J Rehabil Med 2013; 45: 541–545

ORIGINAL REPORT

ANKLE DORSIFLEXION, NOT PLANTARFLEXION STRENGTH, PREDICTS THE FUNCTIONAL MOBILITY OF PEOPLE WITH SPASTIC HEMIPLEGIA

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Objective: **To determine the relationships between affected ankle dorsiflexion strength, other ankle muscle strength measurements, plantarflexor spasticity, and Timed "Up & Go" (TUG) times in people with spastic hemiplegia after stroke.**
Design: **A cross-sectional study.**
Setting: **A university-based rehabilitation centre.**
Participants: **Seventy-three subjects with spastic hemiplegia.**
Main outcome measures: **Functional mobility was assessed using TUG times. Plantarflexor spasticity was measured using the Composite Spasticity Scale. Affected and unaffected ankle dorsiflexion and plantarflexion strength were recorded using a load-cell mounted on a foot support with the knee bent at 50º and subjects in supine lying.**
Results: **TUG times demonstrated strong negative correlation with affected ankle dorsiflexion strength (r = –0.67, $p \leq 0.001$) and weak negative correlations with other ankle muscle strength measurements (r = –0.28 to –0.31, $p \leq 0.05$), but no significant correlation with plantarflexor spasticity. A linear regression model showed that affected ankle dorsiflexion strength was independently associated with TUG times and accounted for 27.5% of the variance. The whole model explained 47.5% of the variance in TUG times.**
Conclusion: **Affected ankle dorsiflexion strength is a crucial component in determining the TUG performance, which is thought to reflect functional mobility in subjects with spastic hemiplegia.**

Key words: stroke; ankles; walking; functional mobility; rehabilitation.

J Rehabil Med 2013; 45: 541–545

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Accepted Jan 17, 2013; Epub ahead of print May 24, 2013

INTRODUCTION

Difficulties in performing sequential motor tasks that are important for functional mobility, including standing up from sitting, walking and turning, have been systematically documented in patients with chronic stroke (1, 2). In order to promote independence in the activities of daily living and community participation, a major aim of stroke rehabilitation is to maximize functional mobility. Consequently, clinicians need to identify the major determinants of functional mobility in stroke survivors.

The Timed "Up & Go" (TUG) test was initially introduced by Podsiadlo & Richardson (3) as a simple measure of functional mobility. These investigators used the term "functional mobility" to reflect the balance and gait manoeuvres used in everyday life, such as getting in and out of a chair, walking, and turning. The TUG test requires subjects to perform a sequential task involving standing up from a chair, walking 3 m forward, turning 180º, returning, and sitting down again (3). The time taken to complete the task is measured in seconds. Our previous study (1) showed that the TUG test had excellent reliability, with intraclass correlation coefficients (ICCs) ranging from 0.95 to 0.96 in subjects with chronic stroke (cf. also 4). Moreover, TUG times have been found to correlate with the strength of affected ankle dorsiflexors (1), gait speed (r = –0.55), Berg Balance Scale score (r = –0.72), and Barthel Activities of Daily Living Index (r = – 0.51) (3). In addition, TUG times had proven to be clinically sensitive for detecting changes, with a 9% change in TUG time showing a sensitivity of 93% for detecting clinically relevant changes in a study of 85 frail elderly subjects (5). TUG times are now widely used as a measure of functional mobility for subjects with both acute (6, 7) and chronic stroke (8, 9).

The ankle plantarflexors are known to generate most of the energy required in walking after stroke (10, 11). Decreased ankle dorsiflexion strength is commonly observed in hemiparetic gait (12), and its underlying causes appear to be multi-factorial. While a reduction in descending voluntary commands to the paretic dorsiflexors (tibialis anterior) could be an underlying cause, spastic ankle plantarflexors might also act as an active restraint limiting ankle dorsiflexion (13). However, neither the role of affected ankle dorsiflexors, nor the relationships between affected and unaffected ankle dorsiflexion and plantarflexion strength, and TUG performance has been clearly delineated in stroke survivors with spastic plantarflexors.

