The Spine Journal 19 (2019) 157–162

Clinical Study

The use of a novel tablet application to quantify dysfunction in cervical spondylotic myelopathy patients

Brett D. Rosenthal, MD[a,*], Tyler J. Jenkins, MD[a], Arjun Ranade, BS[b], Surabhi Bhatt, BS[a], Wellington K. Hsu, MD[a], Alpesh A. Patel, MD, FACS[a]

[a] *Northwestern University, Department of Orthopaedic Surgery, 676 N. Saint Clair, Suite 1350, Chicago, IL 60611, USA*
[b] *Rosalind Franklin University of Medicine and Science, 3333 Green Bay Rd., North Chicago, IL 60064, USA*
Received 12 February 2018; revised 27 April 2018; accepted 24 May 2018

Abstract

BACKGROUND CONTEXT: Despite the prevalence and importance of myelopathy, there is a paucity of objective and quantitative clinical measures. The most commonly used diagnostic tools available are nonquantitative physical exam findings (eg, pathologic reflexes, and gait disturbance) and subjective scoring systems (eg, modified Japanese Orthopaedic Association [mJOA]). A decline in fine motor coordination is a hallmark of early myelopathy, which may be useful for quantitative testing.

PURPOSE: To identify if a novel tablet application could provide a quantitative measure of upper extremity dysfunction in cervical spondylotic myelopathy.

STUDY DESIGN/SETTING: Prospective cohort study Patient Sample: Adult patients with a diagnosis of cervical spondylotic myelopathy from a board-certified, spine surgeon were compared with age-matched, healthy, and adult control patients. Outcome Measures: Self-reported function was assessed via the mJOA. Upper extremity function was measured via the fine motor skills (FiMS) tablet test.

METHODS: Subjects and controls prospectively completed the mJOA paper survey and the FiMS tablet testing, which consisted of four challenges.

RESULTS: After age-matching, 65 controls and 28 myelopathic patients were available for comparison. The mean mJOA was 13.5 ± 2.9 in the myelopathic cohort and 17.3 ± 1.1 in the control cohort ($p < .0001$). The average scores for challenges 1–4 in control patients were 24.4, 16.3, 3.2, and 6.6, respectively, whereas the average scores for the myelopathic patients were 16.6, 10.5, 1.4, and 1.8, respectively (p values for all four challenges <.001). Based upon the 15 control subjects who repeated FiMS testing four sequential times, intrarater reliability was excellent, yielding an interclass correlation coefficient of 0.88

CONCLUSIONS: The FiMS tablet application produced significantly lower scores in a myelopathic cohort when compared with an age-matched control cohort. This is true for all four challenges in the FiMS tablet application. The test can be completed in 1.5 minutes, producing a

FDA device/drug status: Not applicable.

Author disclosures: ***BDR***: Nothing to disclose. ***TJJ***: Nothing to disclose; ***AR***, Nothing to disclose. ***SB***: Nothing to disclose. ***WKH***: Royalties: Stryker (F); Consulting: Stryker (F), Allosource (A), Agnovos (A), Mirus (B), JBJS (C), Graftys (A), Wright Medical (B), Micromedicine (B), Medtronic (C), Bioventus (A); Speaking and/or Teaching Arrangements: AONA (A); Trips/Travel: Stryker (B), Medtronic (B), Micromedicine (A); Board of Directors: Lumbar Spine Research Society (Nonfinancial, 0), American Academy of Orthopaedic Surgeons (Nonfinancial, 0), North American Spine Society (Nonfinancial, 0), Cervical Spine Research Society (Nonfinancial, 0); Scientific Advisory Board: Bioventus (Nonfinancial, 0); Grants: Medtronic (E, BMP carriers, Paid directly to institution/employer). ***AAP***: Royalties: Amedica (B); Stock Ownership: Amedica (<1%), Cytonics (<1), Nocimed (<1), Vital5 (<1), Endoluxe (1%), Tissue Differentiation Intelligence (1%); Consulting: Amedica (Nonfinancial), Zimmer Biomet (B), Depuy Synthes (Nonfinancial), Nuvasive (Nonfinancial); Board of Directors: Cervical Spine Research Society (Nonfinancial, None), Lumbar Spine Research Society (Nonfinancial, None); Grants: Cervical Spine Research Society (B, Paid directly to institution/employer); Fellowship Support: AO Spine North America (E, Paid directly to institution/employer), Nuvasive (D, Paid directly to institution/employer), Globus (D, Paid directly to institution/employer).

