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A comparison of dysphagia rates between long-segment anterior versus posterior cervical fusion

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OBJECTIVE The goal of this study was to compare rates of dysphagia and patient-reported outcomes (PROs) following long-segment (≥ 3 levels) anterior cervical spinal fusion (ACF) and posterior cervical spinal fusion (PCF) at 3 and 12 months postoperatively. PROs were also compared for patients with dysphagia versus those without dysphagia.

METHODS A prospectively collected quality improvement database was used to identify patients who had a long-segment cervical spinal fusion. Cohorts were divided into ACF and PCF groups. Eating Assessment Tool–10 scores and PROs were obtained for all patients preoperatively and at 3 and 12 months postoperatively to compare. Multivariate analysis was also performed to evaluate risk factors for dysphagia.

RESULTS A total of 132 patients met the inclusion criteria, 77 of whom had undergone ACF and 55 of whom had undergone PCF. Dysphagia rates between ACF and PCF cohorts were similar at baseline (13.0% vs 18.2%, p = 0.4). New-onset dysphagia rates were also comparable at 3-month follow-up (39.7% vs 23.1%, p = 0.08) and 12-month follow-up (32.6% vs 32.4%, p > 0.99). Patients who underwent PCF had worse Neck Disability Index (NDI) scores at 3 months than did patients with ACF (13.67 ± 9.49 vs 10.55 ± 6.24, respectively; p = 0.03). There were significantly higher NDI scores for patients with dysphagia at 3 months in both the ACF and PCF groups and at 12 months for those in the PCF group. Analogously, EuroQol–5 Dimensions scores were worse for patients with dysphagia; however, this was only significant for patients in the ACF group at 3 months. There were no significant risk factors for the development of dysphagia found on multivariate analysis.

CONCLUSIONS Similar rates and severity of dysphagia were seen following ACF and PCF at 3- and 12-month follow-up. This suggests that long-term dysphagia following cervical fusion surgery may be due to structural changes from the fusion rather than the surgical approach. However, the ACF cohort was significantly younger, and this may have partially accounted for the findings. PROs were also compared for patients with and without dysphagia, demonstrating worsened outcomes in some domains for patients who presented with dysphagia at 3- and 12-month follow-up. This suggests that dysphagia may be associated with a decreased quality of life after cervical fusion.

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KEYWORDS dysphagia; Eating Assessment Tool–10; EAT-10; patient-reported outcomes; anterior cervical discectomy and fusion; posterior cervical fusion; long-segment cervical fusion

Cervical spinal fusion is indicated for a variety of degenerative conditions, including cervical spondylotic myelopathy and medically refractory cervical radiculopathy.[1] Surgery may be performed via anterior and/or posterior approaches. The anterior approach involves dissection of the platysma muscle before retracting structures including the carotid sheath and esophagus. Conversely, the posterior approach involves the dissection and retraction of paraspinal musculature to expose the cervical posterior elements. Although the anterior approach is more commonly used for single- and two-level degenerative pathologies,[2] the decision regarding which approach to use for multilevel cervical disease is multifaceted and remains controversial.

Dysphagia, the impairment of swallowing function, represents a significant adverse outcome in patients un-

ABBREVIATIONS ACDF = anterior cervical discectomy and fusion; ACF = anterior cervical spinal fusion; ASA = American Society of Anesthesiologists; EAT-10 = Eating Assessment Tool–10; EQ-5D = EuroQol–5 Dimensions; EQ-VAS = EuroQol visual analog scale; NASS = North American Spine Society; NDI = neck disability index; NRS-AP = numeric rating scale arm pain; NRS-NP = numeric rating scale neck pain; PCF = posterior cervical spinal fusion; PRO = patient-reported outcome; QOL = quality of life.

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dergoing cervical spine surgery, and its presence may severely negatively impact quality of life (QOL) postoperatively.[3] Several risk factors have been identified in the development of postoperative dysphagia. The use of a cervical plate, use of bone morphogenetic protein–2, an upper surgical level at C3/4, female sex, and an operation involving > 1 surgical level have been indicated to increase the risk of dysphagia after anterior cervical discectomy and fusion (ACDF).[4] Additionally, the anterior approach to cervical spinal fusion introduces significant stress on the esophagus and surrounding structures through dissection and retraction, increasing the risk for postoperative dysphagia.[5] Although few studies have investigated dysphagia following posterior cervical spinal fusion (PCF), some have suggested that dysphagia following PCF may be due to loss of motion in the cervical spine from the procedure.[6,7] However, risk factors for dysphagia following PCF remain poorly understood. Despite the prevalence of these procedures, there remains a gap in the current literature comparing rates of long-term dysphagia between anterior and posterior surgical approaches to cervical spinal fusion. Furthermore, despite the prevalence of dysphagia in the general population, it is not commonly screened for prior to cervical spinal surgery.[8]

Although dysphagia rates following cervical fusion have been cited in the literature, the variability in measurement tools and follow-up times lead to a wide range of reported values. Additionally, many of these studies use nonvalidated measures such as the Bazaz dysphagia score to measure dysphagia. The Bazaz dysphagia score is the most cited dysphagia questionnaire in the spine surgery literature;[9] however, it does not correlate with QOL scores.[8,10] Using validated measurements for dysphagia is important in further understanding the impact of dysphagia on patients following cervical spinal fusion.

Given the paucity of research on dysphagia after cervical fusion and the impact of this disorder on QOL outcomes, the aim of this study was to use a validated measurement of dysphagia to compare rates following long-segment anterior cervical spinal fusion (ACF) and PCF and to investigate the impact of the disorder on patient-reported outcomes (PROs). In doing so we hope to better understand the true rate of long-term dysphagia before and after these procedures and to evaluate risk factors and potential causes of the disorder. We hypothesize that dysphagia is a common adverse outcome for both procedures.

Methods

Patient Selection

This study was a retrospective review of data from a prospectively collected Spine Quality Registry. Patients were included if they had a cervical fusion of ≥ 3 segmental levels performed between November 2020 and May 2022. Cohorts were then created based on whether the procedure was an ACF or a PCF. The ACF group consisted of patients who underwent ACDF and/or anterior cervical corpectomy and fusion. These procedures were performed by the same group of surgeons across four centers. Preoperative demographics, operative indications, and clinical characteristics were collected for all patients.