The first objective of this study was to quantify the relationships among affected and unaffected ankle dorsiflexion and plantarflexion strength, plantarflexor spasticity, and TUG times. The second objective was to determine the relative contribution of affected ankle dorsiflexion strength to TUG times in subjects with spastic hemiplegia.

 doi: 10.2340/16501977-1154

 ISSN 1650-1977

METHODS

Participants

Subjects with chronic stroke were recruited through a community rehabilitation network and local self-help groups. Subjects were recruited if they were 50 years of age or older; had had a single stroke at least 12 months previously; had spastic ankle plantarflexors with a Composite Spasticity Score > 10 (14, 15) and at least 10º of passive ankle dorsiflexion; were able to walk 10 m independently with or without a cane or quadripod but without any ankle-foot orthosis (AFO); and had an Abbreviated Mental Test score of 7 or higher (16). Subjects were excluded if they had displayed any medical comorbidity, receptive dysphasia, or had received any orthopaedic, medical, or neurological diagnosis other than stroke that would hinder proper assessment.

The study was approved by the ethics committee of the local institution and was conducted in accordance with the Declaration of Helsinki of 1975 as amended in 1983. All subjects gave their written informed consent prior to entering the study.

Outcome measurements

All outcome measurements were performed in a random order by the same investigator (SN). All measurement protocols had been tested for their reproducibility in our pilot study on subjects with chronic stroke, with ICCs ranging from 0.80 to 0.98 (1).

Spasticity of affected ankle plantarflexors. Ankle plantarflexor spasticity was measured using the Composite Spasticity Scale (CSS) (14). The CSS had been shown to be reliable and valid in assessing plantarflexor spasticity after stroke (1, 17). It is an ordinal scale based on clinical evaluation of Achilles tendon jerks, resistance to passive ankle dorsiflexion, which is doubly weighted, and the amount and duration of ankle clonus (14, 15). A 4-point scale was used to assess clonus, and a 5-point scale for rating the other components. A total score of 1–6 represents "no spasticity," 7–9 "mild spasticity," 10–12 "moderate spasticity," and 13–16 "severe spasticity" (15).

Strength of affected ankle muscles. Ankle dorsiflexion and plantarflexion strength during maximum isometric voluntary contraction (MIVC) was measured using a load cell mounted on a foot frame (1). Subjects lay supine with the knees fixed at 50º of flexion, and the ankle held in a neutral position on the foot frame by Velcro straps. Three maximum contraction trials were performed for each muscle. The trial that produced the highest torque was selected for further statistical analyses. The highest torque produced was thought to represent the subjects' maximal ability, as marked variability in the levels of peak torque generated had been found in stroke subjects (18). Moreover, in our previous study on subjects with chronic stroke (1), excellent reliability with ICCs ranging from 0.85 to 0.98, was found in the highest torque produced during MIVC of ankle dorsiflexors and plantarflexors.

Functional mobility. Functional mobility was measured using the TUG test (3). Each subject was required to stand up from a chair with armrests, walk 3 m forward, turn around, return to the chair, and sit down using their usual walking aids, without any AFO. The time taken to complete this task was measured in seconds with a stopwatch. The mean of 3 trials was used for analysis.

Statistical analysis

Descriptive statistics summarizing the subjects' demographic characteristics and all the outcome measurements are presented in Table I. The Kolmogorov-Smirnov test was used to assess the normality of the distributions in the test score. As the data were normally distributed, Pearson correlation coefficients were used to describe the relationship of the TUG times with the other variables.

After accounting for demographic factors such as age and body mass index (BMI), and plantarflexor spasticity, the contribution of affected and unaffected ankle dorsiflexion and plantarflexion strength (the independent variables) to the TUG times recorded (the dependent variable) was determined by multiple linear regression with the "enter" method. All the statistical analyses employed version 17.0 of the Statistical Package for the Social Sciences software (SPSS, Chicago, IL). A significance level of 0.05 (two-tailed) was assumed.

