Tally counter test as a simple and objective assessment of cervical myelopathy

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Abstract

Purpose To test the usefulness of a novel performance test, the tally counter test (counter test), which uses a hand tally counter to objectively assess the severity of cervical myelopathy.

Methods Eighty-three patients with compressive cervical myelopathy (mean age 64 ± 13 years) who were undergoing cervical laminoplasty and 280 healthy control subjects (aged 20–89 years) were tested. The subjects were instructed to push the button of a tally counter as many times as possible in 10 s. The average of the right- and left-sided values in each patient was used for analysis. In the patient group, counter test values were compared with Japanese Orthopaedic Association (JOA) and Japanese version of the 36-Item Short Form Health Survey scores preoperatively and 12 months postoperatively.

Results The average counter test value was significantly lower in patients with myelopathy than age- and gender-matched controls (32.9 ± 10.9 vs. 46.9 ± 8.5 , $P < 0.0001$). The counter test value was significantly higher at 2 weeks postoperatively than preoperatively ($P = 0.0014$). Counter test values showed a moderate correlation with JOA scores and a weak to moderate correlation with SF-36 physical functioning, role functioning, and role-emotional scores both pre- and postoperatively. The intraclass correlation coefficient of counter test values was high both pre- and postoperatively.

Conclusion The tally counter test is objective and quantitative assessment method for patients with cervical

myelopathy. The test is simple, reliable, and capable of detecting small functional changes.

Keywords Cervical spine · Myelopathy · Laminoplasty · Outcome · Quantitative assessment

Introduction

Hand clumsiness is one of the most common complaints of patients with compressive cervical myelopathy due to degenerative spondylosis, disc herniation, or ossification of the longitudinal ligament. This hand dysfunction, also called myelopathy hand, is characterised by exaggerated deep tendon reflexes, deficient adduction and/or extension of the ulnar two fingers (the finger escape sign), and difficulty in rapid grip-and-release movements of the fingers [6, 13]. The severity of myelopathy hand can be assessed using functional scales such as the Cooper Myelopathy Scale [4], European Myelopathy Score [8], and Japanese Orthopaedic Association (JOA) score [19]. These scales are widely used to monitor the disease condition and to compare clinical outcomes after decompression surgery. However, because these scales classify a wide range of clinical severity using only a few arbitrary units, the measurements are not strongly quantitative and their sensitivity to change is likely to be poor [17].

Several performance tests have been developed for objectively assessing the severity of myelopathy hand [3, 7, 13]. Ono et al. [13] proposed the original grip-and-release test (10-s test), which evaluates rapid finger motion by counting the maximum number of grips and releases in 10 s. The grip-and-release test is simple and easy to use in clinical settings. However, it is not widely used, mainly because its reliability has not been validated [7]. This test is

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subject to inter-observer variability, depending on whether the observer judges the fingers to be flexed or extended. This judgment is particularly affected by paradoxical wrist motion (trick motion), in which patients with myelopathy compensate for the impaired finger motion with exaggerated wrist motion [13]. Hosono et al. [6, 7] addressed this issue by using an animation file to count the number of grip-and-release cycles in 15 s (15-s test). This modification guarantees the reliability of the grip-and-release test, but requires a video camera and subsequent analysis of the animation files.

We hypothesised that the severity of myelopathy hand is well represented by the motor impairment of the thumb, because thumb opposition plays a key role in hand function [11]. Narrowing the focus of evaluation to the thumb may improve the reliability and reproducibility of performance tests for hand function. In this study, we used a hand tally counter to quantitatively evaluate hand function. The purpose of this prospective cohort study was to validate the usefulness of the tally counter test (counter test) for objectively assessing the severity of cervical myelopathy.

Materials and methods

Study population

Eighty-three patients with compressive cervical myelopathy who were undergoing cervical double-door laminoplasty at our hospital were tested. The patient group included 53 men and 30 women with a mean age of 64 ± 13 years. Patients were excluded if they had a history of previous cervical spine surgery, or other disorders that might impair motor function (e.g. cerebral infarction, rheumatoid arthritis, or cerebral palsy). The diagnosis of myelopathy was confirmed with thorough neurological examination and by imaging studies showing spinal cord compression, which is generally associated with an intramedullary high-intensity area on T2-weighted magnetic resonance imaging (MRI) [15]. The level of maximum compression identified on MRI was C4/5 in 32 patients, C3/4 in 29, C5/6 in 19, C2/3 in 2, and C6/7 in 1. Two hundred and eighty healthy volunteers aged 20–89 years were enrolled in the control group, which comprised 20 males and 20 females in each decade of age. The control group was used to obtain normal age- and gender-specific counter test values. The study protocol was approved by the Institutional Review Board of the authors' institute.

