Original Article

Perioperative and safety outcomes following tissue-sparing posterior cervical fusion to revise a pseudarthrosis: A multicenter retrospective review of 150 cases

ABSTRACT

Background: Posterior cervical fusion (PCF) with lateral mass screws is a favorable treatment option to revise a symptomatic pseudarthrosis due to reliable rates of arthrodesis; however, this technique introduces elevated risk for wound infection and hospital readmission. A tissue-sparing PCF approach involving facet fixation instrumentation reduces the rates of postoperative complications while stabilizing the symptomatic level to achieve arthrodesis; however, these outcomes have been limited to small study cohorts from individual surgeons commonly with mixed indications for treatment.

Materials and Methods: One hundred and fifty cases were identified from a retrospective chart review performed by seven surgeons across six sites in the United States. All cases involved PCF revision for a pseudarthrosis at one or more levels from C3 to C7 following anterior cervical discectomy and fusion (ACDF). PCF was performed using a tissue-sparing technique with facet instrumentation. Cases involving additional supplemental fixation such as lateral mass screws, rods, wires, or other hardware were excluded. Demographics, operative notes, postoperative complications, hospital readmission, and subsequent surgical interventions were summarized as an entire cohort and according to the following risk factors: age, sex, number of levels revised, body mass index (BMI), and history of nicotine use.

Results: The average age of patients at the time of PCF revision was 55 ± 11 years and 63% were female. The average BMI was 29 ± 6 kg/m^2 and 19% reported a history of nicotine use. Postoperative follow-up visits were available with a median of 68 days (interquartile range = 41–209 days) from revision PCF. There were 91 1-level, 49 2-level, 8 3-level, and 2 4±-level PCF revision cases. The mean operative duration was 52 ± 3 min with an estimated blood loss of 14 ± 1.5cc. Participants were discharged an average of 1 ± 0.05 days following surgery. Multilevel treatment resulted in longer procedure times (single = 45 min, multi = 59 min, P = 0.01) but did not impact estimated blood loss (P = 0.94). Total nights in the hospital increased by 0.2 nights with multilevel treatment (P = 0.01). Sex, age, nicotine history, and BMI had no effect on recorded perioperative outcomes. There was one instance of rehospitalization due to deep-vein thrombosis, one instance of persistent pseudarthrosis at the revised level treated with ACDF, and four instances of adjacent segment disease. In patients initially treated with multilevel ACDF, revisions occurred most commonly on the caudal level (48% of revised levels), followed by the cranial (43%), and least often in the middle level (9%).

Conclusions: This chart review of perioperative and safety outcomes provides evidence in support of tissue-sparing PCF with facet instrumentation as a treatment for symptomatic pseudarthrosis

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after ACDF. The most common locations requiring revision were the caudal and cranial levels. Operative duration and estimated blood loss were favorable when compared to open alternatives. There were no instances of postoperative wound infection, and the majority of patients were discharged the day following surgery.

Keywords: Complications, facet fixation, nonunion, posterior cervical fusion, pseudarthrosis, revision, tissue sparing

INTRODUCTION

Pseudarthrosis is a well-documented complication of anterior cervical discectomy and fusion (ACDF), and the greatest risk for this complication is in patients with multilevel treatment.[1] Pseudarthrosis may not always manifest clinically; however, a proportion of these will become symptomatic requiring a subsequent surgical intervention either through a repeat anterior fusion or supplemental fixation with posterior cervical fusion (PCF).[2,3] The risk of persistent symptomatic pseudarthrosis after revision with ACDF is significant. Carreon *et al*.[4] compared rates of subsequent revisions between anterior and posterior approaches and found that 44% of patients revised with ACDF required a subsequent surgical treatment, whereas 4% of patients revised with PCF required a subsequent treatment.