Table I. *Characteristics of the subjects (*n = *73)*

Characteristics	%
Age, years, mean (SD)	57.16 (7.91)
Gender, *n* (%)	
Male	60 (82.2)
Female	13 (17.8)
Hemiplegic side, number (%)	
Left	45 (61.6)
Right	28 (38.4)
Body mass index (kgm^{-2}), mean (SD)	24.87 (3.17)
Years since stroke, year, mean (SD)	5.21 (3.63)
Affected plantarflexor spasticity (CSS score), mean (SD)	12.05 (1.68)
Abbreviated Mental Test score, mean (SD)	9.22 (1.04)
Use of walking aids, *n* (%)	
Cane	26 (35.6)
Quadripod	25 (34.3)
Unaided	22 (30.1)
Peak dorsiflexion torque, Nm, mean (SD)	
Unaffected	23.82 (6.97)
Affected	14.67 (7.01)
Peak plantarflexion torque, Nm, mean (SD)	
Unaffected	29.74 (4.64)
Affected	19.95 (7.30)
Timed Up and Go test time, s, mean (SD)	27.41 (17.63)

SD: standard deviation.

RESULTS

A total of 73 subjects with spastic hemiplegia (60 males and 13 females), with mean age of 57.16 years (standard deviation (SD) 7.91), and a mean post-stroke duration of 5.12 years (SD 3.63) participated in the study. The mean TUG time was 27.41 s (SD 17.63) (Table I).

Ankle strength and Timed "Up & Go" times

The subjects' TUG times showed the strongest (negative) correlation with affected ankle dorsiflexion strength ($r = –0.67$, $p < 0.0001$) (Table II). Significant, but weaker, negative correlations were also found between TUG times and unaffected ankle dorsiflexion strength ($r = –0.31$, $p < 0.01$), as well plantarflexion strength in both affected and unaffected ankles ($r = –0.37$ and $–0.28$, respectively, $p < 0.05$).

After controlling for demographic variables such as age and BMI, and plantarflexor spasticity, linear regression modelling showed that affected ankle dorsiflexion strength remained independently associated with TUG times, accounting for 27.5% of the variance (Table III). Adding the affected ankle dorsiflexion strength significantly improved the models' predictions ($F[1,65] = 37.63$, $p < 0.0001$). The whole model could explain 47.5% of the variance in TUG times (Table III).

Among all the variables, affected ankle dorsiflexion strength was the best predictor of TUG times, as reflected by the magnitude of the standardized regression coefficient ($\beta = –6.13$;

Table II. *Pearson correlation coefficients between Timed "Up and Go" test (TUG) times and other variables* n=73

Variables	Pearson correlation coefficient	*p*-value
Age	0.16	0.183
BMI	–0.14	0.246
Years since stroke	0.10	0.427
AMT scores	0.05	0.698
Plantarflexor spasticity (CSS scores)	–0.01	0.942
Peak dorsiflexor torque		
Affected	–0.67	0.000*
Unaffected	–0.31	0.007*
Peak plantarflexor torque		
Affected	–0.37	0.001*
Unaffected	–0.28	0.016*

*Significant at the 1% level of confidence.
BMI: body mass index; AMT: Abbreviated Mental Test; CSS: Composite Spasticity Scale; TUG: Timed "Up & Go" Test.

Table III). Furthermore, it had the highest Pearson correlation coefficient ($r=-0.67$, $p<0.001$) with TUG times (Table II).

DISCUSSION

Our findings are consistent with the emerging body of results highlighting the contribution of ankle dorsiflexion strength to gait performance in subjects with stroke (12, 19, 20). In addition to being the most important factor determining walking speed, gait symmetry (12) and walking endurance (20), the present study showed that affected ankle dorsiflexion strength is also an independent determinant of functional mobility measured with TUG times, accounting for 27.5% of the variance in TUG results.

Weakness in ankle muscles and increased Timed "Uo & Go" times

The mean TUG times of the hemiplegic subjects in this study (27.41 s (SD 17.63)) were consistent with previous reports (1, 8). However, they were somewhat faster than those of subjects with acute stroke (6, 7) and sub-acute stroke (21). The discrepancies in the results might be due to differences in certain demographic data, such as age and time after stroke. While the level of physical performance is known to be lower in older adults, functional abilities are known to be poorer in subjects with acute stroke (22).