* Corresponding author. Northwestern University, Department of Orthopaedic Surgery, 676 N. Saint Clair, Suite 1350, Chicago, IL 60611, USA. Tel.: 312-926-4444; fax: 312-926-4643.

E-mail address: brett.david.rosenthal@gmail.com (B.D. Rosenthal), tylerjamesjenkins@gmail.com (T.J. Jenkins), arjun.ranade@my.rfums.org (A. Ranade), Surabhi-bhatt@northwestern.edu (S. Bhatt), wkhsu@yahoo.com (W.K. Hsu), alpesh2@gmail.com (A.A. Patel).

https://doi.org/10.1016/j.spinee.2018.05.038

reliable, quantitative measure of cervical myelopathy upper extremity function. In summary, the FiMS tablet application is a novel, easily administered, objectively quantifiable test for analyzing cervical spondylotic myelopathy.

Keywords: Cervical; Classification; Coordination; Degenerative; Diagnostic; Fine motor; mJOA; Myelopathy; Nurick; Spondylotic; Tablet; Testing

Introduction

Cervical spondylotic myelopathy (CSM) is the leading cause of spinal cord dysfunction in the adult population [1–4]. Despite the prevalence and importance of myelopathy, there is a paucity of objective and quantitative clinical measures for patient analysis. The most common diagnostic tools available to the physician are nonquantitative physical exam findings (eg, pathologic reflexes, and gait disturbance) and subjective scoring systems (eg, modified Japanese Orthopaedic Association [mJOA], Nurick scales) [3,5,6]. The lack of an easily performed, objective, and quantitative diagnostic tool for CSM has hindered research and clinical progress.

With the aim of better classifying CSM, diagnosing the condition earlier, and improving clinical outcome measurements, we developed a novel tablet application to test fine motor skills (FiMS) in the hand and upper extremities. A decline in these FiMS is an early hallmark of CSM. We developed a novel tablet application with clinical use in mind and thus, could fine tune the instrument making its use efficient for clinicians and patients.

Materials and methods

Appropriate Institutional Review Board approval was obtained before any recruitment or testing of patients.

Patient selection

Patients were recruited to participate in the study after a clinical diagnosis was made by a board-certified, fellowship-trained, orthopedic spine surgeon using clinical and imaging manifestations of CSM. Age-matched controls were recruited from other orthopedic clinics after survey evaluation did not identify any symptoms concerning for CSM. All subjects were at least 18 years old and had no other neurologic or physical condition (ie, Parkinson's, dementia, blindness, rheumatoid arthritis) that precluded fine motor testing. Informed consent was obtained in all patients.

Interventions

Enrolled patients completed the mJOA for cervical myelopathy and our novel FiMS tablet application [7].

FiMS testing was carried out with the patient seated. For standardization, all testing using the FiMS tablet application was on a 9.7" fourth-generation iPad (Apple, Inc, Cupertino, CA, USA). Participants were instructed to complete the testing twice sequentially. Performing the testing twice allowed the first completion to act as a teaching introduction and the second completion to provide the challenge results. This reduced error associated with any

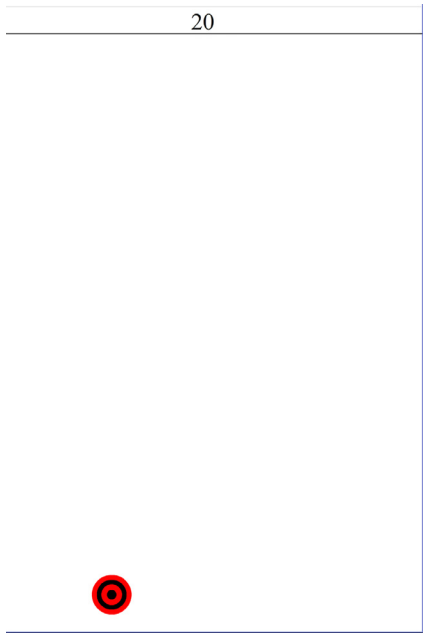

Fig. 1. Screenshot of Challenge 1.