The high rates of arthrodesis published for open PCF make it the preferred approach in most instances.[5] However, the soft-tissue disruption incurs greater blood loss and longer hospital stays[6,7] when compared to repeat ACDF. This increased morbidity is also accompanied by greater rates of postoperative wound complications[8] and hospital readmission,[9] particularly when multiple levels are revised.[10,11]

The use of facet instrumentation in the cervical spine was first described by Goel and Shah,[12-14] with these devices now deployed as part of a tissue-sparing technique for PCF.[15,16] Recent attention on this technique has highlighted its application for the revision of symptomatic pseudarthrosis following ACDF.[17,18] A review focusing on the technique summarized available radiographic, clinical, and perioperative outcomes and has so far shown comparable results to alternative fusion techniques of the cervical spine.[19] Limitations of available studies involving this technique are that outcomes most commonly involve small patient cohorts with diverse indications for PCF and are limited to a single surgeon or institute. The goal of this multicenter retrospective review was to assess operative details and postoperative safety outcomes in a cohort of patients treated with tissue-sparing facet fixation to revise a pseudarthrosis following ACDF.

MATERIALS AND METHODS

A retrospective review of medical records was performed across six sites in the United States. The study protocol was submitted to an independent IRB (Ethical and Independent Review Services) which determined that under 45CFR46.101, study activities did not constitute human subject research, and neither IRB approval nor informed consent from patients was necessary.

Medical records were reviewed to identify patients treated using tissue-sparing PCF with facet fixation instrumentation to revise one or more levels for the treatment of pseudarthrosis following ACDF (CAVUX Facet Fixation System, Providence Medical Technology, Pleasanton CA, USA). Eligibility was determined according to the inclusion and exclusion criteria provided in Table 1.

Eligible records were summarized according to patient demographics, operative details for index ACDF, and revision PCF procedures, insurance type, history of nicotine use, prior and concomitant narcotics, adverse events related to PCF procedure and/or device, and hospital readmission within 30 days of treatment. Operative details included indication for surgery, date of surgery, hardware used, levels treated, concomitant procedures performed, estimated blood loss, operative duration, and nights in hospital. Insurance type was categorized as private, government, or both. Demographics, insurance type, and nicotine history were all recorded at the time of PCF revision. Postoperative complications and adverse events were recorded until the time of the last clinic follow-up visit.

Table 1: Eligibility criteria

Inclusion criteria
Patients of 18 years of age or older at the time of the PCF procedure
Received PCF revision surgery at least a year prior using facet fixation instrumentation to revise a pseudarthrosis following ACDF
Treated levels included C3–C7
Exclusion criteria
PCF revision procedure involved additional procedures such as laminectomy or corpectomy
Revision procedure included lateral mass screws, rods, wires, or other hardware

PCF - Posterior cervical fusion; ACDF - Anterior cervical discectomy and fusion

Statistical analysis

All continuous variables were evaluated for normality using a Shapiro–Wilk test. Variables that approximate a normal distribution are described using means and standard deviations (SDs). For variables that were not normally distributed, medians and interquartile ranges are presented. Subgroup statistical analysis was conducted to explore potential relationships between comorbidities and perioperative outcomes. Outcomes consisted of operative duration, blood loss, length of stay, days to the last follow-up, and days until the last narcotic prescription. Analyses were performed on the following subgroups: single- versus multilevel procedures, sex, age (<65 years vs. ≥65 years), body mass index (BMI) (<30 kg/m^2 vs. ≥30 kg/m^2), nicotine use, minority race, and adjacent level intervention. For continuous variables, subgroups with $n \leq 30$ were evaluated for normality using both a Shapiro–Wilk test and a visual assessment of the histogram. Variables approximating a normal distribution in each group were further evaluated for equivalence of variance of the subgroups, and statistical comparisons were conducted using an independent sample *t*-test. The Mann–Whitney *U*-test was conducted for variables with subgroups of $n \leq 30$ that were not normally distributed. Fisher's exact test was conducted for all binary outcomes. Finally, the Kruskal–Wallis test was conducted for all ordinal outcomes. A significance threshold of $P < 0.05$ was used for all comparisons.