Table III. *Multiple linear regression analyses (Enter method) using Timed "Up & Go" Test (TUG) times as the dependent variable*

Independent variables	$R^2(R^2_{adj})$	R^2 change	β	*p*-value
Regression Model	0.526 (0.475)	0.275		
Age			1.21	0.232
BMI			–0.35	0.731
CSS scores			–0.35	0.730
Peak DF torque (unaffected)			0.04	0.971
Peak PF torque (unaffected)			–1.95	0.055
Peak PF torque (affected)			–1.39	0.170
Peak DF torque (affected)			–6.13	0.000*

*Significant at the 0.1% level of confidence.
B: standardized regression coefficient; BMI: body mass index; CSS: Composite Spasticity Scale; DF: dorsiflexion; PF: plantarflexion.

Previous studies had investigated the cut-off TUG times for distinguishing healthy and subjects with diseases (3, 23, 24). Podsiadlo & Richardson (3) demonstrated that elderly people with TUG times < 20 s were independent in the transfer tasks needed for daily activities, while those having TUG times > 30 s were probably dependent in daily activities and required assistive devices for ambulation. Interestingly, 29 of our 73 subject (39.7%) had TUG times < 20 s, suggesting that they were probably independent in performing transfer tasks and capable of participating in community activities. A total of 27 of our subjects (37%) had times > 30 s, reflecting functional limitations and dependence in some of the activities of daily living. Indeed, 51 of the subjects (69.8%) in our study used canes or quadripods in the TUG tests.

With 413 community-dwelling and 78 institutionalized mobile elderly women, Bischoff et al. (23) identified that those community-dwelling elderly persons with TUG times > 12 s were probably mobility impaired and should receive early evaluation and perhaps intervention. Shumway-Cook et al. (24) had previously shown that TUG times > 13.5 s could predict falling in 15 elderly persons with no history and 15 others with a history of 2 or more falls in the previous 6 months. If the same cut-off times were applied to the subjects in this study, 78.1% of them might have been at high risk of falling. However, further verification of these cut-off times in people with stroke is warranted.

Allet and colleagues (25) investigated the effects of walking aids on walking endurance. Stroke survivors were found to cover longer distances in the 6-min walk test (6MWT) when using a simple cane with an ergonomic handgrip than when using a 4-point cane or a Nordic stick. AFOs are commonly used by subjects with spastic plantarflexors to clear the foot off the ground during the forward swing of the affected leg. Indeed, use of an AFO had been found to improve gait velocity (26, 27) and to reduce the energy cost of walking (26) in people with stroke. Interestingly, Lairamore's group (28) had demonstrated that subjects with stroke exhibit significantly less electromyographic activity in the tibialis anterior muscle during the swing phase of gait when they used an AFO. Since no subjects used AFOs in our current study, investigation of whether AFOs affect TUG times could not have been done. This topic warrants further investigation.

Muscle weakness, including weakness of the affected ankle dorsiflexors and plantarflexors, is common following stroke. It could be attributed to physiological changes in motor systems, including failure in motor unit recruitment and reduced firing frequency of agonist motor neurones or units (29). Localized adaptation of paretic muscle fibres (30) and increased co-contraction of the antagonists during movement of the paretic leg (13) are probably also involved. Moreover, spasticity in the ankle plantarflexors might impede their ability to generate appropriate muscle force as agonists during ankle plantarflexion. It could also act as an active restraint during ankle dorsiflexion

(13). As a result, the ankle dorsiflexion and/or plantarflexion force generated may decrease. Furthermore, disuse atrophy following stroke (31) and age-related decline in muscle strength might also explain reduced ankle muscle strength (32).

Correlations with Timed "Up & Go" times

Consistent with the findings of previous studies (12, 20), the results of the multiple linear regression analyses demonstrated that affected ankle dorsiflexion strength was the most potent predictor of TUG times in patients with stroke (Table III). Lin and his colleagues (12) had previously shown that affected ankle dorsiflexion strength explained 30% of the variance in the walking velocity of subjects with stroke, while Ng & Hui-Chan (20) had demonstrated that affected ankle dorsiflexion strength could independently explain 48.8% of the variance in the distance covered in the 6MWT.

