The Root-Ely Modified Test of Rectus Femoris Spasticity Has Reliability in Individuals with Cerebral Palsy

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Received: 8 September 2017/Accepted: 26 February 2018/Published online: 26 March 2018
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Abstract *Background:* Stiff-knee gait is a common gait deviation in individuals with cerebral palsy (CP) due to rectus femoris (RF) muscle spasticity. The Duncan-Ely test is a velocity-dependent measurement of spasticity that is recorded as positive or negative. At our institution, we use a modification of the Duncan-Ely test, a 5-point ordinal rating scale, which delineates where the catch occurs within the rapid arc of knee flexion. It has been named the Root-Ely test. *Questions/Purposes:* We sought to determine the intra- and inter-rater reliability of the Duncan-Ely and Root-Ely tests in pediatric patients with CP. *Methods:* A convenience sample of 20 ambulatory subjects was recruited; mean age was 10.5 ± 4.5 years, and the Gross Motor Function Classification System (GMFCS) levels were I–III. Five clinicians measured each individual's RF spasticity using the Root-Ely protocol during a single visit. Simple κ statistics with 95% confidence intervals (CI) were utilized for intra-rater reliability and weighted κ statistics with 95% CI for inter-rater reliability. *Results:* The Root-Ely scale intra-rater reliability was 0.77 to 0.90 and inter-rater reliability was 0.32 to 0.87. Inter-rater reliability was good to excellent among experienced clinicians and fair to moderate in new clinicians. *Conclusion:* The Root-Ely 5-point scale has acceptable intra- and inter-rater reliability in pediatric individuals with CP among

experienced clinicians. The Root-Ely test allows experienced clinicians to reliably quantify severity of RF spasticity and may give orthopaedic surgeons a clinical tool to better predict ideal candidates for RF transfers in individuals with CP in order to improve stiff-knee gait.

Keywords Duncan-Ely test · Root-Ely test · rectus femoris spasticity · stiff-knee gait · cerebral palsy

Introduction

The presence of a stiff-knee gait in individuals with cerebral palsy (CP) is well documented and commonly due to rectus femoris (RF) muscle spasticity [4, 12]. A spastic RF muscle can result in delayed and diminished peak knee flexion, leading to poor clearance during the swing phase of gait [14]. Spasticity is defined as a motor disorder, specifically a velocity-dependent response to a phasic muscle stretch, which occurs due to an upper motor neuron injury [5]. The Duncan-Ely test is a velocity-dependent measurement used to assess RF muscle spasticity in individuals with CP, utilizing a positive/negative scoring system. To perform the Duncan-Ely test, the examiner rapidly flexes the knee while the patient is in the prone position. If the ipsilateral hip rises or resistance is felt by the examiner, it is recorded as positive test for RF muscle spasticity [1].

The gold standard to determine ideal candidates for successful rectus femoris transfer (RFT) is electromyography from gait analysis testing. However, it is an expensive test and not always available due to limited facilities nationwide. Therefore, a valid and reliable clinical test to determine which patients should be indicated for RFT is needed. The Duncan-Ely is the only clinical test utilized to measure RF spasticity, but a limitation of the Duncan-Ely test is that it is a binary (positive/negative) measure that does not indicate either the severity or the location of spasticity in the arc of knee flexion. It is hypothesized that more severe RF muscle

Level of Evidence: Diagnostic Study, Level III

Work performed at Hospital for Special Surgery

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11420-018-9609-5>) contains supplementary material, which is available to authorized users.

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spasticity would likely result in more severe stiff-knee gait, limiting swing-phase clearance and increasing individuals' risk for falls.

The Duncan-Ely test has been validated as a positive predictor of RF dysfunction during gait and has potential to identify ideal candidates with CP for RFT [9]. In a previous study, knee kinematics improved in the RFT group that had a positive Duncan-Ely result preoperatively and did not improve in the RFT group that had a negative Duncan-Ely result [6]. This study measured the knee arc of motion in which spasticity occurred and graded the spasticity utilizing the 5-point Modified Ashworth Scale (MAS); however, it did not determine if a higher MAS was associated with RFT outcomes or investigate the reliability of the Duncan-Ely test using the MAS [6].