RESULTS

Patient demographics and surgical history

There were 150 eligible cases identified for the retrospective review across all sites. Demographic details are described in Table 2. The average age of patients at the time of revision was 55 ± 11 years (SD), and 63% were female. A total of 17 (12.1%) subjects reported a race other than Caucasian, and 11 (7.6%) reported Hispanic or Latino ethnicity. The average BMI was 29.2 ± 6.2 kg/m^2, and 18.7% reported a history of nicotine use. Subjects requiring multilevel revision were younger (single = 58 ± 11 years, multi = 53 ± 9 years, $P = 0.01$, one-way ANOVA) and were more likely to report nicotine use (single = 9%, multi = 27%, $P < 0.01$, Fisher's exact). All other demographic variables were consistent across the number of levels revised.

Anterior cervical discectomy and fusion operative details

ACDF operative details were available for 148 of 150 cases and involved a total of 333 levels treated, of which 221 required subsequent PCF for treatment of symptomatic pseudarthrosis. Figure 1 describes the number of levels and location of intervention for both index ACDF and revision PCF procedures. All patients had a history of ACDF indicated for fusion due to symptoms stemming from degenerative causes. Indications included radiculopathy (36.8%), myelopathy (4.4%), degenerative disc disease (10.3%), pseudarthrosis (3.7%), spinal stenosis (26.5%), and disc herniation (18.4%). There were 110 procedures where index ACDF was performed at two or more contiguous levels. The relative location of revision is summarized for multilevel patients in Table 3. For patients with 2-level ACDF procedures, the location of pseudarthroses was equally distributed between the cranial and caudal levels (51% vs. 49%, respectively). For patients with 3-level ACDF, the caudal location was more likely to require revision when compared to the cranial or middle positions (cranial = 34%, middle = 14%, and caudal = 52%). For 4+-level PCF patients, the distribution

Table 2: Patient demographic information summarized as an entire cohort and according to the number of levels treated with posterior cervical fusion

	All subjects	1-level PCF	Multilevel (2+) PCF	2-level PCF	3-level PCF	4+-level PCF
Subjects represented*	150	68	82	61	14	7
Age (years, SD)	55.3 (10.6)	58.2 (11.2)	52.8^ (9.4)	53.8 (9.6)	50.4 (9.7)	49 (5.5)
Sex (female, %)	95 (63.3)	42 (61.8)	53 (64.6)	39 (63.9)	10 (71.4)	4 (57.1)
BMI (kg/m^2, SD)	29.2 (6.2)	28.4 (6.6)	29.8 (5.9)	29.2 (6.2)	31.6 (5.3)	31.5 (3.6)
Unknown or missing	10	7	3	2	1	0
Minority race (% minority race)	17 (12.1)	8 (12.7)	9 (11.5)	6 (10.3)	2 (15.4)	1 (14.3)
Unknown or missing	9	5	4	3	1	0
Ethnicity (% Hispanic or Latino)	11 (7.6)	7 (10.4)	4 (5.2)	2 (3.4)	2 (16.7)	0
Unknown or missing	6	1	5	2	2	1
Insurance type, *n* (%)						
Private	84 (60.4)	33 (55.0)	51 (64.6)	40 (69.0)	7 (50.0)	4 (57.1)
Government	25 (18.0)	8 (13.3)	17 (21.5)	12 (20.7)	3 (21.4)	2 (28.6)
Both	30 (21.6)	19 (31.7)	11 (13.9)	6 (10.3)	4 (28.6)	1 (14.3)
Unknown or missing	11	8	3	3	0	0
Nicotine use (% smoker)	28 (18.7)	6 (8.8)	22# (26.8)	14 (23)	4 (28.6)	4 (57.1)

*Number of levels reported includes treated adjacent segments, not exclusively levels revised for pseudarthrosis; ^Younger than single-level revision, P=0.01; #More likely to use nicotine than single-level revision, P<0.01. PCF - Posterior cervical fusion; BMI - Body mass index; SD - Standard deviation

across locations was consistent (cranial = 31%, middle = 38%, and caudal = 31%).

Posterior cervical fusion operative details

PCF revisions were performed with a median of 19 months (11.3–31.5) from index ACDF on an average of 1.45 levels. Preoperative narcotic use was documented in 45.3% of patients. All patients had pseudarthrosis as a primary indication for surgery, with a subset of patients (22%) having additional adjacent segments included in their treatment plan. Operative details are presented in Table 4.