Dysphagia Evaluation

Eating Assessment Tool–10 (EAT-10) scores were evaluated to assess clinically significant dysphagia and its severity. The EAT-10 is a validated measurement of dysphagia that can be collected in < 2 minutes.[11,12] To calculate an EAT-10 score, 10 questions are posed to the patient, scored using a 5-point Likert scale, and then added to obtain a score between 0 and 40. A score of ≥ 3 indicates clinically significant dysphagia and a higher score indicates more severe dysphagia. The EAT-10 has been shown to demonstrate excellent internal consistency, test–retest reliability, and criterion-based validity.[13] EAT-10 scores were collected preoperatively, at 3 months postoperatively, and at 12 months postoperatively.

PRO Data

PROs were collected preoperatively, at 3-month follow-up, and at 12-month follow-up. The PROs collected included the Neck Disability Index (NDI), numeric rating scale for neck pain (NRS-NP), numeric rating scale for arm pain (NRS-AP), EuroQol–5 Dimensions (EQ-5D), EuroQol visual analog scale (EQ-VAS), and North American Spine Society (NASS) patient satisfaction index.

The NDI is assessed as a value of 0–50 based on 10 questions scored using a 6-point Likert scale. The NDI represents how a patient's neck pain affects their ability to manage in everyday life, with a greater score indicating more severe disability.[14]

NRS-NP is assessed on a scale of 0–10 reflecting the patient's subjective experience of neck pain, with a greater score indicating a higher level of pain. Similarly, NRS-AP is given as a score of 0–10 based on the patient's perceived level of arm pain.[15]

The EQ-5D score is a measurement of the patient's overall health state based on the following five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Each dimension is scored from 1 to 3. A score is then calculated from the EQ-5D to represent the patient's state of health, which can range from scores < 0 (worse than death) to 1 (full health).[16,17]

EQ-VAS is a score of 0–100 given directly by the patient as a representation of their overall health-related QOL, with 100 being the best quality possible and 0 being the worst quality possible.[16,17]

The NASS patient satisfaction index is measured on a scale of 1–4, with scores of 1 and 2 being considered satisfied and scores of 3 and 4 being considered unsatisfied with the procedure outcome.

Statistical Analyses

All data were securely collected and managed using REDCap (Research Electronic Data Capture). Univariate analyses were performed to compare baseline and outcome variables between the ACF and PCF cohorts and assess significant differences. Continuous variables were summarized as means and standard deviations and compared using the independent samples t-test. Categorical variables were presented as counts and percentage of the overall cohort and compared using Pearson's chi-square

test or Fisher's exact test, where appropriate. Multivariate logistic regression analyses were used to assess independent predictors of dysphagia. All baseline demographic and clinical variables with a p value < 0.2 were used in the analysis. Anterior approach with a reference of posterior approach was also analyzed in the multivariate analysis separately. All analyses were performed using R Statistical Software (R Foundation for Statistical Computing, version 4.1.3). The p values were two-tailed, and statistical significance was assumed when a p value < 0.05 was observed.

Results

A total of 132 patients were identified who met the inclusion criteria, 77 of whom had an ACF and 55 who had a PCF. Of these, 119 (90.2%) had a 3-month follow-up response and 94 (71.2%) had a 12-month follow-up response.

Demographics

Patients who underwent ACF did not differ significantly from those who underwent PCF in terms of body mass index, tobacco use, race, ethnicity, or level of education. There was a significant difference in age between the two cohorts, with the ACF group having a younger mean age (58.78 ± 9.46 vs 64.54 ± 11.01 years, respectively; p < 0.01). Due to this age difference, expected differences in insurance status, medical comorbidities such as coronary artery disease, and employment were seen between the ACF and PCF groups. These results and other demographic characteristics can be seen in Table 1.

Baseline Clinical and Surgical Characteristics

Consistent with their younger age, patients within the ACF cohorts had a lower percentage of American Society of Anesthesiologists (ASA) grade III or IV than the PCF cohort (57.1% vs 81.8%, respectively; p < 0.01). The ACF group also had fewer revision surgeries (14.3% vs 36.4%, p < 0.01); more radiculopathy as a surgical indication (72.7% vs 29.1%, p < 0.01); and higher rates of independent ambulation preoperatively (92.2% vs 67.3%, p < 0.01). Furthermore, the ACF group had higher rates of preoperative neck pain symptoms (83.1% vs 61.8%, p < 0.01). Additionally, the ACF cohort had fewer levels fused during their operation (3.10 ± 0.31 vs 5.45 ± 1.56, p < 0.01) (Table 2).

Dysphagia Comparison by Approach

At baseline, 3-month follow-up, and 12-month follow-up, the mean EAT-10 scores were similar between the ACF and PCF cohort. The average increase in EAT-10 score from baseline was also similar between the ACF and PCF groups at both 3-month and 12-month follow-up. There were similar percentages of patients with dysphagia at baseline, 3-month follow-up, and 12-month follow-up between the ACF and PCF cohorts. Notably, the baseline dysphagia rate was 13.0% for the ACF group and 18.2% for the PCF group. When excluding patients with preoperative dysphagia from follow-up analysis, similar rates of dysphagia were still seen. The mean EAT-10 scores and dysphagia rates are summarized in Table 3.

A subgroup analysis was performed in patients with three-level ACF to see if there was a difference in dysphagia by segments fused. Eight of 13 patients (61.5%) who underwent fusion from C3 to C6 had dysphagia at 12-month follow-up compared with 9 of 31 patients

TABLE 1. Demographic characteristics in 132 patients who underwent cervical fusion surgery