There are several techniques described and used to detect and quantify muscle tone and spasticity; most common are the MAS and Tardieu scale. The MAS quantifies an individual's spasticity, tone, and resistance to a passive stretch, though the reliability varies, ranging from 0.25 to 0.83 interclass correlation coefficient (ICC) for intra-rater reliability [8–11] and 0.21 to 0.82 ICC for inter-rater reliability [2, 3, 10, 16]. Additionally, it is not specific to measuring the rectus femoris muscle. In fact, only one study assessed spasticity in the quadriceps muscle using the MAS, with results showing poor inter-rater reliability [2]. The Tardieu scale measures spasticity by performing a passive muscle stretch at a slow and fast velocity. The Tardieu scale has higher intra- and inter-rater reliability than the MAS, with best results when professionals were trained in the protocol [5, 16]. There is only one study that used a modification of the Tardieu scale in testing Duncan-Ely inter-rater reliability; it determined experienced clinicians using fast velocity achieved the best inter-rater reliability when measuring RF spasticity [8].

A positive Duncan-Ely test has also been associated with improved kinematics after RFT; therefore, it has been hypothesized that a gradation of the Duncan-Ely test may be a better predictor of kinematics and clinical outcomes. At our institution, we have developed a modification of the Duncan-Ely test, a 5-point ordinal rating scale, which reports where the resistance occurs within the arc of knee flexion. Anecdotally, this graded scale was utilized to help differentiate those who would benefit from RFT or RF release. This modification of the Duncan-Ely test was developed and used by Leon Root, MD, in his nearly 50-year career in treating

individuals with CP; therefore, it has been named the Root-Ely test.

The purpose of this study was to determine the intra- and inter-rater reliability of the Root-Ely test in pediatric individuals with CP.

Methods

A convenience sample of ambulatory participants between the ages of four and 18 years with a diagnosis of CP, Gross Motor Function Classification System (GMFCS) level I–III [13] and no history of prior RF surgery was recruited. Participants were tested in a single visit and were required to lie prone on an examination table comfortably with neutral hip extension and full knee flexion range of motion; individuals without full knee and/or hip flexion range of motion were excluded. Testing took place during regular pediatric orthopaedics appointments. Twenty subjects and parents consented, including adolescent assent, to participate in this institutional review board-approved study. A total of 20 subjects ($n=40$ limbs) were included with a mean age of 10.5 ± 4.5 years. Of the 20 subjects, 15 were rated by all five testers and five were rated by only four of the five due to clinician availability.

All five raters were educated on how to perform the Root-Ely test and were provided with a written copy of the scoring system during each subject testing (Table 1). Testing occurred on both lower extremities and included individuals with diplegia and hemiplegia. Intra-rater reliability of the Root-Ely test was determined using the scores of two raters, both experienced physical therapists (PT), with the first and second test repeated at least 30 minutes apart. Inter-rater reliability was investigated by assessing the scores of five separate raters (three PTs and two orthopaedic surgeons). Three raters were classified as experienced with more than 8 years, and two were classified as new clinicians with less than 5 years of experience working with children with CP. Testing occurred once with each subject during a single visit, with at least 5 minutes of rest between rater testing.

Subjects were instructed to relax legs completely while lying in the prone position on the exam table. Rectus femoris muscle spasticity was tested with one hand on the subject's posterior pelvis and the other at the distal tibia. Each rater flexed the knee slowly through the full arc of motion and then flexed the knee rapidly, similar to what is described as an R1 velocity-dependent catch using the Tardieu spasticity scale [5]. The angle of knee flexion where the ipsilateral hip rose and/or where resistance was first felt through the arc of motion was recorded using a goniometer (Fig. 1). The angle was then documented using the Root-Ely test 5-point scale as outlined in Table 1.

