Original Article

Single-level posterior cervical foraminotomy associated with increased incidence of early postoperative wound infection rates relative to anterior cervical discectomy with fusion and cervical disc arthroplasty

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Background: To date, there are no studies comparing perioperative outcomes of cervical radiculopathy patients managed by anterior cervical discectomy with fusion (ACDF), cervical disc arthroplasty (CDA), or posterior cervical foraminotomy (PCF). To assess if there were differences in perioperative outcomes between cervical radiculopathy patients who can be appropriately treated with ACDF, CDA, or PCF.

Methods: Patients diagnosed with cervical radiculopathy who underwent a single-level ACDF, CDA, or PCF between 2012 and 2019 were retrospectively identified from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database using current procedural terminology (CPT) codes. Patients were subsequently stratified into those who underwent ACDF, CDA, or PCF, and propensity score-matched to adjust for differences in patient demographics/characteristics. Differences were assessed in terms of operative time, healthcare utilization metrics (reoperations, readmissions, lengths-of-stay), as well as medical and surgical complications.

Results: A total of 18,614 cervical radiculopathy patients undergoing surgery were identified (ACDF: n=15,862; CDA: n=1,731; PCF: n=1,021). After 1:1 propensity score matching (n=535 each), there were no differences in characteristics in patients undergoing ACDF, CDA, or PCF (P>0.05). PCF patients had statistically higher rates of reoperation (2.1%) than ACDF (0.4%), CDA (0.6%) patients (P=0.010). PCF patients also experienced higher rates of superficial infection (P=0.001), and deep infection (P=0.007), relative to ACDF and CDA patients. There were no other significant differences in medical/surgical complications between the ACDF, CDA, or PCF patients.

Conclusions: Cervical radiculopathy patients undergoing PCF are associated with higher rates of perioperative infection and overall reoperation than ACDF or CDA. Further research is required to elucidate the mechanism behind this association.

Keywords: Anterior cervical discectomy with fusion (ACDF); posterior cervical foraminotomy (PCF); cervical disc arthroplasty (CDA); complications; 30-day outcomes

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Introduction

Cervical radiculopathy, a clinical condition characterized by compression of a cervical nerve root leading to unilateral arm pain with or without sensorimotor deficits (1), is relatively common. The most well cited epidemiological studies estimate a prevalence of 103.7 cases per 100,000 for men and 63.7 cases per 100,000 women (2), with an estimated overall incidence of 1.8 per 1,000 person-years (3). There are a variety of proposed pathophysiologic mechanisms leading to cervical radiculopathy (4), although the two most common causes are degenerative cervical spondylosis resulting in decreased disc height with uncovertebral and/or facet hypertrophy leading to foraminal narrowing (5), and disc herniation leading to cervical nerve root impingement (1,2,4,6).

The vast majority of cervical radiculopathy patients improve with non-operative management, with studies citing up to 75% to 90% of initially diagnosed patients (2,5,7). Nevertheless, patients refractory to non-operative treatment for 6 weeks or otherwise experiencing progressive and significant neurologic deficits may be surgical candidates (8). The three leading surgical procedures for managing cervical radiculopathy are anterior cervical discectomy with fusion (ACDF), cervical disc arthroplasty (CDA), and posterior cervical foraminotomy (PCF) (1,2,5). There are advantages and disadvantages associated with each procedure. Notably, certain indications may dictate the preference of a specific procedure. While cervical radiculopathy secondary to central disc herniation is likely to benefit from ACDF or CDA, other underlying mechanical/deformity-related pathologies, including kyphosis and cervical instability, are more likely to require ACDF. Furthermore, some surgeons may reserve PCF for patients with a single osteophyte or for discectomy of a soft herniated disk. Nevertheless, such indications often overlap, and a single cervical radiculopathy patient may benefit from any of the above procedures.

ACDF has been described as the gold standard for managing cervical radiculopathy, which involves removal of disc material (1,9) with subsequent placement of interbody graft to restore cervical disc height and lordosis. While ACDF offers reliable outcomes, it is associated with complications such as pseudarthrosis (10), adjacent disc-segment disease due to fusion, and complications from anterior approach such as dysphagia (9). CDA is a relatively new procedure performed via anterior approach like ACDF, but involves placing a prosthesis instead of graft material, thereby allowing for motion at the affected segment thereby decreasing adjacent segment degeneration and need for secondary procedures (1,11-13). PCF involves a posterior approach and involves foraminal widening and decompressing the nerve root, reducing the risks associated with the anterior approach, such as dysphagia and implant-related complications (14,15).