Characteristic	ACF, n = 77	PCF, n = 55	p Value
Age	58.78 ± 9.46	64.54 ± 11.01	**<0.01**
BMI	32.01 ± 5.94	30.86 ± 7.54	0.3
Female sex	48 (62.3%)	22 (40.0%)	**0.01**
Payer status			**0.04**
Medicare	22 (28.6%)	25 (45.5%)	
Medicare Advantage	5 (6.5%)	8 (14.5%)	
Medicaid	1 (1.3%)	0 (0%)	
State specific, non-Medicaid	7 (9.1%)	1 (1.8%)	
Private/other	42 (54.5%)	21 (38.2%)	
Current tobacco use	14 (18.2%)	12 (21.8%)	0.6
Former tobacco use	21 (27.3%)	13 (23.6%)	0.6
Comorbidities			
Diabetes	13 (16.9%)	15 (27.3%)	0.2
Coronary artery disease	9 (11.7%)	15 (27.3%)	**0.02**
Peripheral vascular disease	1 (1.3%)	0 (0%)	>0.99
Anxiety disorder	23 (29.9%)	17 (30.9%)	0.9
Depression	22 (28.6%)	18 (32.7%)	0.6
Arthritis of major joint	29 (37.7%)	20 (36.4%)	0.9
Chronic renal disease	0 (0%)	0 (0%)	>0.99
Chronic pulmonary disease	10 (13.0%)	9 (16.4%)	0.6
Osteoporosis	3 (3.9%)	1 (1.8%)	0.6
Parkinson disease	0 (0%)	0 (0%)	>0.99
Multiple sclerosis	1 (1.3%)	0 (0%)	>0.99
Hispanic ethnicity	0 (0%)	1 (1.8%)	>0.99
Race			
Asian	1 (1.3%)	0 (0%)	>0.99
American Indian	0 (0%)	1 (1.8%)	>0.99
Black or African American	8 (10.4%)	6 (10.9%)	0.9
White	67 (87.0%)	47 (85.5%)	0.8
≥2 races	1 (1.3%)	0 (0%)	>0.99
≥4 yrs of college	18 (23.4%)	16 (29.1%)	0.5
Use of workers' compensation	1 (1.3%)	0 (0%)	>0.99
Liability & disability claim	5 (6.5%)	3 (5.5%)	>0.99
Employed or employed on leave	42 (54.5%)	13 (23.6%)	**<0.01**

BMI = body mass index.
Unless otherwise indicated, values are expressed as the number of patients (%) or the mean ± SD. Boldface type indicates statistical significance.

TABLE 2. Baseline clinical characteristics in 132 patients who underwent cervical fusion surgery

Characteristic	ACF, n = 77	PCF, n = 55	p Value
Revision	11 (14.3%)	20 (36.4%)	<0.01
ASA grade			<0.01
I/II	33 (42.9%)	10 (18.2%)	
III/IV	44 (57.1%)	45 (81.8%)	
Indications for surgery			
Radiculopathy	56 (72.7%)	16 (29.1%)	<0.01
Myelopathy	44 (57.1%)	44 (80.0%)	<0.01
Neck pain from instability	7 (9.1%)	3 (5.5%)	0.5
Structural pathology			
Disc herniation	22 (28.6%)	9 (16.4%)	0.1
Spondylosis/disc space collapse	1 (1.3%)	1 (1.8%)	>0.99
Stenosis	76 (98.7%)	52 (94.5%)	0.3
Pseudarthrosis	0 (0%)	4 (7.3%)	0.028
Adjacent-segment disease	7 (9.1%)	11 (20.0%)	0.07
Primary Sxs			
Neck pain	64 (83.1%)	34 (61.8%)	<0.01
Arm pain	59 (76.6%)	25 (45.5%)	<0.01
Myelopathy	42 (54.5%)	42 (76.4%)	0.01
Motor weakness	28 (36.4%)	18 (32.7%)	0.7
Location of pain			<0.01
Arm	16 (20.8%)	7 (12.7%)	
Neck	14 (18.2%)	15 (27.3%)	
Arm = neck pain	43 (55.8%)	19 (34.5%)	
No pain	4 (5.2%)	14 (25.5%)	
Motor deficits	36 (46.8%)	33 (60.0%)	0.1
Independent ambulation	71 (92.2%)	37 (67.3%)	<0.01
Listhesis or dynamic instability	20 (26.0%)	19 (34.5%)	0.3
Anticoagulant use	22 (28.6%)	24 (43.6%)	0.07
Opioid/narcotic pain medication use	25 (32.5%)	12 (21.8%)	0.2
Mean no. of levels fused	3.10 ± 0.31	5.45 ± 1.56	<0.01

Sxs = symptoms.
Unless otherwise indicated, values are expressed as the number of patients (%) or the mean ± SD. Boldface type indicates statistical significance.

(29.0%) receiving fusion from C4 to C7 (p = 0.04). A subgroup analysis by age was also performed and showed no differences in dysphagia rates or mean EAT-10 scores when using age cutoffs of 55, 60, or 65 years for the ACF and PCF cohorts. Six patients in the ACF and 5 in the PCF group who had no dysphagia at 3 months developed the disorder at 12 months.

PRO Comparison by Approach

At baseline, all PROs were similar between the ACF and PCF groups, with the exception of NRS-AP, which was higher for the ACF than for the PCF group (6.13 ± 3.10 vs 4.82 ± 3.16, respectively; p = 0.02). As such, when considering change from baseline, there was a significantly larger improvement in NRS-AP seen in the ACF group at 3-month follow-up (–4.06 ± 3.31 vs –2.08 ± 3.77; p < 0.01). In addition, NDI was higher for the PCF group at 3 months (10.55 ± 6.24 for ACP vs 13.67 ± 9.49 for PCF; p = 0.03). Consequently, there was also less improvement in NDI from baseline seen in the PCF group (–10.39 ± 8.37 for ACP vs –5.94 ± 9.02 for PCP; p < 0.01). However, at 12 months, NDI was not significantly different between the two groups and there were similar improvements in NDI from baseline. NRS-NP, EQ-5D, and EQ-VAS all showed similar values between the two cohorts at baseline and follow-up intervals. NASS satisfaction scores were also similar between the groups at both follow-up times, and showed that a large majority of patients were satisfied with their procedure from either approach (Table 3).

PROs by Dysphagia Outcome

All PROs for patients in the ACF group with and without dysphagia were similar at baseline, 3-month and 12-month follow-up. At 3 months, NDI score was significantly higher for those with dysphagia compared to those without (12.27 ± 6.54 vs 9.29 ± 5.76; p < 0.05). Patients in the ACF group who had dysphagia at 3 months also had worse NRS-AP scores (2.70 ± 2.81 vs 1.24 ± 1.95, p = 0.01); less improvement in NRS-AP (–3.07 ± 3.13 vs –4.78 ± 3.28, p = 0.03); worse EQ-5D scores (0.71 ± 0.16 vs 0.79 ± 0.14, p = 0.03); and less improvement in EQ-5D (0.17 ± 0.22 vs 0.29 ± 0.21, p = 0.02) compared with those who did not develop dysphagia (Table 4). At 12 months, patients in the ACF group who had dysphagia had worse NRS-NP scores (4.43 ± 2.89 vs 2.69 ± 2.88, p = 0.04); less improvement in NRS-NP (–1.81 ± 2.87 vs –3.66 ± 3.06, p = 0.03); and worsened NASS satisfaction scores (81.0% vs 100%; p = 0.02) (Table 5). The entire PRO comparison for patients in the ACF group with and without dysphagia can be found in Tables 4 and 5.