The TUG test comprises a series of motor tasks, including rising from a chair, walking forward and turning, then walking back and sitting down. Affected ankle dorsiflexion strength was known to be significantly correlated with timed sit-to-stand test results (33) and walking speed (12) in subjects with stroke. Rising from a chair involves initiating horizontal acceleration and deceleration, followed by vertical acceleration and deceleration (34). Strength of the ankle dorsiflexors and hip flexors had been shown to be essential during the horizontal phase when the body's centre of mass shifts forwards from the buttocks to the feet (35). Both ankle dorsiflexors and plantarflexors had also been found to stabilize the body once upright, maintaining postural stability and balance in standing (35, 36). Weakness in ankle dorsiflexors might also cause difficulties in foot clearance during the swing phase, and insufficient eccentric contraction during the weight-acceptance phase just following heel-strike. This could lead to decreased single-leg support time and increased swing time of the affected leg (19), thus reducing walking speed and increasing TUG times.

It is rather surprising that affected ankle plantarflexion strength was relatively less potent in predicting TUG times than affected ankle dorsiflexion strength, as reflected by its smaller standardized regression coefficient (Table III). Several previous studies had shown that strength of affected ankle plantarflexors correlated significantly with gait velocity (1, 10, 11, 37). There are several reasons that might explain the discrepancies in the results of these studies. In the first place, the demographics of the subjects were different. All the subjects in this study had moderate to severe plantarflexor spasticity (CSS scores: 12.1 (SD 1.7)), and 51 subjects walked with canes or quadripods (although without AFOs) during the TUG test. In contrast, subjects in the other studies (10, 11, 37) had only mild or no plantarflexor spasticity, or they might have used an AFO during testing (1). Consequently, the affected ankle dorsiflexors of the subjects in this study were expected to work harder, in order to overcome the relatively greater plantarflexor spasticity and clear the foot off the ground. In addition, the methodology in measuring ankle strength was different in the different studies. In this study, it was measured by a load cell with the knee flexed to 50º with the subject lying supine. But in at least one other study (37), it was measured using a hand-held dynamometer with the subject sitting, where the effect of gravity might have affected the muscle strength recorded.

Consistent with the results of our previous study (1), plantarflexor spasticity did not correlate significantly with TUG times (Table II). Other studies have found, however, that plantarflexor spasticity was an important determinant of walking performance after stroke (38–40). Such discrepancies might be due to different methods or scales being used to quantify ankle plantarflexor spasticity in the different studies. This study used the Composite Spasticity Scale, while others used a modified Ashworth Scale or other scales (38–40). In addition, different severity of ankle plantarflexor spasticity among the subjects in the different studies might have affected the control of their affected ankle during walking.

The CSS (14) was used for measuring plantarflexor spasticity in our subjects with stroke. In a review, Pandyan et al. (41) concluded that both the Ashworth Scale and Modified Ashworth Scale (MAS) could be used as measures of resistance to passive movement, but not as ordinal measures of spasticity level, which should include tonic and phasic stretch reflexes and clonus (42). Moreover, both the Ashworth Scale and MAS had shown good reliability in measuring spasticity in the upper extremities only, but not in the lower extremities, especially plantarflexor spasticity (41, 43).

Several limitations of this study should be borne in mind. First, the quality of performance in the TUG test was overlooked, with speed being the main focus. Secondly, approximately half of the variance in the TUG times could not be explained by the variables included in the regression models. The TUG test consists of a series of motor tasks, so its performance has other determinants, such as joint proprioception and balance performance, which were not measured in this study. Thirdly, our results should not be generalized to subjects with stroke at large beyond the subject selection criteria in this study. Lastly, the study's cross-sectional design precludes any causal inferences being established among the variables.

Conclusion

The key finding of this study is that affected ankle dorsiflexion strength is an independent predictor of TUG times, accounting for 27.5% of the variance. This finding is consistent with previous recommendations to include assessment and training of ankle dorsiflexors in order to improve gait velocity (12) and walking endurance (20) in subjects with stroke.

ACKNOWLEDGEMENTS

This study was supported by the Health Service Research Fund (reference K-ZK34) from the Food and Health Bureau, The Hong Kong Government to Christina W.Y. Hui-Chan and her team.

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