To the best of our knowledge, to date there have not been studies that have compared the postoperative outcomes of ACDF, CDA, and PCF. Given the unique purported advantages and disadvantages of CDA and PCF over the current gold standard ACDF, such comparison is required to more fully characterize these surgical procedures. The purpose of this study was to assess the postoperative outcomes of cervical radiculopathy patients undergoing ACDF, CDA, or PCF. Specifically, we assessed differences in (I) operative time; (II) healthcare utilization metrics (reoperations, readmissions, lengths-of-stay); and (III) medical and surgical complications in the 30-day postoperative period. We present the following article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-21-39/rc).

Methods

Study design and data sources

The American College of Surgeons National Surgical Quality Improvement Program database (ACS-NSQIP) was retrospectively reviewed for all patients who underwent ACDF, CDA or PCF between 2012 and 2018. ACS-NSQIP is a nationwide database that collects more than 135 variables outlining patient demographics [age, sex, body mass index (BMI), and race], baseline comorbidities, and postoperative details for a random sample of patients undergoing major surgical interventions in over 500 centers in North America. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Such data is presented in a de-identified fashion, thereby obviating the need for Institutional Review Board (IRB) approval for the present study. Besides, the present investigation utilized a publicly available deidentified dataset; therefore, individual consent for this study was not required. Major complications captured by ACS-NSQIP include are: superficial/deep surgical site infections, sepsis, unplanned intubations, and mechanical ventilation, cardiac complications, renal dysfunction, thromboembolic events, and postoperative pneumonia (16).

Definitions of complications was set by the central NSQIP office to maintain adhering to the same guidelines among participating centers (16,17). ACS-NSQIP data capture has been associated with an interrater reliability disagreement of less than 1.8%. Currently, NSQIP is the only national quality improvement database developed and validated by surgeons (18), and enables researchers to conduct multi-institutional studies using large-scale datasets.

Study population

Patients were included if they had undergone isolated single-level ACDF, CDA or PCF as indicated by the current procedural terminology (CPT) codes ACDF: 22551 and 22554, CDA: 22856, PCF: 62380 and 63020. Patients who underwent posterior fusion, >1 level fusion regardless of approach, or additional concomitant spinal procedures were identified through additional procedure CPT codes and subsequently excluded. A total of 18,614 patients were included in the present study (ACDF: n=15,862; CDA: n=1,731; PCF: n=1,021). Of the included cohort, female predominance was detected among patients undergoing ACDF (50.2%) while an equal proportion of males and females underwent CDA (50% each). Conversely, patients who underwent PCF were predominantly male (59.5%; P<0.001) (*Table 1*). Most patients exhibited a BMI >30 (ACDF: 51.1%; PCF: 45.9%; and CDA: 48.7%; P<0.001) and diabetics represented 16.7%, 8.6% and 13.6% among the ACDF, CDA and PCF cohorts respectively (P<0.001). The highest proportion of smokers was found among patients undergoing ACDF (28%; P<0.001). Similarly, the highest burden of comorbidities was detectable among the ACDF cohort which demonstrated the highest prevalence of American Society of Anesthesiologists (ASA) class ≥3 (42.6%; P<0.001).

Outcomes of interest

The primary outcomes of the present investigation were the operative time and healthcare utilization within the early (30-day) postoperative period after ACDF, CDA and PCF, including length of stay, 30-day readmission and 30-day reoperation. Secondary outcomes included the occurrence of early postoperative complications within the same interim, including superficial and deep wound infection, organ/space infection and wound dehiscence. Renal complications including urinary tract infection (UTI), acute renal failure and progressive renal insufficiency were evaluated. Furthermore, cardiopulmonary, thromboembolic and septic adverse events were evaluated, including the need for mechanical ventilation >48 hours postoperatively, pneumonia, reintubation, postoperative transfusion, deep venous thrombosis (DVT) and pulmonary embolism (PE), cardiac arrest, myocardial infarction, sepsis and septic shock.