For patients who underwent PCF, all baseline PROs were similar between patients who had dysphagia and those who did not at 3 and 12 months, with the one exception of a higher baseline NDI in patients who developed dysphagia at 3 months (24.53 ± 8.28 vs 16.90 ± 9.51, p = 0.01). At 3 months, patients in the PCF group who had dysphagia had a worse NDI (17.47 ± 9.39 vs 11.58 ± 9.03, p = 0.04); worse NRS-NP scores (4.29 ± 2.85 vs 2.61 ± 2.20, p = 0.03); and worse NRS-AP scores (3.82 ± 2.65 vs 2.13 ± 2.49, p = 0.03) compared to those who did not develop dysphagia (Table 4). At 12 months, patients in the PCF group who had dysphagia had a worse NDI (12.82 ± 6.62 vs 7.46 ± 6.86, p = 0.02) (Table 5). The entire PRO comparison for patients with and without dysphagia after PCF can be found in Tables 4 and 5.

PRO comparisons were reproduced after excluding patients with baseline dysphagia. At 3 months, patients with dysphagia following ACF had worse EQ-5D scores (0.71 ± 0.15 vs 0.80 ± 0.14, p = 0.03). Patients with dysphagia at 3 months following PCF had worse NDI at baseline (25.33 ± 7.87 vs 16.47 ± 9.35, p = 0.01) and worse NRS-AP scores at 3-month follow-up (4.11 ± 2.32 vs 2.03 ± 2.47, p = 0.03) (Table 6). All other results for the PRO comparison after excluding patients with baseline dysphagia showed no statistical differences. These results are shown in Tables 6 and 7.

TABLE 3. Dysphagia and PRO comparison by surgical approach in patients who underwent cervical fusion surgery

Characteristic	ACF	PCF	p Value
EAT-10			
Baseline	2.08 ± 6.27 (n = 77)	2.76 ± 6.78 (n = 55)	0.6
3 mos	4.56 ± 7.22 (n = 71)	4.38 ± 7.58 (n = 48)	0.9
3-mo change	2.75 ± 8.86 (n = 71)	1.33 ± 5.61 (n = 48)	0.3
12 mos	4.92 ± 6.84 (n = 53)	4.49 ± 6.63 (n = 41)	0.8
12-mo change	2.55 ± 7.99 (n = 53)	1.63 ± 5.49 (n = 41)	0.5
Dysphagia, EAT-10 ≥3			
Baseline	10/77 (13.0%)	10/55 (18.2%)	0.4
3 mos	30/71 (42.3%)	17/48 (35.4%)	0.5
3-mo new onset	25/63 (39.7%)	9/39 (23.1%)	0.08
12 mos	21/53 (39.6%)	17/41 (41.5%)	0.9
12-mo new onset	15/46 (32.6%)	11/34 (32.4%)	>0.99
NDI			
Baseline	20.78 ± 9.77	19.89 ± 9.97	0.6
3 mos	10.55 ± 6.24	13.67 ± 9.49	**0.03**
3-mo change from baseline	–10.39 ± 8.37	–5.94 ± 9.02	**<0.01**
12 mos	9.19 ± 7.92	9.68 ± 7.19	0.8
12-mo change from baseline	–11.65 ± 9.60	–8.02 ± 8.21	0.06
NRS-NP			
Baseline	6.13 ± 2.83	5.93 ± 2.97	0.7
3 mos	2.70 ± 2.43	3.21 ± 2.55	0.3
3-mo change from baseline	–3.51 ± 2.87	–2.58 ± 2.99	0.09
12 mos	3.31 ± 2.99	2.80 ± 2.67	0.4
12-mo change from baseline	–3.02 ± 3.15	–2.59 ± 3.87	0.5
NRS-AP			
Baseline	6.13 ± 3.10	4.82 ± 3.16	**0.02**
3 mos	1.86 ± 2.44	2.73 ± 2.65	0.07
3-mo change from baseline	–4.06 ± 3.31	–2.08 ± 3.77	**<0.01**
12 mos	2.07 ± 3.06	2.10 ± 2.85	>0.99
12-mo change from baseline	–3.76 ± 3.56	–2.37 ± 4.00	0.08
EQ-5D			
Baseline	0.51 ± 0.22	0.51 ± 0.24	>0.99
3 mos	0.76 ± 0.15	0.71 ± 0.16	0.09
3-mo change from baseline	0.24 ± 0.22	0.19 ± 0.24	0.2
12 mos	0.77 ± 0.18	0.71 ± 0.19	0.1
12-mo change from baseline	0.24 ± 0.20	0.18 ± 0.26	0.3
EQ-VAS			
Baseline	63.35 ± 17.87	65.53 ± 14.65	0.5
3 mos	70.72 ± 16.74	68.44 ± 14.15	0.4
3-mo change from baseline	6.87 ± 18.38	1.48 ± 17.99	0.1
12 mos	65.55 ± 20.58	71.80 ± 18.72	0.1
12-mo change from baseline	1.49 ± 15.95	6.76 ± 22.64	0.2
NASS satisfaction score at 3 mos			0.4
1/2, satisfied	68 (95.8%)	44 (91.7%)	
3/4, unsatisfied	3 (4.2%)	4 (8.3%)	
NASS satisfaction score at 12 mos			0.6
1/2, satisfied	49 (92.5%)	36 (87.8%)	
3/4, unsatisfied	4 (7.5%)	5 (12.2%)	

The new-onset categories have excluded patients with baseline dysphagia. Unless otherwise indicated, values are expressed as the number of patients (%) or the mean score ± SD. Boldface type indicates statistical significance.