Operative duration was available for 86 cases, with one removed as an outlier (355 min). The mean time to complete the PCF procedure was 52 ± 3 min with multilevel procedures requiring more time to complete (single = 45 ± 4 min, multi = 59 ± 4 min, $P = 0.01$, two-sample *t*-test). Younger patients had longer procedures than older (young = 57 ± 4 min, older = 40 ± 2 min, $P < 0.001$, two-sample *t*-test). There was no effect of sex ($P = 0.87$, two-sample *t*-test), BMI ($P = 0.84$, two-sample *t*-test), or nicotine use ($P = 0.08$, Mann–Whitney *U*-test) on operative duration.

The total estimated blood loss due to the procedure was available for 71 cases, with one removed as an outlier (150cc). The average amount of blood lost was 14 ± 2cc. There was no

Table 3: Location of revision posterior cervical fusion relative to index anterior cervical discectomy and fusion construct

	2-level ACDF, *n* (%)	3-level ACDF, *n* (%)	4+-level ACDF, *n* (%)	Total (2+-level ACDF), *n* (%)
Levels revised	80	58	16	154
Cranial	41 (51)	20 (34)	5 (31)	66 (43)
Middle	-	8 (14)	6 (38)	14 (9)
Caudal	39 (49)	30 (52)	5 (31)	74 (48)

ACDF - Anterior cervical discectomy and fusion

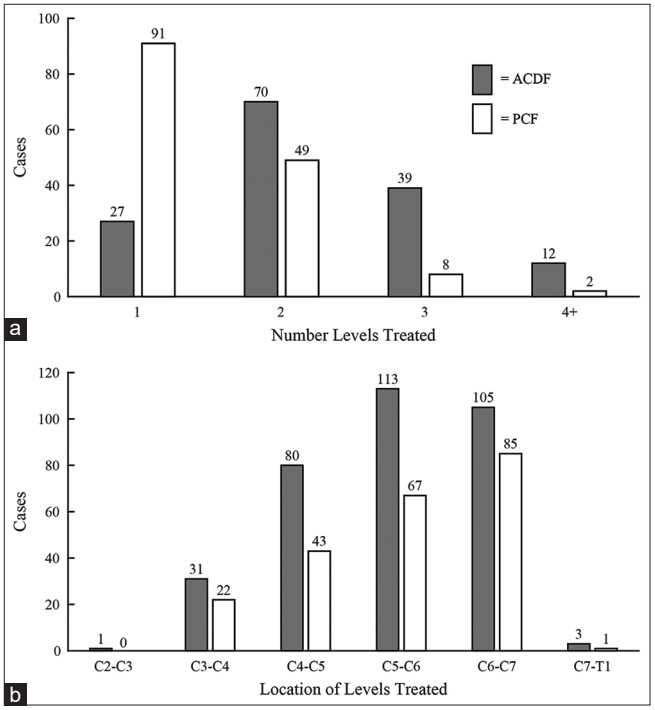

Figure 1: Description of number (a) and location (b) of segments treated during the index anterior cervical discectomy and fusion and revision PCF procedures. ACDF: Anterior cervical discectomy and fusion, PCF: Posterior cervical fusion

Table 4: Posterior cervical fusion operative details stratified according to risk factors

	Operative duration (min) (*n*=85)	Estimated blood loss (cc) (*n*=70)	Nights in hospital (*n*=93)
All cases	51.5±2.9	14.2±1.5	1.0±0.05
Sex			
Male	50.9±5.7	13.6±3.0	1.0±0.09
Female	51.9±3.2	14.5±1.6	1.1±0.06
Age (years)			
<65	56.5±3.9	14.8±1.7	1±0.06
65+	50.3±2.4	11.0±2.4	0.8±0.12
Levels with PCF			
1-level	44.5±3.9	14.3±2.0	0.9±0.09
Multiple levels (2+)	59.1±4.0†	14.1±2.2	1.1±0.05†
2-level	56.4±3.6	14.7±2.3	1.1±0.06
3-level	97.3±27.2	8.3±1.7	1.1±0.09
4+-level	42.0	NA	1.2±0.20
BMI (kg/m^2)			
<30	49.5±3.5	13.5±1.6	1.0±0.06
≥30	50.7±5.4	16.9±3.7	1.1±0.10
Nicotine use			
No nicotine HX	61.1±8.5	18.3±11.4	1.0±0.06
Nicotine HX	50.3±2.8	13.8±1.3	0.9±0.06