Statistical analysis

Univariate analysis was conducted to identify the distribution of patient demographics, baseline comorbidities as well as outcomes among recipients of the three compared spinal surgical interventions. Patient demographics and comorbidities exhibiting a significant difference between the three compared cohorts were then identified and adjusted for through propensity score matching (1:1:1), followed by a comparison of outcomes. Variables used in the matching process included age, sex, race, BMI category, diabetes, smoking status, the presence of underlying chronic obstructive pulmonary disease (COPD), hypertension, functional status and ASA class. Fisher's exact test and Chi-square tests were used to compare counts and percentages of categorical variables as appropriate. Conversely, analysis of variance (ANOVA) was used to compare means ± standard deviations (SDs) of continuous variables. All tests were two-tailed with an alpha level of 0.01 to account for the effect of multiple comparisons.

Propensity score matching was conducted to appropriately adjust for significant differences noted in univariate analysis (*Table 1*), which included 535 cervical radiculopathy patients who either underwent ACDF, CDA, or PCF. All statistically significant discrepancies in baseline comorbidities and patient demographics were eliminated, which included age (P=0.318), BMI (P=0.687), sex, diabetes, smoking status, dyspnea, COPD, hypertension, steroids, functional status, and ASA classification (*Table 1*).

Results

A total of 18,614 patients with cervical radiculopathy were identified undergoing either single-level ACDF, CDA, or PCF (*Table 2*). A total of 15,862 patients undergoing ACDF were identified, with a mean (± SD) age of 53.40 (±12.08) years, a BMI of 30.63 (±6.90), and a slight female predominance (50.2%). A total of 1,731 patients undergoing CDA were identified, with a mean (± SD)

Table 1 Before matching demographics of cervical radiculopathy patients who underwent 1 level ACDF, CDA, or PCF

Variables	ACDF (n=15,862), n (%)	CDA (n=1,731) , n (%)	PCF (n=1,021), n (%)	P
Age (years), mean ± SD	53.49±12.08	45.49±10.37	52.77±10.37	<0.001*#
Sex				<0.001‡#
Female	7,957 (50.2)	865 (50.0)	414 (40.5)	
Male	7,905 (49.8)	866 (50.0)	607 (59.5)	
BMI (kg/m^2), mean ± SD	30.63±6.90	29.77±6.28	30.10±6.28	<0.001‡#
<18.5	130 (0.8)	6 (0.3)	11 (1.1)	
18.5–24.9	2,636 (16.6)	329 (19.0)	163 (16.0)	
25.0–29.9	4,991 (31.5)	603 (34.8)	349 (34.2)	
>29.9	8,105 (51.1)	793 (45.9)	498 (48.7)	
Diabetes				<0.001‡#
No	13,217 (83.3)	1,582 (91.4)	882 (86.4)	
Non-insulin	1,653 (10.4)	105 (6.1)	93 (9.1)	
Insulin	992 (6.3)	44 (2.5)	46 (4.5)	
Smoker				<0.001‡#
No	11,419 (72.0)	1,351 (78.0)	756 (74.0)	
Yes	4,443 (28.0)	380 (22.0)	265 (26.0)	
Dyspnea				<0.001‡#
No	15,076 (95.0)	1,700 (98.2)	996 (97.5)	
Exertion	736 (4.7)	28 (1.6)	22 (2.2)	
Resting	50 (0.3)	3 (0.2)	3 (0.3)	
COPD				<0.001‡#
No	15,163 (95.6)	1,711 (98.8)	979 (95.9)	
Yes	699 (4.4)	20 (1.2)	42 (4.1)	
Hypertension				<0.001‡#
No	8,738 (55.1)	1,321 (76.3)	624 (61.1)	
Yes	7,124 (44.9)	410 (23.7)	397 (38.9)	
Steroids				0.2743‡
No	15,366 (96.9)	1,689 (97.6)	990 (97.0)	
Yes	496 (3.1)	42 (2.4)	31 (3.0)	
Functional status				<0.001‡#
Independent	15,560 (98.1)	1,725 (99.7)	1,011 (99.0)	
Partially dependent	278 (1.8)	6 (0.3)	10 (1.0)	
Totally dependent	24 (0.1)	0 (0.0)	0 (0.0)	
ASA classification				<0.001‡#
1	586 (3.7)	164 (9.5)	69 (6.8)	
2	8,516 (53.7)	1,169 (67.5)	599 (58.7)	
3	6,448 (40.7)	393 (22.7)	337 (33.0)	
4	309 (1.9)	5 (0.3)	16 (1.6)	
5	3 (0.0)	0 (0.0)	0 (0.0)	

*, comparison by ANOVA; ‡, comparison by Chi-squared test; #, statistically significant after correction for multiple comparisions. ACDF, anterior cervical discectomy with fusion; CDA, cervical disc arthroplasty; PCF, posterior cervical foraminotomy; SD, standard deviation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologists; ANOVA, analysis of variance.