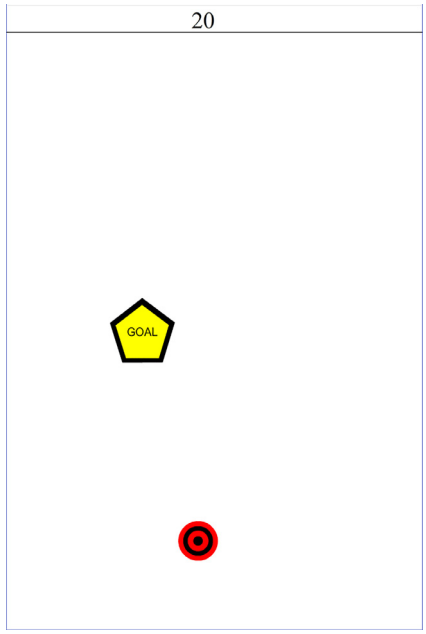

Fig. 2. Screenshot of Challenge 2.

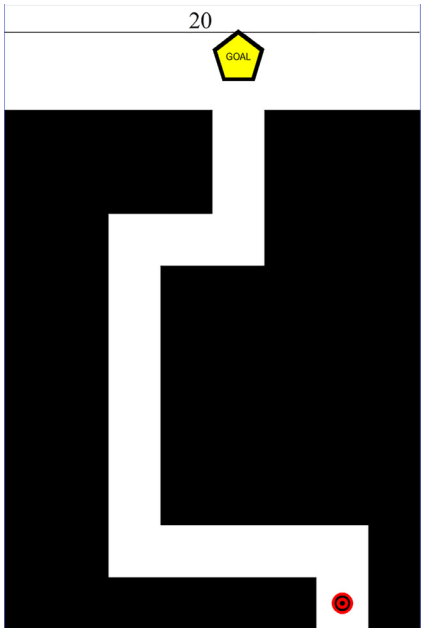

Fig. 3. Screenshot of Challenge 3.

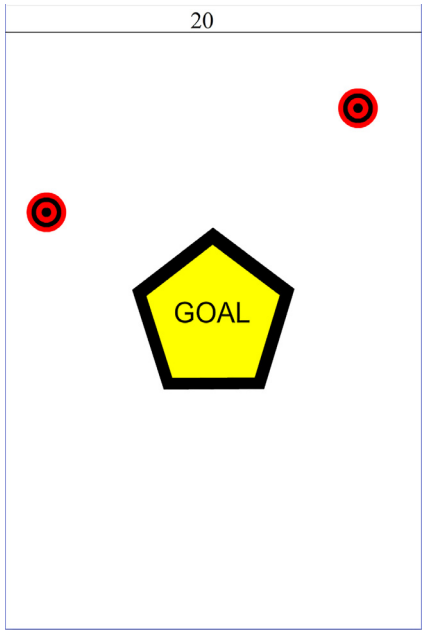

Fig. 4. Screenshot of Challenge 4.

potential learning curve. Participants were not instructed as to which hand to use during challenge testing.

Tablet application details

The FiMS application consists of four unique challenges. All the challenges focus on fine motor dexterity testing. Challenge 1 involves accurately tapping a moving target on the screen (Fig. 1; see Video, Supplemental Digital Content 1, which demonstrates Challenge 1). Challenge 2 necessitates dragging a target on the screen to a goal (Fig. 2; see Video, Supplemental Digital Content 2, which demonstrates Challenge 2). Challenge 3 involves moving a target through a randomly generated maze without touching the maze walls (Fig. 3; see Video, Supplemental Digital Content 3, which demonstrates Challenge 3). Challenge 4 requires the use of both hands to drag two separate targets to a goal simultaneously (Fig. 4; see Video, Supplemental Digital Content 4, which demonstrates Challenge 4). Each challenge lasts 20 seconds and encourages the participant to complete the intended task as many times as possible within the allotted time. For challenges 1, 2, and 3, participants were allowed to use their preferred upper extremity. Scores are totaled based on the number of targets that reach the goal in 20 seconds. A complete round of testing therefore takes the patient under 1.5 minutes to complete all four challenges. At the conclusion of testing, the results are presented on a score review page.

Statistical analysis

The scores were recorded by a research coordinator and analyzed independently for each challenge. A student *t* test was used to determine significance with a p value set at <.01, comparing myelopathic patients to age-matched controls Correlations between FiMS challenge scores and mJOA score were measured by Pearson correlation effect. P values less than 1% were considered to be statistically significant. To assess intrarater reliability, 15 patients completed the FiMS testing four times and the interclass correlation coefficient was calculated. Additionally, analysis of variance testing was performed to identify differences in mean scores with sequential attempts for each challenge. All statistical analyses were performed with the use of Statistical Analysis System (SAS) v9.3 (SAS Institute, Cary, NC, USA).