Counter test procedure

The counter test was performed using a hand tally counter (Kokuyo, Osaka, Japan). Patients and control subjects were

instructed to hold a tally counter with their thumb on the button, and to push the button as many times as possible in 10 s (Fig. 1). The count was recorded bilaterally, and the average of each subject's right- and left-sided values was used for analysis. The test was performed before surgery and at 2 weeks, 3 months, 6 months, and 12 months after surgery in the patient group. Grip strength was measured at the same time points, as another quantitative measurement of hand function. The average of each subject's right- and left-sided strength was used for analysis.

Receiver operating characteristic (ROC) analysis

Receiver operating characteristic (ROC) analysis was performed to evaluate the ability of the counter test value and grip strength to discriminate between the preoperative myelopathy patients and the age- and gender-matched control subjects. The area under the ROC curve (AUC) was calculated as an indicator of diagnostic power. A test with an AUC greater than 0.9 has high accuracy, while an area of 0.7–0.9 indicates moderate accuracy, 0.5–0.7 indicates low accuracy, and 0.5 indicates a chance result [1]. The optimal cutoff value that provides the highest true-positive rate and the lowest false-positive rate for detecting cervical myelopathy was determined.

Surgical outcomes

The JOA score for cervical myelopathy and the Japanese version of the 36-Item Short Form Health Survey (SF-36) score were used to assess the severity of myelopathy in the patient group. Both scales have previously been validated for

Fig. 1 Counter test procedure. Subjects were instructed to hold a tally counter with their thumb on the button, and to push the button as many times as possible in 10 s

grading cervical myelopathy severity [10, 19]. The JOA score was expressed as the sum of the qualitative values in four categories of function: upper and lower extremity motor function (0–4 each); sensory function (0–6); and bladder function (0–3). Spearman correlation coefficients were calculated to examine the relationship between the counter test value and each category of function. The SF-36 consists of eight health dimensions: physical functioning; role-physical; bodily pain; general health perception; vitality; social functioning; role-emotional; and mental health. Spearman correlation coefficients were also calculated to examine the correlations between the counter test value and the severity of myelopathy as evaluated by each of these dimensions.

Test–retest reliability

To assess the consistency of the counter test, test–retest reliability was evaluated in 30 myelopathy patients who were randomly selected from the patient group. The intraclass correlation coefficient (ICC) and 95 % confidence interval (CI) were determined both pre- and post-operatively. An ICC of >0.70 was considered acceptable [16]. All statistical analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL).

Results

Control subjects

The control subjects had a mean counter test value of 52.1 ± 9.3 on the right side and 48.6 ± 8.8 on the left side, with a difference of 3.5 ± 4.5 between the right and left sides (52.3 ± 9.2 on the dominant hand and 48.4 ± 8.8 on the non-dominant hand, with a difference of 3.8 ± 4.3 between the dominant and non-dominant sides). The counter test value (average of the right and left sides) in males was significantly higher than that in females (52.6 ± 8.3 vs. 48.1 ± 8.6 ; Mann–Whitney U test, $P < 0.0001$). Age-dependent changes in the counter test value for each gender are shown in Fig. 2. There was a strong inverse linear correlation between counter test value and age (Spearman correlation coefficient = -0.819 , $P < 0.0001$). The counter test value changed according to the equation: value = $69.5 - 0.35 \times \text{age}$. In males, this equation was: value = $68.0 - 0.31 \times \text{age}$, and in females this equation was: value = $67.6 - 0.35 \times \text{age}$.

Myelopathy patients

The counter test values of patients with myelopathy were compared with the values of age- and gender-matched control subjects (Fig. 3). The average counter test value

Fig. 2 Age-dependent changes in counter test results in healthy controls. Counter test values decreased with age (grey circles males, white circles females). There was a strong linear inverse correlation between counter test values and age (Spearman correlation coefficient = -0.819 , $P < 0.0001$). The normal value in male changed according to the equation: value = $68.0 - 0.31 \times \text{age}$ (black line), and in females this equation was: value = $67.6 - 0.35 \times \text{age}$ (grey line)

was significantly lower in patients with myelopathy than in control subjects (32.9 ± 10.9 vs. 46.9 ± 8.5 ; Mann–Whitney U test, $P < 0.0001$).

