Functional improvement in hand strength and dexterity after surgical treatment of cervical spondylotic myelopathy: a prospective quantitative study

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OBJECTIVE Cervical spondylotic myelopathy (CSM) is the primary cause of adult spinal cord dysfunction. Diminished hand strength and reduced dexterity associated with CSM contribute to disability. Here, the authors investigated the impact of CSM severity on hand function using quantitative testing and evaluated the response to surgical intervention.

METHODS Thirty-three patients undergoing surgical treatment of CSM were prospectively enrolled in the study. An occupational therapist conducted 3 functional hand tests: 1) palmar dynamometry to measure grip strength, 2) hydraulic pinch gauge test to measure pinch strength, and 3) 9-hole peg test (9-HPT) to evaluate upper extremity dexterity. Tests were performed preoperatively and 6–8 weeks postoperatively. Test results were expressed as 1) a percentile relative to age- and sex-stratified norms and 2) achievement of a minimum clinically important (MCI) difference. Patients were stratified into groups (mild, moderate, and severe myelopathy) based on their modified Japanese Orthopaedic Association (mJOA) score. The severity of stenosis on preoperative MRI was graded by three independent physicians using the Kang classification.

RESULTS The primary presenting symptoms were neck pain (33%), numbness (21%), imbalance (12%), and upper extremity weakness (12%). Among the 33 patients, 61% (20) underwent anterior approach decompression, with a mean (SD) of 2.9 (1.5) levels treated. At baseline, patients with moderate and low mJOA scores (indicating more severe myelopathy) had lower preoperative pinch ($p < 0.001$) and grip ($p = 0.01$) strength than those with high mJOA scores/mild myelopathy. Postoperative improvement was observed in all hand function domains except pinch strength in the non-dominant hand, with MCI differences at 6 weeks ranging from 33% of patients in dominant-hand strength tests to 73% of patients in nondominant-hand dexterity tests. Patients with moderate baseline mJOA scores were more likely to have MCI improvement in dominant grip strength (58.3%) than those with low mJOA scores/severe myelopathy (30%) and high mJOA scores/mild myelopathy (9%, $p = 0.04$). Dexterity in the dominant hand as measured by the 9-HPT ranged from < 1 in patients with cord signal change to 15.9 in patients with subarachnoid effacement only ($p = 0.03$).

CONCLUSIONS Patients with CSM achieved significant improvement in strength and dexterity postoperatively. Baseline strength measures correlated best with the preoperative mJOA score; baseline dexterity correlated best with the severity of stenosis on MRI. The majority of patients experienced MCI improvements in dexterity. Baseline pinch strength correlated with postoperative mJOA MCI improvement, and patients with moderate baseline mJOA scores were the most likely to have improvement in dominant grip strength postoperatively.

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KEYWORDS cervical; dexterity; grip; myelopathy; peg; pinch; strength; stenosis

CERVICAL spondylotic myelopathy (CSM) is the primary cause of spinal cord dysfunction in adults.¹⁶ It typically has an insidious onset with symptoms that include hand numbness, hand weakness, loss of man-

ual dexterity, gait difficulty, imbalance, and urinary symptoms such as urgency or hesitancy. The diminished hand strength and dexterity associated with CSM are key contributors to disability.

ABBREVIATIONS 9-HPT = 9-hole peg test; CSM = cervical spondylotic myelopathy; MCI = minimum clinically important; mJOA = modified Japanese Orthopaedic Association.

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Surgical decompression is the mainstay treatment for CSM and has been shown to improve hand function, but a majority of studies rely primarily on health-related quality of life metrics, such as the modified Japanese Orthopaedic Association (mJOA) scale.¹⁵ The goal of this study was to comprehensively investigate the functional impact of CSM severity on hand function using several quantitative hand tests and to evaluate the response to surgical intervention.