†Longer than a single level, P=0.01. BMI - Body mass index; PCF-Posterior cervical fusion

effect of age ($P = 0.33$, Mann–Whitney *U*-test), sex ($P = 0.42$, Mann–Whitney *U*-test), number of levels ($P = 0.94$, two-sample *t*-test), BMI ($P = 0.41$, two-sample *t*-test), or nicotine use ($P = 0.34$, Mann–Whitney *U*-test) on total blood loss.

Patients with multilevel treatment were more likely to spend more than one night in the hospital ($P = 0.01$, Kruskal–Wallis test). There was no effect of sex ($P = 0.24$, Kruskal–Wallis test), age ($P = 0.11$, Kruskal–Wallis test), BMI ($P = 0.20$, Kruskal–Wallis test), or nicotine history ($P = 0.45$, Kruskal–Wallis test) on total nights in the hospital.

Safety outcomes and subsequent surgical intervention

The review of postoperative visit notes was recorded through a median of 68 days (41–209) following treatment. A summary of postoperative outcomes is provided in Table 5. Prescription for postoperative narcotics was renewed through a median of 46 days (20–95) from treatment. There was one instance (0.7% of cases) of unplanned rehospitalization within 30 days of revision, which was a result of left upper-extremity deep-vein thrombosis. There were five instances of patients requiring subsequent surgical interventions. One was for persistent pseudarthrosis and four were for adjacent segment degeneration. Details of all subsequent surgical interventions are provided in Table 6. In addition to the listed surgical re-interventions, adverse events consisted of two reports of new-onset numbness and tingling, one complaint of new-onset neck pain, and one diagnosed incidence of adjacent segment degeneration treated conservatively. Collectively, 6.7% of patients ($n = 10/150$) had documentation of adverse events related to either the PCF procedure or device.

DISCUSSION

This retrospective chart review summarized perioperative morbidity and postoperative safety outcomes in patients treated with a tissue-sparing PCS for the treatment of pseudarthrosis. There were a total of 150 patients, treated across six sites, by seven surgeons, with outcomes tracked over a median of 68 days following revision.

Open PCF with lateral mass screws includes wide exposure of the spine with detachment of muscles and ligaments with retraction of soft tissues. Typically, the surgeon will expose one level above and below the intended level to gain adequate exposure. Fixation with lateral mass screws provides the most secure stabilization and is required when instability is due to trauma. Facet cages with supplemental screw fixation provide sufficient stabilization when needed for the treatment of pseudarthrosis. The technique is guided using fluoroscopy to minimize the need for direct visualization. By minimizing exposure, the risk of postoperative complications and readmissions should improve.

Operative time, estimated blood loss, and nights in hospital

The current study reports perioperative outcomes similar to what has been previously reported for this technique. The average operative duration was 52 min, and the average blood loss was 14cc. Patients were discharged after an average of one night in the hospital. Smith *et al*.[17] presented the use of tissue-sparing PCF to revise a prior ACDF for 25 patients and reported an operative duration of 104 min, estimated blood loss of 88cc, and a hospital stay of 1.4 nights. In their cohort, 36% of patients were additionally treated

Table 5: Postoperative outcomes based on the number of levels revised with posterior cervical fusion

	All cases	1-level PCF	Multilevel (2+) PCF	2-level PCF	3-level PCF	4+-level PCF
Median follow-up (days, IQR)	68 (41–209)	61 (44–201)	71.5 (41–209)	68 (41–163)	143 (40–281)	156 (60–265)
Median time to last narcotics prescription (days, IQR)	46 (20–95)	63 (28–128)	41 (14–69)	46 (21–78)	14 (13–35)	41 (14–50)
30-day unplanned readmission	1 (0.7)	0	1	0	1	0
Persistent pseudarthrosis requiring revision	1 (0.7)	0	1	1	0	0
Adjacent segment degeneration requiring revision	4 (2.7)	0	4	2	1	1
Surgical site infection, C5 palsy, or vascular injury	0	0	0	0	0	0