Results

Twenty-eight myelopathic patients and 87 healthy control subjects participated in testing. The FiMS data from healthy controls were analyzed using linear regression and Pearson correlation effect, demonstrating a negative correlation with age, which was true for each challenge (Challenge 1, $r = -0.566$, $p < .0001$; Challenge 2, $r = -0.6003$, $p < .0001$; Challenge 3, $r = -0.3507$, $p = .00089$; Challenge 4, $r = -0.4967$, $p < .0001$).

Therefore, we age matched the controls with the myelopathic patients for data analysis. This resulted in a study group of 65 age-matched controls and 28 myelopathic patients for comparison (Table 1). The average mJOA score (scale 0–18) for the myelopathic cohort was 13.5. For reference, a score between 12 and 14 signifies moderate myelopathy [7]. The 65 control patients had a mean mJOA score of 17.3, with a score greater than 17 being inconsistent with myelopathy [7].

When compared with age-matched healthy controls, the myelopathic cohort had significantly lower FiMS scores for

Table 1
Fine motor skills (FiMS) tablet application results for age-matched controls vs. myelopathics

	Healthy controls n=65		Myelopathic patients n=28		
	Average (SD)	95% CI	Average (SD)	95% CI	p value
Age (years)	58.0 (9.1)	55.8–60.2	60.5 (9.3)	57.1–63.9	.2228
mJOA score	17.3 (1.1)	17.0–17.6	13.5 (2.9)	12.4–14.6	<.0001*
FiMS scores					
Challenge 1	24.4 (3.8)	23.4–25.3	19.1 (6.6)	16.6–21.5	<.0001*
Challenge 2	16.3 (3.2)	15.5–17.1	12.1 (4.4)	10.5–13.7	<.0001*
Challenge 3	3.2 (1.5)	2.8–3.6	1.9 (1.4)	1.4–2.4	.00017*
Challenge 4	6.6 (2.9)	5.9–7.3	2.8 (2.8)	1.8–3.9	<.0001*

mJOA, modified Japanese Orthopaedic Association; CI, confidence interval; SD, standard deviation.
* Indicates that the p value reached clinical significance (p<.01 set value for significance).

Table 2
Mean scores from control reliability testing

	N	Challenge 1 (mean ± SD)	Challenge 2 (mean ± SD)	Challenge 3 (mean ± SD)	Challenge 4 (mean ± SD)
Attempt 1	15	25.27 ± 4.73	15.53 ± 2.67	2.13 ± 1.41	5.93 ± 2.09
Attempt 2	15	25.13 ± 4.22	15.20 ± 3.28	2.47 ± 1.41	6.20 ± 2.98
Attempt 3	15	26.40 ± 4.53	16.27 ± 3.22	2.73 ± 1.22	7.00 ± 1.93
Attempt 4	15	25.47 ± 4.27	16.53 ± 3.04	2.80 ± 1.26	7.87 ± 2.75

SD, standard deviation.