Table 2 After matching demographics of cervical radiculopathy patients who underwent 1 level ACDF, CDA, or PCF

Variables	ACDF (n=535), n (%)	CDA (n=535), n (%)	PCF (n=535), n (%)	P
Age (years), mean ± SD	48.43±10.74	48.13±10.00	49.07±10.64	0.318*
Sex				1.000‡
Female	236 (44.1)	236 (44.1)	236 (44.1)	
Male	299 (55.9)	299 (55.9)	299 (55.9)	
BMI (kg/m^2), mean ± SD	29.04±5.90	29.11±5.46	29.33±5.63	0.687‡
<18.5	1 (0.2)	1 (0.2)	1 (0.2)	
18.5–24.9	92 (17.2)	92 (17.2)	92 (17.2)	
25.0–29.9	218 (40.7)	218 (40.7)	218 (40.7)	
>29.9	224 (41.9)	224 (41.9)	224 (41.9)	
Diabetes				1.000‡
No	513 (95.89)	513 (95.89)	513 (95.89)	
Non-insulin	15 (2.80)	15 (2.80)	15 (2.80)	
Insulin	7 (1.31)	7 (1.31)	7 (1.31)	
Smoker				1.000‡
No	438 (81.9)	438 (81.9)	438 (81.9)	
Yes	97 (18.1)	97 (18.1)	97 (18.1)	
Dyspnea				0.8652‡
No	528 (98.7)	527 (98.5)	529 (8.9)	
Exertion	7 (1.3)	8 (1.5)	6 (1.1)	
Resting	0 (0.0)	0 (0.0)	0 (0.0)	
COPD				1.000‡
No	535 (100.0)	535 (100.0)	535 (100.0)	
Yes	0 (0.0)	0 (0.0)	0 (0.0)	
Hypertension				1.000‡
No	405 (75.7)	405 (75.7)	405 (75.7)	
Yes	130 (24.3)	130 (24.3)	130 (24.3)	
Steroids				1.000‡
No	534 (99.8)	534 (99.8)	534 (99.8)	
Yes	1 (0.2)	1 (0.2)	1 (0.2)	
Functional status				1.000‡
Independent	535 (100.0)	535 (100.0)	535 (100.0)	
Partially dependent	0 (0.0)	0 (0.0)	0 (0.0)	
Totally dependent	0 (0.0)	0 (0.0)	0 (0.0)	
ASA classification				1.000‡
1	35 (6.5)	35 (6.5)	35 (6.5)	
2	402 (75.2)	402 (75.2)	402 (75.2)	
3	98 (18.3)	98 (18.3)	98 (18.3)	
4	0 (0.0)	0 (0.0)	0 (0.0)	
5	0 (0.0)	0 (0.0)	0 (0.0)	

*, comparison by ANOVA; ‡, comparison by Chi-squared test. ACDF, anterior cervical discectomy with fusion; CDA, cervical disc arthroplasty; PCF, posterior cervical foraminotomy; SD, standard deviation; BMI, body mass index; COPD, chronic obstructive pulmonary disease; ASA, American Society of Anesthesiologists; ANOVA, analysis of variance.

Table 3 Before matching operative and post-operative data for cervical radiculopathy patients who underwent 1 level ACDF, CDA, or PCF