TABLE 4. The 3-month PRO comparison stratified by clinical dysphagia at 3-month follow-up, by surgical approach

Characteristic	ACF, n = 71			PCF, n = 48		
	Dysphagia, n = 30	No Dysphagia, n = 41	p Value	Dysphagia, n = 17	No Dysphagia, n = 31	p Value
NDI						
Baseline	21.40 ± 8.76	20.61 ± 9.95	0.7	24.53 ± 8.28	16.90 ± 9.51	**0.01**
3 mos	12.27 ± 6.54	9.29 ± 5.76	**<0.05**	17.47 ± 9.39	11.58 ± 9.03	**0.04**
3-mo change from baseline	–9.13 ± 7.40	–11.32 ± 8.99	0.3	–7.06 ± 9.60	–5.32 ± 8.79	0.5
NRS-NP						
Baseline	6.47 ± 2.53	6.02 ± 2.87	0.5	6.71 ± 2.47	5.29 ± 2.99	0.1
3 mos	3.13 ± 2.54	2.39 ± 2.33	0.2	4.29 ± 2.85	2.61 ± 2.20	**0.03**
3-mo change from baseline	–3.33 ± 2.70	–3.63 ± 3.01	0.7	–2.41 ± 3.26	–2.68 ± 2.88	0.8
NRS-AP						
Baseline	5.77 ± 3.27	6.02 ± 3.00	0.7	5.41 ± 3.06	4.48 ± 3.13	0.3
3 mos	2.70 ± 2.81	1.24 ± 1.95	**0.01**	3.82 ± 2.65	2.13 ± 2.49	**0.03**
3-mo change from baseline	–3.07 ± 3.13	–4.78 ± 3.28	**0.03**	–1.59 ± 4.49	–2.35 ± 3.36	0.5
EQ-5D						
Baseline	0.54 ± 0.20	0.50 ± 0.23	0.4	0.47 ± 0.24	0.55 ± 0.22	0.2
3 mos	0.71 ± 0.16	0.79 ± 0.14	**0.03**	0.71 ± 0.16	0.71 ± 0.16	>0.99
3-mo change from baseline	0.17 ± 0.22	0.29 ± 0.21	**0.02**	0.24 ± 0.24	0.15 ± 0.24	0.2
EQ-VAS						
Baseline	62.83 ± 15.35	64.59 ± 19.22	0.7	65.29 ± 14.73	67.87 ± 14.43	0.6
3 mos	67.83 ± 17.65	72.83 ± 15.92	0.2	67.35 ± 11.61	69.03 ± 15.51	0.7
3-mo change from baseline	5.00 ± 17.81	8.24 ± 18.89	0.5	2.06 ± 18.80	1.16 ± 17.84	0.9
NASS satisfaction score at 3 mos			>0.99			0.6
1/2, satisfied	29 (96.7%)	39 (95.1%)		15 (88.2%)	29 (93.5%)	
3/4, unsatisfied	1 (3.3%)	2 (4.9%)		2 (11.8%)	2 (6.5%)	

Unless otherwise indicated, values are expressed as the number of patients (%) or the mean score ± SD. Boldface type indicates statistical significance.

Multivariate Analyses

At 3 months and 12 months, there were no significant risk factors for the development of dysphagia. Anterior surgical approach was not seen to be a significant risk factor for the development of dysphagia compared to posterior fusion at 3 months (OR 1.40, 95% CI 0.95–2.07; p = 0.09) or 12 months (OR 1.63, 95% CI 0.97–2.72; p = 0.07), although it did trend toward significance (Table 8).

Discussion

Dysphagia is a common occurrence following cervical spinal fusion, and can negatively impact patient outcomes. It remains poorly studied and the cause and risk factors remain poorly understood. Rates of dysphagia following cervical spinal fusion vary widely in the literature due to differences in defining dysphagia and the tools used to quantify it. The majority of previous studies investigate dysphagia following anterior fusion approaches and few studies investigate dysphagia after PCF. A recent review of the literature on dysphagia following ACF found that the incidence varied from 1.9% to 63.6%, with a mean of 19.4% (95% CI 9.6%–29.1%).[18] Included in the review were 73 studies that used different dysphagia measures and follow-up times, leading to a wide range of results. Dysphagia rates following PCF range from 1.67% to 27%.[6,7,19] Again, each study used different follow-up times and methods of measuring dysphagia. Due to the variability and inconsistency in measurements, understanding rates of dysphagia following cervical spinal fusion and the risk factors involved remain controversial.

In our study, EAT-10 was used as a measurement due to its tested validity, excellent internal consistency, test–retest reliability, and ease of collection.[11–13] Therefore, using EAT-10 as a measurement in this study strengthens the likelihood of the observed results representing true dysphagia in the study groups. To our knowledge, this study is the first to investigate long-term dysphagia following PCF by using a validated, noninvasive clinical scoring system as a measurement of dysphagia.

We found that 3 months after long-segment cervical fusion, 39.7% of patients in the ACF group and 23.1% of patients in the PCF group without preoperative dysphagia had developed the disorder. Although this was not statistically significant, there was a trend toward significance. The difference in dysphagia rates at 3 months may be due to anterior approach risks such as pharyngeal swelling and esophageal manipulation. At 12 months, however, the rates were nearly identical, with 32.6% of patients who underwent ACF and 32.4% of those who received PCF having developed new-onset dysphagia. At the 12-month time frame it is likely that symptoms resulting from pharyngeal swelling and esophageal manipulation have resolved, leading to the similarities in dysphagia

TABLE 5. The 12-month PRO comparison stratified by clinical dysphagia at 12-month follow-up, by surgical approach