Methods

Patients aged 18–75 years with a diagnosis of CSM who were planning for surgical treatment at a single center were prospectively identified and screened for study enrollment. Patients with cognitive impairment, intrinsic hand dysfunction, or other comorbid neurological disease were excluded. All aspects of this study protocol were approved by the local institutional review board prior to patient enrollment. Informed consent for study enrollment was obtained from all patients. Study participation had no bearing on surgical decision-making.

Functional Hand Testing

All patients were tested by a licensed occupational therapist who performed 3 tests to assess hand function. These tests included palmar dynamometry to measure grip strength, the hydraulic pinch gauge test to measure pinch strength, and the 9-hole peg test (9-HPT) to evaluate upper extremity dexterity. Testing was performed preoperatively and 6–8 weeks postoperatively.

Grip strength was tested using a standard commercially available Digital Palmar Dynamometer (Jamar, Patterson Medical Holdings). The patient is seated with their shoulder adducted, elbow flexed, forearm neutral, and feet resting on the ground. The participant squeezes the handle at maximal exertion. The highest reading is recorded. The test is repeated 3 times with each hand, and the scores are averaged for each hand.

Pinch strength was tested using a standard commercially available hydraulic pinch gauge (Jamar, Patterson Medical Holdings). The patient is seated with their shoulders adducted, elbows flexed 90°, forearms neutral, and feet resting on the ground. The patient presses the instrument at maximal exertion. The highest reading is recorded. The test is repeated 3 times with each hand, and the scores are averaged for each hand.

The 9-HPT is a standard commercially available device (Jamar, Patterson Medical Holdings). The test is performed as described by Mathiowetz et al.⁵ The dominant hand is tested first, followed by the nondominant hand. The patient performs the test twice with each hand, and the scores are averaged for each hand.

Radiological Assessment

Preoperative MR images were reviewed by three independent physicians, and the severity of stenosis in the treated levels was classified using the Kang classification system.³ This classification describes grade 0 as no central canal stenosis; grade 1 as almost complete obliteration of the subarachnoid space, with obliteration of the arbi-

trary subarachnoid space of more than 50% without cord deformation; grade 2 as central canal stenosis including cord deformity but lacking spinal cord signal change; and grade 3 as the occurrence of spinal cord signal change near the compressed level.

Statistical Analysis

All test values were normalized to age- and sex-specific means and were expressed as percentiles.^{5,6,8–10,13} Preoperative and postoperative values were expressed as the percentile change, and whether the change reached a minimum clinically important (MCI) difference was assessed.^{4,17} The total mJOA score was analyzed as a continuous variable and by group as severe myelopathy (≤ 11 points), moderate myelopathy (12–14 points), and mild myelopathy (≥ 15 points). The MCI improvement in the mJOA score was determined as established by Tetreault et al.¹⁵ and varied by myelopathy severity: 1 for mild, 2 for moderate, and 3 for severe myelopathy.

Preoperative compared to postoperative test values were analyzed using one-tailed paired t-tests. Correlation between continuous variables was analyzed using Pearson's product moment correlation coefficient. Categorical values were analyzed using two-tailed Fisher exact tests. Multiple comparisons were corrected using the Holm-Bonferroni method with an adjusted p value < 0.05 considered significant. All statistics were performed using R version 3.5.1 (R Foundation for Statistical Computing, <https://cran.r-project.org>). A p value < 0.05 was considered statistically significant.

Results

Demographics, Baseline Hand Function, and Baseline mJOA

Thirty-eight patients were initially identified, 4 patients were excluded, and 1 patient was lost to follow-up and did not complete postoperative testing, which resulted in a total of 33 patients in the study. Cohort demographics are listed in Table 1. The mean patient age $\pm$ SD was 58.1 ± 13.1 years, and 52% of the patients were women. The mean number of operated levels was 2.94 ± 1.5 , with 7 patients (21%) undergoing single-level procedures. Among the 33 patients, 20 (61%) underwent an anterior approach, 24 (73%) self-reported hand weakness, and 28 (85%) reported general hand symptoms. Neck pain was the chief complaint in 11 patients, followed by hand numbness in 7 patients, and imbalance and upper extremity weakness in 4 patients each.