Variables	ACDF (n=15,862), n (%)	CDA (n=1,731), n (%)	PCF (n=1,021), n (%)	P
Operation time (min), mean ± SD	105.37±45.16	109.49±39.77	99.93±47.56	<0.001*#
Length of stay (days), mean ± SD	1.79±2.30	1.29±1.00	1.70±1.63	<0.001*#
Any readmission	604 (3.8)	24 (1.4)	41 (4.0)	<0.001‡#
Any reoperation	239 (1.5)	14 (0.8)	21 (2.1)	0.020‡
Superficial infection	45 (0.3)	4 (0.2)	17 (1.7)	<0.001‡#
Deep infection	13 (0.1)	1 (0.1)	8 (0.8)	<0.001‡#
Organ/space infection	26 (0.2)	0 (0.0)	3 (0.3)	0.134‡
Wound dehiscence	2 (0.0)	0 (0.1)	4 (0.4)	<0.001‡#
Transfusions	32 (0.2)	1 (0.1)	2 (0.2)	0.422‡
UTI	95 (0.6)	3 (0.2)	7 (0.7)	0.070‡
Progressive renal insufficiency	6 (0.0)	0 (0.0)	0 (0.0)	0.594‡
Acute renal failure	8 (0.1)	1 (0.1)	1 (0.1)	0.815‡
Mechanical ventilation	44 (99.9)	0 (0.0)	1 (0.1)	0.052‡
Pneumonia	95 (0.6)	0 (0.0)	1 (0.1)	0.001‡#
Unplanned intubation	57 (0.4)	2 (0.1)	1 (0.1)	0.101‡
PE	32 (0.2)	0 (0.0)	1 (0.1)	0.137‡
Deep vein thrombosis	45 (0.3)	1 (0.1)	4 (0.4)	0.167‡
Cardiac arrest	20 (0.1)	0 (0.0)	1 (0.1)	0.329‡
Myocardial infarction	20 (0.1)	1 (0.1)	1 (0.1)	0.721‡
Cerebrovascular accident	4 (0.0)	1 (0.1)	0 (0.0)	0.636‡
Sepsis	43 (0.3)	1 (0.1)	9 (0.9)	<0.001‡#
Septic shock	11 (0.1)	0 (0.0)	2 (0.2)	0.171‡

*, comparison by ANOVA; ‡, comparison by Chi-squared test; #, statistically significant after correction for multiple comparisons. ACDF, anterior cervical discectomy with fusion; CDA, cervical disc arthroplasty; PCF, posterior cervical foraminotomy; SD, standard deviation; UTI, urinary tract infection; PE, pulmonary embolism; ANOVA, analysis of variance.

age of 45.49 (±10.37) years, BMI of 29.77 (±6.28), and equal male/female ratios (50.0%). A total of 1021 patients undergoing PCF were identified, with a mean (± SD) age of 52.77 (±10.37) years, BMI of 30.10 (±6.28), and slight male predominance (59.5%). Univariate analysis demonstrated significant differences between baseline comorbidities: ASA classification (P<0.001), diabetes (P<0.001), smoking status (P<0.001), dyspnea (P<0.001), COPD (p<0.001), hypertension (P<0.001), functional status (P<0.001) but not steroid use (P=0.2743).

Before matching and postoperative data for cervical radiculopathy, there were statistically significant differences in operation time (P<0.001), length of stay (P<0.001), any readmission (P<0.001), any reoperation (P=0.020), superficial infection (P<0.001), deep infection (P<0.001), pneumonia (P=0.001), and sepsis (P<0.001) between cervical radiculopathy patients who underwent ACDF, CDA, or PCF (*Table 3*). There were no such statistically significant differences in organ/space infection, transfusions, UTI, progressive renal insufficiency, acute renal failure, mechanical ventilation, unplanned intubation, PE, DVT, cardiac arrest, myocardial infarction, cerebrovascular accident, and septic shock.

After propensity score matching, several postoperative outcomes maintained statistically significant outcomes between cervical radiculopathy patients undergoing

Table 4 After matching operative and post-operative data for cervical radiculopathy patients who underwent 1 level ACDF, CDA, or PCF

Variables	ACDF (n=535), n (%)	CDA (n=535), n (%)	PCF (n=535), n (%)	P
Operation time (min), mean ± SD	103.70±46.52	110.07±38.45	99.00±47.27	<0.001*#
Length of stay (days), mean ± SD	1.54±1.71	1.33±1.18	1.50±1.27	0.039*
Any readmission	12 (2.2)	7 (1.3)	18 (3.4)	0.081‡
Any reoperation	2 (0.4)	3 (0.6)	11 (2.1)	0.010‡#
Superficial infection	1 (0.2)	1 (0.2)	10 (1.9)	0.001‡#
Deep infection	0 (0.0)	0 (0.0)	5 (0.9)	0.007‡#
Organ/space infection	2 (0.4)	0 (0.0)	1 (0.2)	0.367‡
Wound dehiscence	0 (0.0)	0 (0.0)	3 (0.6)	0.050‡
Transfusions	1 (0.2)	1 (0.2)	8 (1.1)	0.606‡
UTI	3 (0.6)	1 (0.2)	4 (0.7)	0.415‡
Progressive renal insufficiency	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Acute renal failure	0 (0.0)	1 (0.2)	0 (0.0)	0.368‡
Mechanical ventilation	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Pneumonia	1 (0.2)	0 (0.0)	0 (0.0)	0.368‡
Unplanned intubation	2 (0.4)	0 (0.0)	0 (0.0)	0.135‡
PE	3 (0.6)	0 (0.0)	1 (0.2)	0.173‡
Deep vein thrombosis	1 (0.2)	0 (0.0)	1 (0.2)	0.606‡
Cardiac arrest	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Myocardial infarction	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Cerebrovascular accident	0 (0.0)	0 (0.0)	0 (0.0)	N/A
Sepsis	0 (0.0)	0 (0.0)	3 (0.6)	0.050‡
Septic shock	0 (0.0)	0 (0.0)	0 (0.0)	N/A