Characteristic	ACF, n = 53			PCF, n = 41		
	Dysphagia, n = 21	No Dysphagia, n = 32	p Value	Dysphagia, n = 17	No Dysphagia, n = 24	p Value
NDI						
Baseline	21.86 ± 9.39	19.88 ± 8.67	0.4	20.59 ± 9.07	15.67 ± 9.95	0.1
12 mos	11.76 ± 8.73	7.78 ± 7.00	0.07	12.82 ± 6.62	7.46 ± 6.86	**0.02**
12-mo change from baseline	–10.10 ± 9.45	–12.09 ± 9.34	0.5	–7.76 ± 8.02	–8.21 ± 8.52	0.9
NRS-NP						
Baseline	6.24 ± 2.83	6.34 ± 2.52	0.9	5.53 ± 2.76	5.29 ± 3.30	0.8
12 mos	4.43 ± 2.89	2.69 ± 2.88	**0.04**	3.71 ± 2.80	2.17 ± 2.43	0.07
12-mo change from baseline	–1.81 ± 2.87	–3.66 ± 3.06	**0.03**	–1.82 ± 3.88	–3.13 ± 3.86	0.3
NRS-AP						
Baseline	5.62 ± 3.29	5.88 ± 2.97	0.8	4.24 ± 3.44	4.63 ± 3.16	0.7
12 mos	2.33 ± 3.65	1.97 ± 2.68	0.7	2.47 ± 3.37	1.83 ± 2.46	0.5
12-mo change from baseline	–3.29 ± 3.73	–3.91 ± 3.40	0.5	–1.76 ± 5.12	–2.79 ± 3.04	0.4
EQ-5D						
Baseline	0.56 ± 0.20	0.51 ± 0.22	0.4	0.47 ± 0.24	0.56 ± 0.22	0.2
12 mos	0.73 ± 0.18	0.78 ± 0.18	0.3	0.66 ± 0.16	0.74 ± 0.21	0.2
12-mo change from baseline	0.17 ± 0.19	0.28 ± 0.20	0.06	0.19 ± 0.24	0.18 ± 0.27	0.9
EQ-VAS						
Baseline	63.57 ± 15.26	64.38 ± 18.78	0.9	65.12 ± 13.07	65.00 ± 15.46	>0.99
12 mos	67.33 ± 18.34	64.38 ± 22.13	0.6	66.88 ± 19.45	75.29 ± 17.78	0.2
12-mo change from baseline	3.76 ± 15.72	0.00 ± 16.16	0.4	1.76 ± 23.31	10.29 ± 21.96	0.2
NASS satisfaction score at 12 mos			**0.02**			0.6
1/2, satisfied	17 (81.0%)	32 (100%)		14 (82.4%)	22 (91.7%)	
3/4, unsatisfied	4 (19.0%)	0 (0.0%)		3 (17.6%)	2 (8.3%)	

Unless otherwise indicated, values are expressed as the number of patients (%) or the mean score ± SD. Boldface type indicates statistical significance.

rates seen in the anterior and posterior approach. These results suggest that at 12 months postoperatively, structural fixation in the cervical spine that causes decreased mobility and changes in cervical spinal alignment may have a strong influence on the development of persistent dysphagia, independently of surgical approach. During swallowing, micromovements in the cervical spine can help facilitate esophageal peristalsis and pharyngeal muscle contraction. When a long-segment cervical fusion is performed, there will be decreased mobility of the neck as well as changes in alignment that may make these movements more difficult to perform, possibly resulting in dysphagia.

Our results for dysphagia rates following ACF are similar to those of other investigators who also used EAT-10 as a measurement when studying dysphagia following ACDF. Ohba et al. found that 25.5% of patients who underwent ACDF had persistent dysphagia at 1-year follow-up.[20] Similarly, Haller et al. found that 38% of patients who underwent ACDF had clinically significant dysphagia at least 1 year postoperatively.[21] Due to a lack of prior research in which validated measurements were used to study dysphagia following PCF, our results of 23.1% of patients with new-onset dysphagia at 3 months and 32.4% at 12 months are novel. Although further studies are needed to better define dysphagia rates after long-segment PCF, the prevalence seen in this study shows that this disorder should be viewed as a common adverse effect following long-segment PCF, similar to dysphagia following ACF.

Previous studies have cited performing fusion at higher cervical levels, including those at C4 and above, as a risk factor for the development of dysphagia.[22–25] A subanalysis with our study data showed that when comparing patients with 3-level ACF, 61.5% of those who underwent fusion from C3 to C6 had dysphagia at 12-month follow-up compared to 29.0% of patients in whom fusion was performed at C4–7. Due to the sparsity of research involving dysphagia following PCF, risk factors specific to this approach are not well understood.

In a multivariate analysis, we did not find any significant risk factors for dysphagia at 3 or 12 months. This finding may be due to the small sample size rather than the risk factors not being present. In other studies, one of the most commonly cited risk factors is number of surgical levels fused.[3,4,13,23,24,26–31] More spinal levels being fused leads to a greater restriction of motion in the cervical spine that can make swallowing more difficult. Given that only long-segment cervical fusions were considered in this study, differences between dysphagia rates of patients in our study were more minimal.

Due to differences in indications for anterior versus posterior fusion, there was variability seen in baseline demographic and clinical characteristics between the two cohorts. However, these differences are to be expected because our

TABLE 6. The 3-month PRO comparison stratified by new-onset clinical dysphagia at 3-month follow-up, by surgical approach

Characteristic	ACF, n = 63			PCF, n = 39		
	Dysphagia, n = 25	No Dysphagia, n = 38	p Value	Dysphagia, n = 9	No Dysphagia, n = 30	p Value
NDI						
Baseline	21.16 ± 9.40	20.45 ± 10.29	0.8	25.33 ± 7.87	16.47 ± 9.35	**0.01**
3 mos	11.72 ± 6.77	9.39 ± 5.91	0.2	16.67 ± 8.70	11.07 ± 8.71	0.1
3-mo change from baseline	–9.44 ± 7.75	–11.05 ± 9.23	0.5	–8.67 ± 9.06	–5.40 ± 8.93	0.3
NRS-NP						
Baseline	6.20 ± 2.63	6.13 ± 2.93	0.9	6.33 ± 1.50	5.20 ± 3.00	0.3
3 mos	3.00 ± 2.69	2.47 ± 2.35	0.4	4.00 ± 2.40	2.43 ± 1.99	0.06
3-mo change from baseline	–3.20 ± 2.92	–3.66 ± 3.11	0.6	–2.33 ± 2.00	–2.77 ± 2.88	0.7
NRS-AP						
Baseline	5.56 ± 3.42	6.00 ± 3.07	0.6	4.44 ± 3.09	4.37 ± 3.11	0.9
3 mos	2.40 ± 2.77	1.34 ± 1.99	0.08	4.11 ± 2.32	2.03 ± 2.47	**0.03**
3-mo change from baseline	–3.16 ± 2.90	–4.66 ± 3.34	0.07	–0.33 ± 4.77	–2.33 ± 3.42	0.2
EQ-5D						
Baseline	0.52 ± 0.19	0.50 ± 0.23	0.7	0.42 ± 0.23	0.56 ± 0.22	0.1
3 mos	0.71 ± 0.15	0.80 ± 0.14	**0.03**	0.70 ± 0.10	0.71 ± 0.16	0.9
3-mo change from baseline	0.19 ± 0.22	0.29 ± 0.21	0.06	0.28 ± 0.23	0.15 ± 0.24	0.2
EQ-VAS						
Baseline	62.20 ± 14.73	64.42 ± 19.66	0.6	66.11 ± 10.24	67.97 ± 14.67	0.7
3 mos	66.00 ± 17.26	72.92 ± 15.87	0.1	70.00 ± 11.46	69.67 ± 15.37	>0.99
3-mo change from baseline	3.80 ± 18.83	8.50 ± 19.59	0.3	3.89 ± 16.16	1.70 ± 17.88	0.7
NASS satisfaction score at 3 mos			>0.99			0.2
1/2, satisfied	24 (96.0%)	37 (97.4%)		7 (77.8%)	28 (93.3%)	
3/4, unsatisfied	1 (4.0%)	1 (2.6%)		2 (22.2%)	2 (6.7%)	

