	37.7
Combined Low (MAS 1+ and MAS 2)				
X (SD)	0.044 (0.027)	0.018 (0.033)	0.062 (0.029)	29.8 (7.8)
95% CI Lower	0.027	−0.003	0.044	24.8
Upper	0.061	0.040	0.081	34.7
High (MAS 3)				
X (SD)	0.030 (0.019)	0.007 (0.030)	0.038 (0.021)	18.1 (5.7)
95% CI Lower	0.020	−0.010	0.026	15.0
Upper	0.041	0.024	0.049	21.3

are shown in Table 2.

The correlational analysis was used to assess the convergent validity of the four predictor variables with MAS scores. Except for Δnormalized tendon length (ρ=−0.068, p=0.674), the Spearman's rho (ρ) between resistance to passive movement were significant for three out of the four predictor variables as follows: (1) Δnormalized muscle length (ρ=−0.314, p=0.045); (2) Δ muscle-tendon length (ρ=−0.374, p=0.016) and (3) Δankle ROM (ρ=−0.555, p<0.001). In other words, as tone or resistance to passive movement increased (from normal to high), Δnormalized muscle length, Δ muscle-tendon length and Δankle ROM decreased significantly. A separate analysis was performed with MAS1+ and 2 combined (i.e., reduced to 3-point ordinal scale), and the results were the same as for the 4-point MAS scores.

The one-way ANOVA analyses were used to assess the discriminant validity of the four predictor variables with MAS. Two separate analyses were performed on resistance to passive movement based on a 4-point and 3-point MAS ordinal scores. With regards to the 4-point MAS score analysis, the results showed that for Δ muscle-tendon length, there was a significant difference between high (MAS3) and medium resistance (MAS2) (p<0.05, 95%CI = 0.01 to 0.05). For Δankle ROM, there were significant differences between high (MAS3) and normal resistance (TD) (p<0.01, 95%CI = −16.43 to 3.43), between high (MAS3) and low resistance (MAS1+) (p<0.05, 95%CI = −19.60 to 0.43), and between high (MAS3) and medium resistance (MAS2) (p<0.001, 95%CI = −21.16 to 6.37). All other results were not significant.

With regards to the 3-point MAS score analysis, the results showed that for Δnormalized muscle length, there were significant differences between high (MAS3) and normal resistance (TD) (p<0.05, 95%CI = −0.00 to 0.04). For Δ muscle-tendon length, there was a significant difference between high (MAS3) and combined low resistance (combined MAS1+, 2) (p<0.05, 95%CI = 0.00 to 0.05). For Δankle ROM, there were significant differences between high (MAS3) and normal resistance (TD) (p<0.01, 95%CI = −15.82 to −4.04), between high (MAS3) and combined low resistance (combined MAS1+, 2) (p<0.01, 95%CI = −18.40 to −6.63). All other results were not significant.

DISCUSSION

In order to assess the convergent validity of the four predictor variables with MAS, a correlational analysis was performed. The results showed that Δnormalized tendon length was not significantly correlated with increased tone, i.e., as resistance to passive movement increased, normalized tendon length did not change. This can be attributed to the following reasons: (1) in comparison with muscle tissue, tendon tissues have a higher viscoelastic property, and (2) the 5-kg tension force did not exceed the threshold needed to cause lengthening of the tendon. Other studies have also reported similar results[19, 21]. In

contrast, the Δnormalized muscle length, as well as Δ muscle-tendon length, demonstrated a significant reduction in length change as resistance to passive movement increased. This was supported by a similar significant reduction in ROM change at the ankle joint. To our knowledge, no other studies have reported this relationship.

In order to assess the discriminant validity of the four predictor variables with MAS, a one-way ANOVA analysis was performed. The results showed that based on a 4-point MAS ordinal score, Δnormalized muscle-tendon length had limited value because it was only able to discriminate between high (MAS3) and moderate resistance (MAS2) to passive movement. On the other hand, Δankle ROM was able to discriminate between high (MAS3) and the other grades. However, Δankle ROM was not able to discriminate among medium (MAS2), low (MAS1+) and normal (TD). When MAS1+ and 2 were combined into a single grade as suggested by Pandyan[13], the results based on this 3-point MAS ordinal score showed that Δmuscle length and Δmuscle-tendon length were able to discriminate between high (MAS3) and normal (TD), and between high (MAS3) and combined low (combined MAS1+, 2) respectively. The results for Δankle ROM were similar for both the 4-point and 3-point MAS scores, i.e., Δankle ROM could discriminate between high (MAS3) and the other grades. To our knowledge, no other studies have reported these differences.