*, comparison by ANOVA; ‡, comparison by Chi-squared test; #, statistically significant after correction for multiple comparisons. ACDF, anterior cervical discectomy with fusion; CDA, cervical disc arthroplasty; PCF, posterior cervical foraminotomy; SD, standard deviation; UTI, urinary tract infection; PE, pulmonary embolism; N/A, not available; ANOVA, analysis of variance.

ACDF, CDA, or PCF (*Table 4*). There were statistically significant differences in operative time of ACDF (103.70±46.52 minutes), CDA (110.07±38.45 minutes), and PCF (99.00±47.27 minutes) (P<0.001). Notably, patients undergoing PCF had higher rates of reoperation (2.1%) *vs.* those undergoing ACDF (0.4%) or CDA (0.6%) (P=0.010). Patients undergoing PCF had higher rates of superficial infection (1.9%) relative to those undergoing ACDF (0.2%) or CDA (0.2%) (P=0.001) (*Table 4*). Similarly, patients undergoing PCF also experienced higher rates of deep infection (0.9%) relative to those undergoing ACDF (0%) or CDA (0%) (P=0.001). Furthermore, patients undergoing single-level PCF had higher rates of wound dehiscence (0.6%) relative to patients who underwent ACDF (0%) or CDA (0%) (P=0.050) despite not attaining a statistically significant level of P<0.01 (*Table 4*). Similarly, patients undergoing PCF experienced higher rates of sepsis (0.6%) relative to patients who underwent ACDF (0%) or CDA (0%) that was not deemed statistically significant after correction (P=0.050). There were no other statistically significant differences in postoperative outcomes of cervical radiculopathy patients who underwent single-level ACDF, CDA or PCF which included any readmission, organ/space infection, transfusions, UTI, acute renal failure, unplanned intubation, pneumonia, unplanned intubation, PE, and DVT (P>0.05, each) (*Table 4*).

Discussion

This study was a retrospective cohort study aimed to analyze postoperative outcome differences in cervical radiculopathy patients undergoing single-level ACDF, CDA, or PCF. We initially hypothesized that there would be no significant differences in reoperation rates or 30-day postoperative outcomes amongst the 3 procedures, consistent with prior literature (19,20). We found that patients who underwent PCF experienced higher rates of reoperation, superficial infection, deep infection, wound dehiscence, and sepsis relative to patients undergoing ACDF or CDA. There were statistically significant differences in operative time, however these averages were within 10 minutes of each other and all less than 2 hours; as such, this is likely clinically insignificant. There were no significant differences in other postoperative medical or surgical outcomes measured between the three patient groups.

Optimal surgical management for cervical radiculopathy is incompletely understood, and not all cases of cervical radiculopathy can be appropriately treated with any of the studied procedures. For instance, central disc herniations, cervical kyphosis, or segment instability may specifically require anterior or combined approaches. However, in the specific cervical radiculopathy circumstance that could be appropriately treated with ACDF, CDA, or PCF, there is no consensus. While ACDF remains the gold standard, issues such as adjacent segment degeneration persist, which have increased 3-8% annually in recent years (21). Other potential ACDF complications such as adjacent segment disc height collapse (4,5), end-plate subsidence and potential pseudarthrosis (10) have opted surgeons to consider CDA and PCF to maintain spine motion (22). However, CDA can be associated with implant failure, component dislodgement, end plate subsidence, adjacent segment kyphosis, and metallosis (23). Although ACDF and CDA can be approached with muscle-sparing anterior approaches, PCF requires dissection of posterior muscle which can lead to increased pain, bleeding, wound complications, and nerve complications. The inherent invasiveness of PCF may in-part explain the higher local complication rates as well as the greater need for transfusion detected within the PCF cohort of this study (the latter was only detected in the pre-propensity score-matched comparison). However, PCF avoids implant-related complications and costs. Furthermore, while controversial, the recent emergence of full endoscopic PCF may mitigate the complications associated with open PCF (24). Future investigations are warranted to explore how endoscopic PCF compares to other surgical interventions for cervical radiculopathy.