Unless otherwise indicated, values are expressed as the number of patients (%) or the mean score ± SD. Boldface type indicates statistical significance.

population is representative of a real-world cohort for the two approaches. As such, patients who underwent PCF were older and had more myelopathy, leading to the larger posterior fusion, whereas the ACF cohort had more neck pain and radiculopathy. Similarly, differences in PROs between cohorts such as higher baseline values and improvement in NRS-AP in patients who underwent ACF may be explained by the greater levels of radiculopathy in that cohort.

Although our ACF and PCF cohorts were representative of patient demographics seen for each procedure, the significant age difference between the two cohorts may represent selection bias within the study. Most previous studies have suggested that older age is a risk factor for dysphagia.[7,20,22,25,27,31] Conversely, some other studies found that younger age was associated with increased risk for developing dysphagia.[13,30] We performed a subgroup analysis based on age for both the ACF and PCF groups and found no significant differences in dysphagia rate or EAT-10 scores between younger and older patients when using ages 55, 60, or 65 years as cutoffs. However, the sample size for this subgroup analysis may limit the conclusions. Despite this, the significant difference in age between the ACF and PCF cohorts still may represent selection bias and may have an influence on the results.

An interesting result from this study was the magnitude of baseline dysphagia that was seen in both cohorts. Although dysphagia is a well-known and common adverse effect following cervical fusion, patients are rarely screened for it prior to undergoing cervical spinal surgery.[8] If dysphagia is considered, it often is asked in the form of an absolute yes or no. However, patients with more mild or atypical dysphagia symptoms may not say yes to this question. This emphasizes the importance of screening for dysphagia preoperatively with a validated scoring system—such as EAT-10—that asks more specific and diverse questions to help classify dysphagia. Another notable finding was that 6 patients who received ACF and 5 who received PCF did not have dysphagia at 3 months, but developed dysphagia by the 12-month follow-up. The reason for this finding is difficult to elucidate in the current study. One theory is that this may be due to increased rigidity of the construct as bony fusion takes place over that time frame.

In addition to investigating dysphagia rates and risk factors, we examined the PROs of patients with dysphagia versus those without dysphagia. Riley et al. found that patients with dysphagia at 3 months had a significantly higher self-reported disability at subsequent assessments.[3] Our results showed that patients with dysphagia had significantly worsened NDI scores after both ACF and PCF at 3 months and after PCF at 12 months, with a trend toward significance for patients in the ACF group at 12 months after surgery. This demonstrates that patients with dysphagia following cervical fusion also have worsened self-reported disability due to neck pain. We also saw increased neck pain at both follow-

TABLE 7. The 12-month PRO comparison stratified by new-onset clinical dysphagia at 12-month follow-up, by surgical approach

Characteristic	ACF, n = 46			PCF, n = 34		
	Dysphagia, n = 15	No Dysphagia, n = 31	p Value	Dysphagia, n = 11	No Dysphagia, n = 23	p Value
NDI						
Baseline	21.27 ± 10.81	19.90 ± 8.81	0.7	20.55 ± 9.74	15.04 ± 9.68	0.1
12 mos	9.93 ± 9.65	7.61 ± 7.05	0.4	12.55 ± 7.51	7.30 ± 6.97	0.05
12-mo change from baseline	–11.33 ± 10.94	–12.29 ± 9.43	0.8	–8.00 ± 6.80	–7.74 ± 8.38	0.9
NRS-NP						
Baseline	6.13 ± 3.04	6.29 ± 2.55	0.9	5.18 ± 2.52	5.09 ± 3.22	0.9
12 mos	4.13 ± 3.04	2.58 ± 2.86	0.1	4.00 ± 2.90	2.09 ± 2.45	0.05
12-mo change from baseline	–2.00 ± 3.02	–3.71 ± 3.10	0.08	–1.18 ± 2.99	–3.00 ± 3.90	0.2
NRS-AP						
Baseline	5.20 ± 3.57	5.81 ± 2.99	0.5	3.18 ± 3.37	4.39 ± 3.01	0.3
12 mos	2.67 ± 3.98	2.03 ± 2.70	0.5	3.18 ± 3.54	1.91 ± 2.48	0.2
12-mo change from baseline	–2.53 ± 3.94	–3.77 ± 3.37	0.3	0.00 ± 4.88	–2.48 ± 2.68	0.07
EQ-5D						
Baseline	0.58 ± 0.18	0.50 ± 0.22	0.2	0.43 ± 0.23	0.56 ± 0.22	0.1
12 mos	0.79 ± 0.16	0.78 ± 0.18	0.8	0.62 ± 0.18	0.74 ± 0.22	0.1
12-mo change from baseline	0.21 ± 0.20	0.28 ± 0.20	0.3	0.19 ± 0.23	0.18 ± 0.27	0.9
EQ-VAS						
Baseline	64.33 ± 14.86	63.87 ± 18.87	0.9	64.73 ± 13.99	63.91 ± 14.84	0.9
12 mos	69.33 ± 20.08	63.55 ± 21.99	0.4	71.36 ± 12.06	74.65 ± 17.89	0.6
12-mo change from baseline	5.00 ± 17.42	–0.32 ± 16.33	0.3	6.64 ± 12.31	10.74 ± 22.34	0.6
NASS satisfaction score at 12 mos			0.1			>0.99
1/2, satisfied	13 (86.7%)	31 (100%)		10 (90.9%)	21 (91.3%)	
3/4, unsatisfied	2 (13.3%)	0 (0.0%)		1 (9.1%)	2 (8.7%)	

Unless otherwise indicated, values are expressed as the number of patients (%) or the mean score ± SD. Boldface type indicates statistical significance.

up times and increased arm pain at 3 months for patients with dysphagia compared to those without the disorder, which was either statistically significant or trending toward significance. This is likely to also represent the worsened pathology and/or greater perception of symptoms associated with dysphagia. Despite the negative impact of dysphagia on patient outcomes, > 80% of patients with dysphagia still reported satisfaction with the results of their surgery.