Receiver operating characteristic (ROC) analysis

Receiver operating characteristic analysis revealed counter test value and grip strength AUC to be 0.886 (95 % CI 0.845–0.928) and 0.780 (95 % CI 0.720–0.839), respectively (Fig. 4). The larger counter test value AUC demonstrated that the counter test is better at detecting cervical myelopathy than the grip strength test. The optimal counter test cutoff value for detecting cervical myelopathy was 39.5 (sensitivity 83.3 %, specificity 80.4 %).

Fig. 3 Comparison between myelopathy patients and age- and gender-matched control subjects. The average counter test value was significantly lower in patients with myelopathy than in control subjects (32.9 ± 10.9 vs. 46.9 ± 8.5 ; Mann–Whitney U test, $P < 0.0001$)

Fig. 4 Receiver operating characteristic (ROC) analysis. ROC analysis demonstrated AUCs of counter test value and grip strength to be 0.886 (black line) and 0.780 (grey line), respectively. The larger AUC of counter test value linear shows that the counter test is superior to grip strength for detecting cervical myelopathy. The optimal counter test cutoff value for detecting cervical myelopathy was 39.5 (sensitivity 83.3 %, specificity 80.4 %)

Counter test values after decompression surgery

There was a significant increase in counter test values at 2 weeks postoperatively when compared with preoperative values (one-way ANOVA followed by Bonferroni post hoc test, $P = 0.0014$) (Fig. 5a). Grip strength also increased postoperatively, but was not significantly different until 6 months postoperatively ($P = 0.024$) (Fig. 5b).

Correlation between an early increase in counter test value and a longer-term increase in the JOA score

There was a weak but significant correlation between the increase in counter test value at 2 weeks postoperatively and the increase in JOA score at 12 months postoperatively

(Spearman correlation coefficient = 0.364, $P = 0.0012$) (Fig. 6).

Correlations between counter test values and previously validated myelopathy scales

Correlations between counter test values and previously validated scales to assess the severity of myelopathy (JOA score and SF-36) are summarised in Table 1. Counter test values showed a moderate but significant correlation with JOA scores both pre- and postoperatively. When each functional category of JOA score was analysed separately, counter test values were significantly correlated with both upper and lower extremity function. Counter test values also showed weak to moderate correlation with the SF-36 physical functioning, role-physical, and role-emotional scores both pre- and postoperatively.

Test-retest reliability

The ICC for test-retest reliability was high both preoperatively (0.951, 95 % CI 0.903–0.976) and postoperatively (0.982, 95 % CI 0.964–0.991).

Discussion

We evaluated the usefulness of the counter test as an objective and quantitative assessment of cervical myelopathy severity in the present study. Counter test values were significantly lower in patients with cervical myelopathy than in healthy control subjects. Counter test values were significantly higher at 2 weeks after surgery than before surgery, suggesting that this test can be used to detect small changes in hand function. Counter test values were moderately but significantly correlated with previously validated scales for cervical myelopathy. Furthermore, the high pre- and postoperative ICCs suggest that this is a reliable and reproducible test. These results validate the use of the

Fig. 5 Counter test values and grip strengths at different time points after decompression surgery. **a** Counter test values were significantly higher at 2 weeks postoperatively than preoperatively (one-way ANOVA followed by Bonferroni post hoc test, $P = 0.0014$). **b** Grip strength increased postoperatively, but this difference was not significant until 6 months ($P = 0.024$). * $P < 0.05$; ** $P < 0.01$; † $P < 0.001$

Fig. 6 Correlation between an early increase in counter test value and a longer-term increase in the JOA score. The increase in the counter test value at 2 weeks postoperatively was significantly correlated with the increase in the JOA score at 12 months postoperatively (Spearman correlation coefficient = 0.364, $P = 0.0012$)

Table 1 Correlations between counter test values and previously validated scales

	Preoperative		Postoperative	
	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>
JOA score				
Upper-extremity motor function	0.607	<0.001 [†]	0.551	<0.001 [†]
Lower-extremity motor function	0.598	<0.001 [†]	0.621	<0.001 [†]
Sensory function	0.226	0.024*	0.174	0.167
Bladder function	0.201	0.045*	0.272	0.019*
Total score	0.585	<0.001 [†]	0.596	<0.001 [†]
SF-36				
PF	0.488	<0.001 [†]	0.520	<0.001 [†]
RP	0.372	0.003**	0.379	0.001**
BP	0.063	0.632	0.110	0.360
GH	0.255	0.047*	0.215	0.072
VT	0.146	0.261	0.052	0.665
SF	0.294	0.021*	0.165	0.167
RE	0.421	<0.001 [†]	0.316	0.006**
MH	0.079	0.584	0.047	0.700

JOA Japanese Orthopaedic Association, *PF* physical functioning, *RP* role-physical, *BP* bodily pain, *GH* general health perception, *VT* vitality, *SF* social functioning, *RE* role-emotional, *MH* mental health, *R* Spearman correlation coefficient

* $P < 0.05$; ** $P < 0.01$; [†] $P < 0.001$

counter test for assessing the severity of cervical myelopathy.