Recent literature comparing the three procedures have been mixed. A meta-analysis of four randomized controlled trials reported all three surgical techniques are effective for treating cervical radiculopathy, with PCF having the lowest of rate of adverse events, and CDA having the lowest rate of secondary procedures (19). Similarly, in a retrospective investigation of 528 patients, Lubelski *et al.* (25) found that patients who received single-level PCF had higher odds of requiring over 1 unit of blood transfusions [odds ratio (OR) =4.31; 95% confidence interval (CI): (1.18–15.75); P=0.027] and non-home discharge [OR =3.68 95% CI: (2.17–6.25); P<0.001], in addition to an increased LOS (P<0.001) compared to those who underwent ACDF. A propensity score-matched study comparing 188 patients undergoing ACDF and 140 patients undergoing PCF from a single tertiary-care institution determined no difference in 2-year reoperation rates at the index level (25). A U.S. commercial health insurance claims database study including 46,147 patients undergoing ACDF and 4,851 patients undergoing PCF found higher rates of wound infections (14.6/1,000; P<0.001) and 30-day readmissions in the PCF cohort (9.8/1,000; P<0.001) (19,20). Our findings similarly suggest that patients undergoing PCF are associated with a higher postoperative infection risk (superficial/deep infection, wound dehiscence, sepsis, reoperation) relative to ACDF and CDA. The findings of this study are consistent with current literature that have found generally higher infection rates associated with posterior exposures (26).

This study has several limitations. As a database study, we were limited to assessing certain variables identified within the database and were therefore unable to evaluate other events specific to cervical spine surgery, such as dysphagia or hoarseness. Similarly, the lack of reliably recorded cause of reoperation precluded further granular analysis of this outcome based on the designated diagnosis prior to each reoperation. Furthermore, the retrospective nature of this investigation makes it subject to several inherent limitations including selection bias. However, our propensity score matching aimed to reduce this risk by identifying patients from the ACDF, CDA, and PCF groups with similar baseline characteristics. Our study was limited to 30-day postoperative outcomes and associated complications available by NSQIP, and we were not able to assess long-term outcomes. While such a design is

suitable for evaluating healthcare utilization parameters, including the need for early reoperation, future studies may be warranted to compare longer-term complication and reoperation rates. Similarly, BMI and comorbidity-stratified analysis may outline differences in outcomes within certain cohorts, thereby rendering a certain surgical intervention more preferable within patient subgroups with distinct comorbidity profiles. However, this study aimed to compare ACDF, PCF, and CDA using propensity score-matched cohorts to provide a quasi-randomized effect that serves to mitigate potential selection bias. In this study, we analyzed only patients undergoing single-level ACDF, CDA, or PCF, excluding patients who received a second or third level procedure during the same surgery. While a meta-analysis has indicated similar outcomes for single-level and multi-level CDA (27), single *vs.* multilevel PCF data has not been published (1), and a database study noted patients undergoing multi-level ACDF experience higher rates of revision surgery and complications relative to single-level (28). Despite these limitations, to our knowledge, this is the first study to use a sophisticated matching algorithm for an observational retrospective study to compare outcomes between these three surgical spine procedures.

Conclusions

In conclusion, our study demonstrates that cervical radiculopathy patients undergoing single-level PCF experience higher rates of postoperative infection (superficial infection, deep infection, wound dehiscence, sepsis) and overall reoperation than patients undergoing single-level ACDF or CDA. The average operative times between the three procedures are all less than 2 hours and within 10 minutes of each other. Although these three procedures are largely safe and effective, future studies should further characterize the mechanism behind the apparent increased infection risk seen in patients who undergo PCF, potentially attributable to the violation of the posterior cervical musculature. Nevertheless, to the best of our knowledge, our study is the first to compare postoperative outcomes in cervical radiculopathy patients appropriately treated with single-level ACDF, CDA, or PCF.

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