Root-Ely score was collected for each subject by the available clinicians. The Duncan-Ely score was recorded as positive when a subject scored 1–4+ and negative when scored 0 on the Root-Ely scale. Intra- and inter-rater agreement for the Root-Ely was assessed with weighted κ statistics and 95% confidence interval (CI) [15]. Intra- and inter-

Table 1 Root-Ely Test scoring scale

Score 4+	0–29° of knee flexion at first catch and/or pelvic elevation
Score 3+	30–59° of knee flexion at first catch and/or pelvic elevation
Score 2+	60–89° of knee flexion at first catch and/or pelvic elevation
Score 1+	≥ 90° of knee flexion at first catch and/or pelvic elevation
Score 0 (negative)	No catch or pelvis rising off table with full knee flexion

Fig. 1. Angle of knee flexion [8].

rater agreement for the Duncan-Ely test was assessed with simple κ statistics and 95% CI. Analyses were performed with SAS 9.3 (Cary, NC, USA). Based on definitions from Landis and Koch [7], the reliability measurement of observer agreement for categorical data is 0.81–1.00, excellent; 0.61–0.80, good; 0.41–0.60, moderate; 0.21–0.40, fair; and less than 0.20, poor. A total of 42 limbs provides 90% power to detect a κ of at least 0.5 with a two-sided level of significance of 0.05 [15].

Results

Twenty subjects ($n = 40$ limbs) with mean age of 10.5 ± 4.5 years participated. Subject demographics included eight females and 12 males, 35% GMFCS level I, 30% GMFCS level II, and 35% GMFCS level III. The highest Root-Ely

test intra-rater reliability was 0.90 (0.81, 0.98) and the lowest was 0.77 (0.62, 0.92) (Table 2). The highest inter-rater reliability for the Root-Ely test was 0.86 (0.76, 0.97) and the lowest 0.32 (0.09, 0.54) (Table 3). The inter-rater reliability of the Root-Ely test was good to excellent when measuring RF spasticity among experienced clinicians and fair to moderate when comparing new clinicians to both experienced and other new clinicians.

The Duncan-Ely (positive/negative) intra-rater reliability ranged from 0.81 (0.63, 0.99) to 0.91 (0.78, 1.00) (Table 2), while the inter-rater reliability ranged from 0.03 (−0.22, 0.28) to 0.79 (0.60, 0.98) (Table 4). Overall, the Duncan-Ely test inter-rater reliability was moderate to good when comparing experienced clinicians to each other and poor to fair when comparing new clinicians to both experienced and other new clinicians. All participants were comfortable throughout testing and completed the full testing procedure.

Table 2 Intra-rater reliability of Root-Ely and Duncan-Ely tests

Rater ^a	Root-Ely Simple κ (95% CI)	Agreement ^b	Duncan-Ely Simple κ (95% CI)	Agreement ^b
1	0.90 (0.81, 0.98)	Excellent	0.91 (0.78, 1.00)	Excellent
2	0.77 (0.62, 0.92)	Good	0.81 (0.63, 0.99)	Good

^a Raters 1, 2 classified as experienced clinicians

^b Based on definitions from Landis and Koch [7]

Table 3 Inter-rater reliability of Root-Ely test

Raters ^a	Weighted κ (95% CI)	Agreement ^b
1 vs. 3	0.86 (0.76, 0.97)	Excellent
2 vs. 3	0.65 (0.46, 0.84)	Good
1 vs. 2	0.64 (0.46, 0.81)	Good
1 vs. 4	0.62 (0.44, 0.81)	Good
4 vs. 3	0.56 (0.36, 0.76)	Moderate
2 vs. 4	0.55 (0.35, 0.75)	Moderate
3 vs. 5	0.52 (0.29, 0.75)	Moderate
2 vs. 5	0.50 (0.26, 0.74)	Moderate
1 vs. 5	0.47 (0.24, 0.70)	Moderate
4 vs. 5	0.32 (0.09, 0.54)	Fair

^a Raters 1, 2, 3 classified as experienced clinicians and raters; 4, 5 classified as new clinicians

^b Based on definitions from Landis and Koch [7]

Discussion

The goal of this study was to evaluate the intra- and inter-rater reliability of the Root-Ely and Duncan-Ely tests for RF spasticity. Both the Root-Ely and Duncan-Ely tests showed excellent intra-rater reliability; this is the first study to report intra-rater reliability on the Duncan-Ely test. The Root-Ely test was found to have good-to-excellent intra- and inter-rater reliability for experienced clinicians and fair-to-moderate for new clinicians. Inter-rater reliability for the Duncan-Ely was moderate to good among experienced clinicians and poor to fair among new clinicians. As expected, the 5-point ordinal Root-Ely scale is more reliable in raters with experience.