Overall, 33%, 36%, and 79% of patients scored 2 SDs below the mean score in at least one hand for the tests of grip strength, pinch strength, and dexterity, respectively. Patients exhibited significantly more baseline impairment in the 9-HPT than in the pinch and grip strength tests for both dominant and nondominant hands. Preoperative hand function tests were then compared to preoperative mJOA scores (Table 2). Dominant pinch ($p < 0.001$) and grip ($p = 0.01$) strengths were significantly associated with the preoperative mJOA score. Mean percentiles for dominant pinch strength and dominant grip strength were 57.3 ± 19.7 and 46.7 ± 28.7 in the high mJOA score/mild my-

TABLE 1. Demographics, presenting symptoms, and treatment variables of 33 patients with CSM

Characteristic	Patients (n = 33)
Mean age in yrs (SD)	58.1 (13.1)
Sex	
Female	17 (52)
Male	16 (48)
Anterior approach	20 (61)
Mean no. of treated levels (SD)	2.9 (1.5)
Chief complaint	
Neck pain	11 (33)
Numbness	7 (21)
Imbalance	4 (12)
Upper extremity weakness	4 (12)
Back pain	3 (9)
Radiculopathy	3 (9)
Other	1 (3)
Any hand symptom (including pain, numbness, weakness, or loss of dexterity)	28 (85)

Data are expressed as number (percent) unless otherwise indicated.

elopathy group, respectively, with all percentiles less than 30 in the low- and moderate-scoring mJOA groups.

In order to visualize test improvement postoperatively, Fig. 1 was created for dominant and nondominant hands with each test mean, grouped by preoperative or postoperative status, plotted in three dimensions.

Postoperative Hand Function Change and Correlation to mJOA Score

An MCI improvement in one hand was achieved by 52% of patients in the grip test, 48% in the pinch test, and 91% in the 9-HPT. Postoperatively, bilateral hand strength and dexterity improved significantly (Table 3). These improvements included dominant-hand pinch strength ($p = 0.03$), dominant-hand grip strength ($p = 0.002$), nondominant-

hand grip strength ($p = 0.004$), dominant-hand 9-HPT ($p = 0.001$), and nondominant-hand 9-HPT ($p = 0.046$).

Overall, mJOA scores improved significantly from a mean of 13.00 ± 2.9 preoperatively to 15.24 ± 2.5 postoperatively ($p < 0.001$); 64% of patients experienced an MCI improvement in their mJOA score, while 36% of patients remained stable, and no patient experienced a worse mJOA score. We then assessed the correlation between preoperative hand test percentile score and mJOA MCI improvement postoperatively (Table 4). We observed that worse preoperative dominant-hand pinch strength was the only hand function test significantly correlated to mJOA improvement postoperatively ($r = -0.34$, $p = 0.049$).

Conversely, we evaluated whether preoperative myelopathy severity correlated with postoperative hand function improvement (Table 5). Only the group with moderate mJOA/myelopathy had a majority of patients with improvement in dominant-hand grip strength (58%, $p = 0.04$); in the group with low mJOA scores (severe myelopathy), 30% of patients improved, and in the group with high mJOA scores (mild myelopathy), only 9% of patients improved. There was no association between hand testing MCI improvement and mJOA MCI improvement postoperatively.

Preoperative Stenosis Severity and Clinical Correlation

In order to quantitatively assess whether spinal cord compression related to preoperative and postoperative clinical measures, we classified preoperative MRI stenosis by Kang grade and compared it to hand test scores and mJOA scores before and after surgery. Dexterity (mean dominant-hand 9-HPT percentile) was less than 1 in patients with spinal cord signal change and was 15.9 in patients with subarachnoid effacement only ($p = 0.03$; Table 6). There was no association between Kang grade and preoperative mJOA score or postoperative MCI change in hand testing or mJOA score at 6 weeks. No correlation was found between level of compression and preoperative hand function, with the exception of patients with compression at C6–7. These patients had better 9-HPT scores in their nondominant hand than the patients without compression (9.46 ± 15.6 vs 0.39 ± 0.65 , $p = 0.045$). At the C7–T1 level, we found no correlation between compres-