Therefore, the results showed that any of these three variables might be a reasonable quantitative substitute for MAS in a clinical situation to evaluate the effects of treatment on the patient (for within subject comparisons), and also in research (for between group comparisons). However, of these three variables, Δankle ROM had the highest construct (convergent and discriminant) validity and therefore, would be the most appropriate quantitative alternative to the MAS. Also, Δankle ROM can be easily and quickly measured with a standard goniometer and would be the most easily implemented. The next alternative to MAS would be muscle-tendon length changes, which can be measured with a tape measure, and if an ultrasound-imaging device were not readily available, by using palpation techniques to identify the appropriate anatomical landmarks. The discriminant validity of Δmuscle-tendon length measurements can be improved by using it together with Δmuscle length measurements. The least appropriate alternative to the MAS would be Δmuscle length measurements, since this would require access to an ultrasound-imaging device, and except for most research facilities and some clinical institutions, this may not be practical. Also, while the convergent validity for Δmuscle length was similar to Δmuscle-tendon length, its discriminant validity was not as good.

However, it is proposed that any or all of these three options would still be better than the MAS in the assessment of resistance to passive movement. While the MAS is the most commonly used method to assess increased muscle tone in children with CP, the qualitative nature of its 6-point ordinal scale is a major limiting factor in both clinical practice and research. Although grades “0” (no increase in tone) and “4” (rigid) may be easily and correctly identified, the intervening four other grades (1, 1+, 2, 3) are prone to errors in judgment and this has led to some researchers suggesting that they should be simplified to two grades by merging 1, 1+ and 2 into a single grade[13]. While this modification of the MAS from a 6-point to a 4-point ordinal scale may seem reasonable, it would create problems by decreasing its sensitivity. It is believed that any scale that compromises on its sensitivity may also lead to a reduction in its usefulness in both clinical practice and research, and therefore, this may not be a realistic solution. Instead, a quantitative measure of resistance to passive movement that requires no additional or custom-made equipment, and is quick and easy to implement, may be a better solution.

In this study, measurements of other muscle morphology/architecture variables, such as pennation angle, muscle width, and fascicle length were also measured. However, the results showed that these parameters had no significant correlations with MAS, and they were intentionally not reported for brevity.

Our study had three limitations. Firstly, with the patient in prone and the knee extended, the assessment of muscle tone in the plantarflexor muscles and ankle ROM were mostly due to the effects of the gastrocnemius muscle (both medial and lateral portions) rather than soleus. The measurement of the muscle-tendon unit length, however, was performed on the MG only. While we do not expect different results for the lateral gastrocnemius, this possibility cannot be ruled out. Secondly, with regards to the one-way ANOVA analysis for discriminant validity, the small sample sizes for grades MAS1+ (n=4) and MAS2 (n=8) may have contributed to a Type II error. Thirdly, the sensitivity of these tests could not be evaluated, as comparison with a gold standard was not carried out. In fact, it can be argued that a gold standard for measurement of muscle tone is severely lacking.

In conclusion, the results form this study demonstrated that measuring the change in the passive properties of the muscle-tendon unit (i.e., muscle length and muscle-tendon length changes), as well as the corresponding change in ROM, might provide a better option for assessing resistance to passive movement or tone. This quantitative assessment, when compared with the MAS, was shown to have reasonable construct (convergent and discriminant) validity. However, similar with the MAS, our quantitative assessment method would not be able to distinguish between the causes for the resistance to passive movement (i.e., spasticity, changes in passive properties of the muscle-tendon unit, or both). In this regard, measurements of changes in the passive properties of the muscle-tendon unit, together with electromyographic studies to assess spasticity, might be necessary to investigate the causes for the resistance to movement. In addition, further studies are also needed to examine the inter-rater and intra-rater reliability, as well as the sensitivity of our proposed quantitative method to assess tone in different patient populations.

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