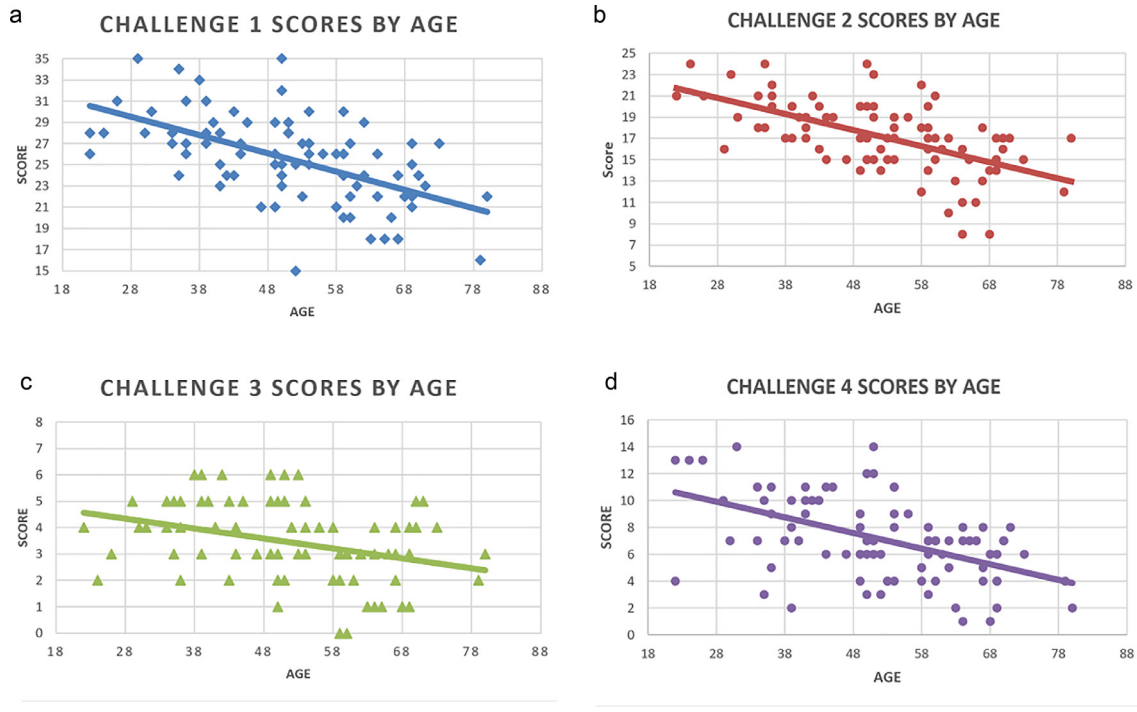

Fig. 5. Challenge scores by age.
(a) Challenge 1
(b) Challenge 2
(c) Challenge 3
(d) Challenge 4

all challenges 1–4 (Table 1). The average scores for challenges 1–4 in control patients were 24.4, 16.3, 3.2, and 6.6, respectively, whereas the average scores for the myelopathic patients were 16.6, 10.5, 1.4, and 1.8, respectively (p values for all 4 challenges <.001). Based upon the 15 control subjects who repeated FiMS testing four sequential times, intrarater reliability was excellent, yielding an interclass correlation coefficient of 0.88. Analysis of variance testing did not demonstrate any significant differences between any of the four attempts at each challenge (Table 2).

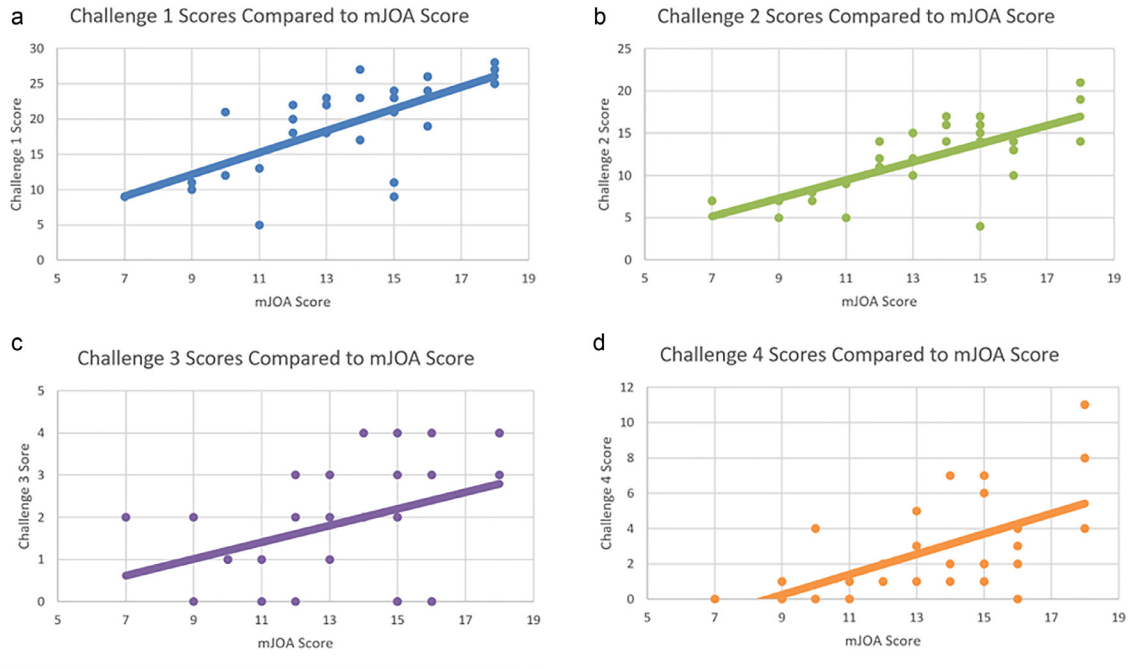

Fig. 6. Challenge scores compared with mJOA (modified Japanese Orthopaedic Association).
(a) Challenge 1
(b) Challenge 2
(c) Challenge 3
(d) Challenge 4