TABLE 2. Association of baseline hand strength and dexterity testing percentile with baseline mJOA score

Variable	mJOA Score/Severity of Myelopathy* (percentile [SD])			p Value			
	Low/Severe (n = 10)	Moderate (n = 12)	High/Mild (n = 11)	Overall	Low/Severe vs Moderate	Low/Severe vs High/Mild	Moderate vs High/Mild
Pinch strength, preop, dom	25.8 (24.8)	15.7 (19.1)	57.3 (19.7)	<0.001	0.51	0.01	<0.001
Pinch strength, preop, nondom	42.8 (16.4)	50.8 (13.2)	36.0 (20.7)	0.13	0.52	0.63	0.11
Grip strength, preop, dom	20.7 (26.2)	13.9 (23.2)	46.7 (28.7)	0.01	0.82	0.07	0.01
Grip strength, preop, nondom	26.6 (27.1)	31.9 (33.3)	41.3 (37.3)	0.59	0.93	0.57	0.77
9-HPT dexterity, preop, dom	0.6 (1.4)	5.9 (11.9)	8.49 (16.3)	0.32	0.55	0.29	0.86
9-HPT dexterity, preop, nondom	3.2 (6.6)	6.5 (13.8)	10.9 (18.4)	0.45	0.85	0.43	0.73

dom = dominant; n = number of patients; nondom = nondominant.

Boldface type indicates statistical significance.

* Severe myelopathy, ≤ 11 points on mJOA scale; moderate myelopathy, 12–14 points; mild myelopathy, ≥ 15 points.

FIG. 1. Preoperative and postoperative mean percentiles for grip strength, pinch strength, and 9-HPT for the dominant hand (**A**) and nondominant hand (**B**). Measurements are scaled to 0 for all patients.

sion and hand function. Radiologically, all patients with central stenosis at C7–T1 also had concurrent moderate neuroforaminal stenosis of the exiting C8 nerve root, and all 5 of these patients had more severe central stenosis at higher levels in the cervical spine. Two of these patients underwent decompression and instrumentation across the C7–T1 level, and 1 of these 2 patients had Kang grade 3 central stenosis at C7–T1. The remaining 3 patients had symptoms that were believed to be unrelated to the C7–T1 level; these 3 patients all had Kang grade 1 central stenosis with mild to moderate neuroforaminal stenosis.

Discussion

There is a trend in spinal surgery toward using quantitative data to guide treatment decisions and outcomes.¹ Several tools have gained acceptance in CSM, specifically,

the mJOA scale,¹⁴ Nurick scale,¹¹ and walking test.¹² Hand dysfunction is among the most common and debilitating clinical features of CSM, yet these commonly used scales either address hand dysfunction subjectively or omit it.

Olindo et al.⁸ performed the 9-HPT in 40 patients and identified significant preoperative impairment, postoperative improvement, and a correlation with the mJOA score. The authors advocated implementation of the 9-HPT in the clinical evaluation of CSM. Similarly, John et al.² performed the 9-HPT in 47 patients with CSM. They identified prolonged baseline scores in 77% of patients, similar to the 79% of patients in our study. Their study did not demonstrate significant improvement in the 9-HPT 1 week after surgery, but significant improvement was seen 6 months postoperatively.

In distinction from prior studies, the current study evaluated hand function in three domains: pinch strength, grip

TABLE 3. Hand strength and dexterity testing percentiles before and after surgery in 33 patients with CSM

Variable	Percentile			p Value	% Patients w/ MCI Improvement
	Preop	Postop	Change		
Pinch strength, dom	32.6	41.4	8.8	0.03	33
Pinch strength, nondom	43.4	40.9	-2.5	0.67	24
Grip strength, dom	26.9	36.4	9.6	0.002	33
Grip strength, nondom	33.4	45.2	11.8	0.004	39
9-HPT dexterity, dom	5.2	11.2	6.0	0.001	67
9-HPT dexterity, nondom	7.0	10.2	3.2	0.046	73

Boldface type indicates statistical significance.