One of the advantages of the counter test is that the severity of myelopathy hand is determined by a simple mechanical device, which eliminates inter-observer

variability. This objectivity is particularly important when assessing finger movements in patients with cervical myelopathy, because movement is frequently exaggerated by paradoxical wrist motion (trick motion) [13]. In the grip-and-release test, inter-observer variability may occur depending on whether the observer considers the fingers to be extended or flexed [7]. Hosono et al. [6, 7] used a video camera and animation files to ensure objectivity in the grip-and-release test, but additional time and energy are required to implement such video-assisted testing. In contrast, the counter test can be performed with an easily available device and requires no special skill in neurological examination.

The relatively high AUC of 0.886 in the ROC analysis suggests that the counter test may be a useful screening test for cervical myelopathy. As the counter test showed the highest true-positive rate and the lowest false-positive rate at a cutoff value of 39.5, an individual with a counter test value of 39 or less could be considered for further physical examination and imaging, including MRI. Although other central nervous system disorders that affect the pyramidal tract must be considered in the differential diagnosis, the simplicity and easy accessibility of the counter test make it a useful screening test.

Counter test values showed a significant gender difference, and a relatively steep decline with increasing age. These gender- and age-dependent differences may affect comparisons between treatment groups. However, because the age-dependent changes show a strong linear correlation in both genders, the effect of age can be corrected based on the formulas shown above. Considering the growing number of elderly patients who require cervical spine decompression surgery, age-specific standard values would be useful.

Patients with cervical myelopathy sometimes report immediate improvement of subjective symptoms of the hands after decompression surgery, but it is usually difficult to detect this improvement using conventional myelopathy scales. Objective performance tests could provide evidence of this improvement in the early postoperative period. Hosono et al. [8] recently demonstrated a significant improvement in 15-s test results in patients with cervical myelopathy at 24 h after surgery. However, Igarashi et al. [9] did not find any significant improvement in 10-s test results in patients with cervical myelopathy 2 weeks after surgery, although they noted significant improvements in target-reaching movements measured by an electric apparatus. The discrepancy between the results of these two studies may be partly attributable to the relatively small number of subjects (28 patients and 15 age-matched controls) recruited in the latter study. This discrepancy also suggests that inter-observer variability in the original 10-s test decreases its sensitivity to subtle functional changes.

Objective assessment using the counter test may provide important information for the treatment of cervical myelopathy. First, the test may help us to understand the natural history of compressive cervical myelopathy, which typically results in a slow, gradual deterioration in a step-wise fashion [2, 5]. Second, counter test results obtained as continuous variables would facilitate statistically optimised comparisons of surgical outcomes. Such comparisons would reveal the most appropriate timing of surgery using a cutoff value [12]. Finally, objective measurements may help patients to understand their disease condition. The simple results of the counter test are easy for patients to interpret, and would help them to track an insidious functional decline before surgery and a slow functional recovery after surgery.

The present study has several limitations. First, the counter test value can be affected by coexisting cervical radiculopathy. In particular, patients with the eighth cervical (C8) radiculopathy may show discrepancy between the severity of spinal cord compression and the result of counter test, because the C8 nerve root mainly controls the flexion and extension of the thumb [18]. However, the impact of coexisting cervical radiculopathy remains to be elucidated, because cervical radiculopathy is a diagnosis with no “gold standard” test [14]. Second, the results of counter test could be influenced by the performance of a hand tally counter. Although our preliminary experiment to compare tally counters manufactured by three different companies resulted in almost the same results (data not shown), standardisation of tally counters would be ideal to perform a stringent comparison of results.

In conclusion, we established the usefulness of counter test as an objective and quantitative assessment method for patients with cervical myelopathy. The test is simple, reliable, and capable of detecting small functional changes in patients with cervical myelopathy. A cutoff value of 39.5 shows the highest accuracy for detecting cervical myelopathy in a screening test.

Conflict of interest The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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