Linear regression was performed to compare the myelopathic patient challenge scores to mJOA scores. Pearson correlation effect was calculated to identify which challenge was best able to correlate with mJOA severity (Fig. 5a–d). Challenge 2 had the strongest Pearson coefficient with a value of r = 0.705, meaning that as mJOA scores decreased there was a strong tendency for the Challenge 2 scores to decrease. Challenges 1 and 4 produced moderate Pearson coefficients of r = 0.678 and 0.590, respectively. Challenge 3 produced the weakest Pearson coefficient of r = 0.393 (Fig. 6).

Discussion

A large hurdle in the rigorous evaluation of cervical myelopathy is the lack of an easily administered, objective, and quantitative myelopathy assessment. Such a tool could open significant doors in cervical myelopathy research with the potential to better assess natural history, optimize treatment outcomes, and diagnose pathology earlier. This study validates the use of a novel, tablet-based, patient-driven objective measurement tool for the evaluation of patients with CSM.

Physical examination remains the hallmark of early diagnosis for cervical myelopathy. However, the nonquantitative nature that many of the physical exam findings (eg, pathologic reflexes, gait disturbance, and change in muscle tone) demonstrate makes objective documentation over time difficult. Similarly, many scoring systems have been developed (eg, mJOA, Nurick scale, Myelopathic Disability Index), which allow for classification of disease severity, but their subjective and rigid nature limits their application [3,8,9]. Many of these scales are based on patients' reporting of their own symptoms, which can create confounding factors based on patients' expectation and personality. These scales also are poorly quantitative, with one gradation covering a large range of clinical severity.

Various quantitative myelopathy assessments have been reported with several limitations. The foot-tapping test, triangle step test, and simple walking test have all been described to evaluate cervical myelopathy patients with lower extremity dysfunction [6,10]. All of the aforementioned tests require the patient to have no confounding lower extremity pathology and require clinical staff to be present for evaluation. Tandem lumbar stenosis could also lead to confounding results, making interpretation difficult in some myelopathic patients.

Upper extremity quantitative assessments have also been described. The myelopathic hand findings of decreased power and extension of the ulnar 2 digits and inability to grip-and-release fingers rapidly are classically discussed [11]. Grip strength testing requires a hand dynamometer, which is a single-function, expensive, and inconvenient tool for clinic assessment. Grip-and-release testing is simple but requires clinical staff for assessment and documentation [12].

Our study presents a quantitative and easily administered test with the use of a novel tablet application. The use of an electronic test has the added benefits of reduced burden on clinical staff for the testing administration, evaluation, and

documentation of test results. The results of these tests can be tracked immediately and compared with prior individual results and correlated to other patients. Another added benefit is that lower extremity dysfunction does not preclude testing as with other quantitative myelopathy exams.

This study demonstrated that the FiMS application scores were significantly reduced in patients with cervical myelopathy when compared with age-matched healthy controls. This was true for all four challenges. The intrarater reliability testing was excellent for the FiMS application (Interclass Correlation Coefficient [ICC] = 0.88). The Pearson correlation coefficient between FiMS challenge scores and mJOA was excellent overall. Specifically, the correlation coefficient between Challenge 2 results and mJOA was very high ($r = 0.705$). The mJOA scores were significantly different between the control and myelopathic groups (control: 17.3, myelopathic: 13.5; $p < .0001$). This demonstrates patients in the myelopathy cohort did, in fact, meet myelopathic score thresholds on the basis of the mJOA's pre-existing measures. These results illustrate that the novel FiMS application was a reliable, quantitative assessment of upper extremity dysfunction in patients with cervical myelopathy. The FiMS application may be especially useful in patients with severe lower extremity dysfunction that precludes other quantitative testing.