Limitations of this study include its relatively small sample size of 20 subjects, resulting in wide 95% CIs. All raters were instructed to measure RF spasticity by rapidly flexing the knee; however, the velocity that each clinician selected was not measured. Variations in technique may have resulted in clinicians measuring RF spasticity catches at different points. While spasticity is a manifestation of a brain injury and velocity dependent, it should not be affected by six raters measuring each limb in a short time period. However, there may have been a learned effect by the children, which is difficult to control and a limitation of any reliability study.

Table 4 Inter-rater reliability of the Duncan-Ely test

Raters ^a	Simple κ (95% CI)	Agreement ^b
1 vs. 3	0.79 (0.60, 0.98)	Good
2 vs. 3	0.57 (0.32, 0.82)	Moderate
1 vs. 2	0.53 (0.26, 0.80)	Moderate
2 vs. 3	0.52 (0.25, 0.80)	Moderate
1 vs. 4	0.36 (0.05, 0.68)	Fair
1 vs. 5	0.25 (−0.06, 0.56)	Fair
2 vs. 4	0.29 (0.01, 0.58)	Fair
2 vs. 5	0.29 (−0.02, 0.61)	Fair
4 vs. 3	0.39 (0.09, 0.68)	Fair
4 vs. 5	0.03 (−0.22, 0.28)	Poor

^a Raters 1, 2, 3 classified as experienced clinicians and raters; 4, 5 classified as new clinicians

^b Based on definitions from Landis and Koch [7]

The Root-Ely test categorizes RF spasticity by severity, instead of a simple binary outcome as demonstrated by the Duncan-Ely test. The reliability was improved with the 5-point Root-Ely scale among both experienced and new clinicians. The Duncan-Ely is a valid measure that has been shown to be a positive predictor for RF spasticity, as well as a helpful predictor of optimal outcomes in children having RFT surgery in order to improve stiff-knee gait [6, 9]. Future research needs to validate the Root-Ely test to gait kinematics to confirm its utility in assisting in predicting ideal candidates for RFT, similar to Duncan-Ely validation based on gait analysis.

This study also confirms previous findings that the inter-rater reliability is best when performed at high velocity by experienced clinicians, as Lee et al. reported at 0.82 [8]. We similarly found best intra- (0.90) and inter-rater (0.86) reliability for the Root-Ely 5-point scale among experienced clinicians. Measuring spasticity is inherently difficult to quantify; therefore, it is not surprising that clinician experience and training helps improve the test reliability. Therefore, we recommended clinicians be trained and practice measuring spasticity before utilizing the Root-Ely as a tool to predict candidates for RFT surgery in addition to a full clinical exam and observational and/or gait analysis.

Future research should validate the Root-Ely 5-point scale using gait analysis to determine if it is associated with improved treatment outcomes for stiff-knee gait (swing-phase peak knee flexion following RFT) and whether it outperforms the Duncan-Ely test for this purpose [6, 9]. We hypothesize that the Root-Ely test will allow more detailed stratification for those undergoing RFT, such that we may be able to provide an estimate for knee range of motion improvement for each Root-Ely level. Ultimately, this may help surgeons, who do not have access to a gait-analysis lab, to better predict which individuals with CP will benefit from RFT.

In conclusion, there is acceptable intra- and inter-rater reliability in experienced clinicians for the Root-Ely test as a measure of RF spasticity on a 5-point scale. Assuming future research shows that categorization of RF spasticity is valid, the Root-Ely test has potential to assist experienced orthopaedic surgeons as a clinical test used in identifying ideal candidates for RFT with the goal of improving swing-phase knee flexion during gait in individuals with CP.

Acknowledgements The authors acknowledge Leon Root, MD (1929–2015), for providing exceptional care to his patients and for generously sharing his time and knowledge with his colleagues. He was and continues to be an inspiration to all. Thank you to all patients and families who volunteered to participate in this study.

Compliance with Ethical Standards

Conflict of Interest: Lisa C. Drefus, PT, DPT, Siobhan Clarke, PT, DPT, Karen Resnik, PT, DPT, Jayme Koltsov, PhD, Emily R. Dodwell, MD, David M. Scher, MD declare that they have no conflicts of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: Informed consent was obtained from all patients for being included in this study.

Required Author Forms: Disclosure forms provided by the authors are available with the online version of this article.

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