PCF - Posterior cervical fusion; IQR - Interquartile range

Table 6: Summary of subsequent surgical interventions

Case	Age	Sex	Risk	Index ACDF	Revision PCF	Days to SSI	Indication	Intervention
1	64	Male	BMI >30	C3–C6	C5–C7[%]	427	Pseudarthrosis	Repeat anterior fusion
2	34	Female	Smoker BMI >30	C5–C7	C5–C7	260	Adjacent segment degeneration	Tissue-sparing PCF C3–C5
3	56	Female	Smoker BMI >30	C3–C6	C3–C6	792	Adjacent segment degeneration	ACDF at the superior and inferior adjacent levels
4	40	Male	Smoker BMI >30	C5–C7	C2–C7	211	Adjacent segment degeneration	ACDF C2–C5
5	31	Female	Smoker	C5–C7	C5–C7	570	Adjacent segment degeneration	ACDF and tissue-sparing PCF at C3–C5

[%]Revision for pseudarthrosis performed at C5–C6 with adjacent segment treatment at C6–C7. PCF - Posterior cervical fusion; SSI - Subsequent surgical interventions; ACDF - Anterior cervical discectomy and fusion; BMI - Body mass index

with ACDF at the time of procedure, providing a possible explanation for the slightly elevated operative outcomes. One reason for the relatively low perioperative outcomes associated with this technique is likely due to the minimal tissue disruption required to gain access to the facets with little increase in perioperative costs when treating additional levels.[20] Open procedures, whether through a posterior or anterior approach, require longer operative times and result in greater blood loss, particularly when multiple levels are treated. Carreon *et al*.[4] reported on operative morbidity for ACDF and open PCF in the revision of pseudarthrosis. For ACDF, the procedure required 135 min, an estimated blood loss of 102cc, and an average hospital stay of 1.3 nights. Open PCF had a similar procedure length of 139 min, but greater blood loss at 282cc and length of stay at 3.4 nights.

Postoperative complications and readmission

Across the 150 cases performed by the seven participating surgeons, there was one major postoperative complication requiring readmission within 30 days of treatment (0.7% of cases) and an overall related adverse event rate of 6.7%. There were no instances of surgical wound infection, C5 palsy, cord or nerve root injuries, vascular injuries, or device malfunction/malpositioning requiring correction. Malpositioning of the facet instrumentation into the neural foramen can result in a C5 palsy;[21] however, the rates of these violations appear low when compared to open PCF.[22] Siemionow *et al*.[23] tracked complications following tissue-sparing PCF through 7 months and reported one instance of neurological complications related to the device or procedure. Rates of postoperative complications and persistent axial pain tend to increase with an open approach.[24,25] Yue *et al*.[7] performed an analysis of 30-day postoperative complications following open PCF and found that 4% of patients required blood transfusions, 3% had postoperative pneumonia, and 2% had surgical site infection. Across all categories, open PCF was associated with a postoperative complications rate of 12.5% and a 30-day reoperation rate of 4.5%. Zaki *et al*.[11] reported a 17% readmission rate following open PCF on 160 cases with the number of levels treated and length of stay predicting increased risk. In their cohort, the most common reasons for readmission were systemic infection and wound complications. A meta-analysis by Youssef *et al*.[26] summarized complications following PCF in a pooled 1238 cases, with C5 palsy and wound infection having two of the highest incidences. Similarly, Nayak *et al*.[27] reported PCF to have the highest rates of readmission for wound infection when compared to ACDF and artificial disc arthroplasty.