TABLE 4. Correlation of preoperative strength and dexterity percentile with postoperative mJOA MCI change in 33 patients treated for CSM

Variable	Correlation Coefficient (r)	p Value
Pinch strength, preop, dom	-0.34	0.049
Pinch strength, preop, nondom	0.04	0.84
Grip strength, preop, dom	-0.24	0.18
Grip strength, preop, nondom	-0.09	0.62
9-HPT dexterity, preop, dom	-0.04	0.82
9-HPT dexterity, preop, nondom	-0.05	0.80

Boldface type indicates statistical significance.

strength, and dexterity/coordination (9-HPT). Patients were most commonly affected at baseline in the 9-HPT in both frequency and severity. This result provides further evidence of discoordination as the predominant hand symptom in CSM, and indeed, the 9-HPT was the only clinical measure that correlated with imaging findings preoperatively. However, MCI gains were seen in all three domains following the intervention.

The current study further validates the findings of Olindo et al.⁸ and John et al.² in the sense that the 9-HPT is a useful objective measurement of hand dysfunction in CSM. Furthermore, clinically meaningful gains were

achieved in 24%–73% of patients, depending on the test, which indicates that hand function improves rapidly following surgical intervention, within 6–8 weeks. The benefits of surgical intervention for CSM are well demonstrated; therefore, a nonoperative CSM cohort would not have reflected equipoise in the design of our study. Synthesizing the results of Olindo et al.,⁸ John et al.,² and our study, we suggest that using the 9-HPT as a preoperative assessment for surgical decision-making is a useful and practical approach in a busy clinical setting. This suggestion does not exclude the use of pinch and grip tests in the clinical setting with further study and validation in additional cohorts of patients with myelopathy, but instead reflects the robust evidence supporting the use of the 9-HPT.

Both Olindo et al.⁸ and John et al.² demonstrated a correlation between mJOA and 9-HPT scores. The authors noted that this correlation further validated the use of the 9-HPT. An alternate interpretation is that the self-reported, multidomain mJOA adequately captures the objective findings of the 9-HPT. However, because neither the preoperative 9-HPT nor the preoperative grip strength correlated with the postoperative mJOA change in our study, we cannot support their conclusion.

Indeed, the only preoperative test that correlated with mJOA improvement was dominant-hand pinch strength. The poor association between the hand tests in this study and the mJOA score may reflect that the mJOA scale does not adequately quantify hand disability in CSM patients.

TABLE 5. Association of preoperative mJOA score with postoperative strength and dexterity MCI change

Variable	mJOA Score/Severity of Myelopathy (no. [%])			p Value
	Low/Severe (n = 10)	Moderate (n = 12)	High/Mild (n = 11)	
Pinch strength, MCI, dom				0.08
Stable	8 (80)	5 (42)	9 (82)	
Improved	2 (20)	7 (58)	2 (18)	
Pinch strength, MCI, nondom				0.60
Stable	8 (80)	10 (83)	7 (64)	
Improved	2 (20)	2 (17)	4 (36)	
Grip strength, MCI, dom				0.04
Declined	1 (10)	0 (0)	0 (0)	
Stable	6 (60)	5 (42)	10 (91)	
Improved	3 (30)	7 (58)	1 (9)	
Grip strength, MCI, nondom				0.82
Stable	7 (70)	7 (58)	6 (54)	
Improved	3 (30)	5 (42)	5 (46)	
9-HPT dexterity, MCI, dom				0.50
Declined	2 (20)	1 (8)	0 (0)	
Stable	1 (10)	4 (33)	3 (27)	
Improved	7 (70)	7 (58)	8 (73)	
9-HPT dexterity, MCI, nondom				0.49
Declined	3 (30)	1 (8)	2 (18)	
Stable	1 (10)	2 (17)	0 (0)	
Improved	6 (60)	9 (75)	9 (82)	

Boldface type indicates statistical significance.