Several limitations are present in our study and this initial iteration of the FiMS application. FiMS testing is not disease specific. Many pathologic conditions could lead to decreased FiMS challenge scores. We attempted to control this in our study by employing strict inclusion criteria. The dexterity involved in hand and extremity movements is a complex pathway that requires involvement of neurologic, visual, and musculoskeletal pathways. Unrelated disabilities to these pathways may limit the applicability of the FiMS. The study was designed to allow patient preference to drive hand use (right or left) during the evaluation. This may underestimate disease severity by allowing patients to use their better functioning hand, but we felt this was a strength of the application as the patient could use whichever hand they felt most competent with to complete the challenge. Disagreements in hand dominance and symptomatic extremities throughout testing could confound the results. Another benefit to testing in this manner is that we designed the FiMS application to eventually be used without clinical personnel monitoring patients. If ensuring correct hand usage during testing is necessary, then testing without clinical personnel monitoring would be difficult.

Future studies using the FiMS application should focus on continued cross-sectional analysis and prospective outcomes data. With additional data collection, a model that can provide age-adjusted scoring may be possible. The ability to track patients with upper extremity myelopathic symptoms quantitatively over time should yield new insights into the natural history of myelopathy and outcomes evaluation.

Conclusions

The novel FiMS tablet application produced significantly lower scores in a myelopathic cohort when compared with an age-matched control cohort. This is true for all four challenges in the FiMS tablet application. The test can be completed in one and half minutes, producing reliable, quantitative outcomes for patients with cervical myelopathy. In summary, the FiMS tablet application is a novel, easily administered, objectively quantifiable test for analyzing cervical myelopathy.

Acknowledgment

There were no sources of financial support for this study. Appropriate Institutional Review Board approval was obtained before any recruitment or testing of patients.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spinee.2018.05.038.

References

[1] Bednarik J, Kadanka Z, Dusek L, Novotny O, Surelova D, Urbanek I. et al. Presymptomatic spondylotic cervical cord compression. Spine 2004;29:2260–9.
[2] Fehlings MG, Wilson JR, Kopjar B, Yoon ST, Arnold PM, Massicotte EM. et al. Efficacy and safety of surgical decompression in patients with cervical spondylotic myelopathy: results of the AOSpine North America prospective multi-center study. J Bone Joint Surg Am 2013;95:1651–8.
[3] Nurick S. The pathogenesis of the spinal cord disorder associated with cervical spondylosis. Brain 1972;95:87–100.
[4] Rao RD, Gourab K, David KS. Operative treatment of cervical spondylotic myelopathy. J Bone Joint Surg Am 2006;88:1619–40.
[5] Kalsi-Ryan S, Singh A, Massicotte EM, Arnold PM, Brodke DS, Norvell DC. et al. Ancillary outcome measures for assessment of individuals with cervical spondylotic myelopathy. Spine (Phila Pa 1976) 2013;38(22 Suppl 1):S111–22.
[6] Numasawa T, Ono A, Wada K, Yamasaki Y, Yokoyama T, Aburakawa S. et al. Simple foot tapping test as a quantitative objective assessment of cervical myelopathy. Spine 2012;37:108–13.
[7] Benzel EC, Lancon J, Kesterson L, Hadden T. Cervical laminectomy and dentate ligament section for cervical spondylotic myelopathy. J Spinal Disord 1991;4:286–95.
[8] Vitzthum HE, Dalitz K. Analysis of five specific scores for cervical spondylogenic myelopathy. Eur Spine J 2007;16:2096–103.
[9] Casey AT, Bland JM, Crockard HA. Development of a functional scoring system for rheumatoid arthritis patients with cervical myelopathy. Ann Rheum Dis 1996;55:901–6.
[10] Mihara H, Kondo S, Murata A, Ishida K, Niimura T, Hachiya M. A new performance test for cervical myelopathy: the triangle step test. Spine 2010;35:32–5.
[11] Ono K, Ebara S, Fuji T, Yonenobu K, Fujiwara K, Yamashita K. Myelopathy hand. New clinical signs of cervical cord damage. J Bone Joint Surg Br 1987;69:215–9.
[12] Yukawa Y, Nakashima H, Ito K, Machino M, Kanbara S, Kato F. Quantifiable tests for cervical myelopathy; 10-s grip and release test and 10-s step test: standard values and aging variation from 1230 healthy volunteers. J Orthop Sci 2013;18:509–13.