Although the only statistically significant EQ-5D difference seen between patients with dysphagia versus those without the disorder was for patients in the ACF group at 3 months, there were also notably lower EQ-5D scores at 12 months seen after both ACF and PCF procedures in patients who had dysphagia; however, those were not statistically significant. When investigating responses to the EQ-5D questionnaire in patients who had dysphagia, the most common categories leading to lower scores were usual activities and pain/discomfort, which can probably be attributed to their cervical pathology and dysphagia as well as to the impact that has on their ability to maintain the activities they enjoy. It is also possible that the psychological burden due to dysphagia along with their physical condition may lead to the patients' perception that their QOL and medical condition are worse.

The limitations of this study include its retrospective design. Whereas all data presented herein were collected in prospective fashion, they were analyzed retrospectively. These data were also collected from a high-volume tertiary care surgical practice. Accordingly, the data are more applicable to other high-volume specialty care surgical groups that have similarly complex patient populations, with the ancillary staff and resources needed for complex patient care. These data therefore may not be generalizable to other institutions with different surgeons and patient demographics. Nonetheless, we have incorporated clinical and surgical characteristics into the logistic regression model in order to ensure that they did not confound our findings. In this study, radiographs were not reviewed for alignment parameters that may contribute to difficulty swallowing. Another limitation is the 25.4% of patients in the ACF group and 14.6% of those in the PCF cohort were lost to follow-up between the 3- and 12-month follow-up evaluations. This is likely to be a source of selection bias given that patients who do well after surgery may be less likely to attend follow-up appointments compared to those who have ongoing neck pain or other issues. Regardless, future prospective, multiinstitutional studies are needed to validate these findings.

Conclusions

This study is the first to investigate and compare dysphagia following ACF and PCF by using a validated, noninvasive clinical scoring system as a measurement of dysphagia. Similar rates and severity of dysphagia were

TABLE 8. Logistic regression analysis for predictors of dysphagia at 3-month and 12-month follow-up

Characteristic	3 Mos			12 Mos		
	Beta (95% CI)	OR (95% CI)	p Value	Beta (95% CI)	OR (95% CI)	p Value
Age	0.00 (–0.02 to 0.01)		0.6	0.01 (–0.02 to 0.03)		0.6
Female sex		1.04 (0.83 to 1.30)	0.7		1.22 (0.93 to 1.60)	0.2
Payer status—ref: private/other						
Medicaid		0.65 (0.20 to 2.08)	0.5		2.03 (0.47 to 9.02)	0.3
Medicare		1.10 (0.78 to 1.58)	0.6		0.85 (0.56 to 1.28)	0.5
Medicare Advantage		1.09 (0.70 to 1.70)	0.7		0.79 (0.45 to 1.39)	0.4
State-specific plan, non-Medicaid		1.18 (0.74 to 1.90)	0.5		0.80 (0.47 to 1.38)	0.4
Coronary artery disease		1.23 (0.94 to 1.60)	0.1		1.05 (0.77 to 1.45)	0.7
Employed or employed on leave		0.99 (0.75 to 1.31)	>0.99		0.93 (0.66 to 1.31)	0.7
Revision surgery		0.86 (0.65 to 1.14)	0.3		1.00 (0.71 to 1.42)	>0.99
ASA grade—ref: grade I or II						
III or IV		1.17 (0.92 to 1.51)	0.2		0.93 (0.68 to 1.27)	0.6
Radiculopathy		0.89 (0.65 to 1.24)	0.5		0.82 (0.54 to 1.23)	0.3
Myelopathy		1.13 (0.70 to 1.82)	0.6		0.88 (0.38 to 2.07)	0.8
Neck pain from instability		0.95 (0.61 to 1.49)	0.8		1.10 (0.65 to 1.84)	0.7
Pseudarthrosis		1.59 (0.89 to 2.72)	0.1		1.27 (0.53 to 3.00)	0.6
Primary Sx						
Neck pain		1.20 (0.83 to 1.72)	0.3		0.87 (0.55 to 1.36)	0.5
Arm pain		0.98 (0.66 to 1.46)	1.0		1.06 (0.63 to 1.78)	0.8
Myelopathy		1.01 (0.60 to 1.70)	>0.99		1.05 (0.43 to 2.56)	>0.99
Predominant location of pain—ref: arm pain						
Neck = arm pain		0.92 (0.65 to 1.31)	0.7		1.17 (0.79 to 1.75)	0.4
Neck		0.68 (0.41 to 1.13)	0.1		1.07 (0.60 to 1.94)	0.8
None		0.79 (0.47 to 1.34)	0.4		0.97 (0.52 to 1.82)	>0.99
Independent ambulation		1.21 (0.86 to 1.70)	0.3		1.20 (0.83 to 1.73)	0.3
No. of levels fused	–0.04 (–0.12 to 0.04)		0.3	0.06 (–0.04 to 0.15)		0.3
Surgical approach—ref: posterior						
Anterior		1.40 (0.95 to 2.07)	0.09		1.63 (0.97 to 2.72)	0.07

seen following ACF and PCF at 3-month and 12-month follow-up. This suggests that long-term dysphagia following cervical fusion surgery may be due to structural changes from the fusion rather than surgical approach. However, the ACF cohort was significantly younger, and this may have partially accounted for the findings. PROs were also compared for patients with dysphagia versus those without dysphagia, and showed worsened outcomes in some domains for patients who presented with dysphagia at 3-month and 12-month follow-up. This suggests that dysphagia may be associated with a decreased QOL after cervical fusion.

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Disclosures

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Author Contributions

Conception and design: Potts, Visconti, Alentado. Acquisition of data: Potts. Analysis and interpretation of data: all authors. Drafting the article: Potts, Visconti, Alentado, Neher. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Potts. Statistical analysis: Visconti, McFatridge. Administrative/technical/material support: Potts. Study supervision: Potts, Visconti.

Supplemental Information

Previous Presentations

Oral presentation at Spine Summit, held in Las Vegas, NV, February 21–22, 2024; oral presentation at Winter Clinics, held in Aspen, CO, March 3–7, 2024.

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