TABLE 6. Association of radiographic cervical stenosis (Kang grade) with preoperative hand strength and dexterity tests

Variable	Percentile (SD)			p Value
	Subarachnoid Obliteration (n = 6)	Cord Deformity (n = 18)	Cord Signal Change (n = 9)	
Pinch strength, preop, dom	30.9 (31.4)	36.8 (28.9)	25.5 (22.5)	0.60
Pinch strength, preop, nondom	50.0 (0.0)	45.9 (17.9)	34.2 (20.4)	0.16
Grip strength, preop, dom	34.9 (31.0)	30.3 (31.5)	14.7 (20.7)	0.33
Grip strength, preop, nondom	51.9 (31.9)	35.9 (32.9)	16.1 (26.2)	0.10
9-HPT dexterity, preop, dom	15.9 (19.7)	4.03 (9.9)	0.3 (0.6)	0.03
9-HPT dexterity, preop, nondom	15.7 (24.0)	7.55 (11.8)	0.04 (0.1)	0.09

Boldface type indicates statistical significance.

However, we note that only the patients with moderate myelopathy as classified by the mJOA score actually experienced improvement in hand function (dominant-hand grip). This finding was also noted by Revanappa and Rajshekhar,¹¹ who reported that recovery rates were better in patients with moderate myelopathy than in those with mild or severe myelopathy. Accordingly, it is plausible to counsel patients with severe and mild myelopathy that the goal of surgical treatment should be to prevent functional decline, whereas patients with moderate myelopathy could be more likely to experience subjective and objective improvement in the 6-week perioperative period.

Regarding the radiographic severity of CSM, our findings are in line with those of Nouri et al.,⁷ who demonstrated that radiographic spinal cord compression correlates with worse clinical impairment. However, the only preoperative hand test in our study that correlated with preoperative imaging was the 9-HPT. The remaining preoperative hand tests, as well as the postoperative improvement in the hand tests and the mJOA score, did not correlate with the imaging findings (data not presented). Interestingly, we observed better nondominant hand function on the 9-HPT if there was compression at the C6–7 level. We speculate that this finding may indicate that a lower degree of upper cervical spinal cord compression preserves the function of the proximal upper extremity muscle groups innervated by nerve roots above C8, stabilizing the hands and allowing better hand dexterity. In addition, 5 patients in our cohort had central stenosis at the C7–T1 level, which was not specifically correlated with hand function. These 5 patients all had both central compression and mild to moderate neuroforaminal compression. Because both types of compression were present, it was difficult to determine whether patients' symptoms were caused by central stenosis/myelopathy or neuroforaminal stenosis/radiculopathy. Because of the frequent coincidence of central and foraminal stenosis at all cervical levels, the most accurate way to study the differential effects of central versus foraminal stenosis would be with preoperative electromyography and nerve conduction studies. These tests were not performed as part of this study, but future studies would benefit from this preoperative assessment. Taken together, these results emphasize the need to assess the entire clinical presentation of the patient with CSM for surgical decision-making.

The first limitation of this study is the single postoperative assessment time point. Hand function likely continues to improve beyond 6–8 weeks. Thus, our results, though significant, may underestimate the ultimate extent of the recovery of hand function in these patients. Those with severe myelopathy as assessed by the mJOA scale or with severe spinal cord compression as assessed by the Kang classification may require a year or more to experience improvement. A future study investigating the kinetics of recovery and the long-term assessment of hand function would be a valuable addition to this work. We also acknowledge the limited size of the study cohort.

Conclusions

Patients with CSM achieved significant improvement in hand strength and dexterity postoperatively. Baseline strength measures correlated best with the preoperative mJOA myelopathy score; however, baseline dexterity correlated best with the severity of stenosis on MRI. The majority of patients experienced MCI improvement in dexterity. Baseline pinch strength correlated with postoperative mJOA MCI improvement, and patients with a moderate baseline mJOA score were the most likely to have an improvement in dominant-hand grip strength postoperatively.

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References

- Bennett C, Xiong G, Hu S, Wood K, Kamal RN: What is the state of quality measurement in spine surgery? *Clin Orthop Relat Res* **476**:725–731, 2018
- John S, Moorthy RK, Sebastian T, Rajshekhar V: Evaluation of hand function in healthy individuals and patients undergoing uninstrumented central corpectomy for cervical spondylotic myelopathy using nine-hole peg test. *Neurol India* **65**:1025–1030, 2017
- Kang Y, Lee JW, Koh YH, Hur S, Kim SJ, Chai JW, et al: New MRI grading system for the cervical canal stenosis. *AJR Am J Roentgenol* **197**:W134–W140, 2011
- Lang CE, Edwards DF, Birkenmeier RL, Dromerick AW:

- Estimating minimal clinically important differences of upper-extremity measures early after stroke. **Arch Phys Med Rehabil** **89**:1693–1700, 2008
5. Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S: Grip and pinch strength: normative data for adults. **Arch Phys Med Rehabil** **66**:69–74, 1985
 6. Mathiowetz V, Wiemer DM, Federman SM: Grip and pinch strength: norms for 6- to 19-year-olds. **Am J Occup Ther** **40**:705–711, 1986
 7. Nouri A, Martin AR, Kato S, Reihani-Kermani H, Riehlm LE, Fehlings MG: The relationship between MRI signal intensity changes, clinical presentation, and surgical outcome in degenerative cervical myelopathy: analysis of a global cohort. **Spine (Phila Pa 1976)** **42**:1851–1858, 2017
 8. Olindo S, Signate A, Richech A, Cabre P, Catonne Y, Smadja D, et al: Quantitative assessment of hand disability by the Nine-Hole-Peg Test (9-HPT) in cervical spondylotic myelopathy. **J Neurol Neurosurg Psychiatry** **79**:965–967, 2008
 9. Oxford Grice K, Vogel KA, Le V, Mitchell A, Muniz S, Vollmer MA: Adult norms for a commercially available Nine Hole Peg Test for finger dexterity. **Am J Occup Ther** **57**:570–573, 2003
 10. Poole JL, Burtner PA, Torres TA, McMullen CK, Markham A, Marcum ML, et al: Measuring dexterity in children using the Nine-hole Peg Test. **J Hand Ther** **18**:348–351, 2005
 11. Revanappa KK, Rajshekhar V: Comparison of Nurick grading system and modified Japanese Orthopaedic Association scoring system in evaluation of patients with cervical spondylotic myelopathy. **Eur Spine J** **20**:1545–1551, 2011
 12. Singh A, Crockard HA: Quantitative assessment of cervical spondylotic myelopathy by a simple walking test. **Lancet** **354**:370–373, 1999
 13. Singh A, Tetreault L, Casey A, Laing R, Statham P, Fehlings MG: A summary of assessment tools for patients suffering from cervical spondylotic myelopathy: a systematic review on validity, reliability and responsiveness. **Eur Spine J** **24** (Suppl 2):209–228, 2015
 14. Tetreault L, Kopjar B, Nouri A, Arnold P, Barbagallo G, Bartels R, et al: The modified Japanese Orthopaedic Association scale: establishing criteria for mild, moderate and severe impairment in patients with degenerative cervical myelopathy. **Eur Spine J** **26**:78–84, 2017
 15. Tetreault L, Wilson JR, Kotter MRN, Nouri A, Côté P, Kopjar B, et al: Predicting the minimum clinically important difference in patients undergoing surgery for the treatment of degenerative cervical myelopathy. **Neurosurg Focus** **40**(6):E14, 2016
 16. Tracy JA, Bartleson JD: Cervical spondylotic myelopathy. **Neurologist** **16**:176–187, 2010
 17. Villafañe JH, Valdes K, Bertozzi L, Negrini S: Minimal clinically important difference of grip and pinch strength in women with thumb carpometacarpal osteoarthritis when compared to healthy subjects. **Rehabil Nurs** **42**:139–145, 2017

Disclosures

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