Persistent pseudarthrosis

There was one instance of revision for persistent pseudarthrosis. A well-documented risk factor for pseudarthrosis in the cervical spine is the number of contiguous levels treated at the index fusion procedure.[1] In the current chart review, 74% of revision cases were performed on individuals with a multilevel index ACDF procedure. Along the treated segment, the most common location for pseudarthrosis was at the caudle end, representing 48% of levels followed closely by the cranial level with 43%. Middle levels represented only 9% of revised levels. Nichols *et al*.[28] characterized radiographic nonunion rates in 3-level ACDF patients according to position along the segment. They similarly reported the caudal position as the most likely to not fuse. These results were further supported by Wewel *et al*.[29] who found that 46% of 3- and 4-level ACDF patients had radiographic pseudarthrosis, with the location most commonly being at the caudal level. McClure *et al*.[30] documented pseudarthrosis rates along the cervical spine following 3- and 4-level ACDF based on absolute position and reported a radiographic pseudarthrosis rate of at the C6–C7 segment of more than 50% at 24+ months compared to < 20% at the C3–C4 segment. Of the patients with multilevel index ACDF, nearly half were revised at multiple levels (57/121, 47%). Patients with multilevel revisions incurred a longer operative duration and required longer stays in the hospital but had similar blood loss. In addition, all patients treated with subsequent surgical interventions had a multilevel revision following index ACDF. These trends are similar to what was reported by Leckie *et al*.[10] who observed higher rates of complications when revising more than one level with PCF. For long 4-segment treatment, Joo *et al*.[9] reported that PCF had a greater odds ratio of 2.12 over ACDF for postoperative complications.

Limitations

This retrospective review draws conclusions based on data compiled from information collected as part of a surgeon's standard of care. This design introduces a few limitations, including incomplete data for some fields and a limited window in which to follow up patients, particularly if their prognosis was positive. The methods to track patient-reported outcomes were inconsistent across sites and surgeons making it unfeasible to comment on pooled relief of symptoms in the days following treatment. Smith *et al*.[17] tracked clinical improvements in patients treated with the same tissue-sparing PCF technique to revise pseudarthrosis. They reported improvements in VAS_{neck} of 3.8, VAS_{arm} of 3.1, and neck disability index of 29. The use of fluoroscopy is an essential adjunct to direct visualization for proper guidance and positioning of the spinal instruments. Including regular fluoroscopy introduces the risk of additional radiation exposure when compared to open approaches. Fluoroscopy time is rarely collected outside of an academic setting and was not available in any of the patient charts. Future studies into this technique would benefit from including exposure

time to better understand how this risk compares to other approaches.

With a median follow-up of 68 days, radiographic conclusions on arthrodesis are limited. Haglund *et al*.[18] assessed long-term radiographic outcomes in 45 patients revised with tissue-sparing PCF over a median of 39 months with surgeon-assessed fusion achieved in 91% of patients and satisfaction reported in 74% of patients.

All patients included symptomatic pseudarthrosis as a primary indication for revision with many instances of multilevel revision. In this series, 66% of ACDF levels were revised which suggests a high rate of multilevel pseudarthrosis; however, it is the authors' opinion that not all revised levels contributed to the reported symptoms. Treating multiple levels introduced an additional 15 min to the procedure, and as such, a surgeon may have been more willing to include additional levels to prevent the potential need for future interventions, especially if the symptomatic level was difficult to localize.

CONCLUSIONS

This retrospective chart review summarized perioperative and safety outcomes in a cohort of patients revised with tissue-sparing PCF to treat symptomatic pseudarthrosis. Multilevel treatment had an effect on operative duration and length of stay but did not impact estimated blood loss. When compared to open PCF with lateral mass fixation, patients had shorter procedure times, less blood loss, and were discharged earlier from the hospital.

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Conflicts of interest

This study was funded by Providence Medical technology (PMT). Dr. McCormack has a financial interest in PMT. Dr. Summerside is an employee of PMT. Drs Lemons, Haglund, Williams, and Bohr have no financial interests that would be impacted by outcomes reported in this study.

REFERENCES

1. Zuckerman SL, Devin CJ. Pseudarthrosis of the cervical spine. Clin Spine Surg 2022;35:97-106.
2. Crawford CH 3rd, Carreon LY, Mummaneni P, Dryer RF, Glassman SD. Asymptomatic ACDF nonunions underestimate the true prevalence of radiographic pseudarthrosis. Spine (Phila Pa 1976) 2020;45:E776-80.
3. Kaiser MG, Mummaneni PV, Matz PG, Anderson PA, Groff MW, Heary RF, *et al*. Management of anterior cervical pseudarthrosis. J Neurosurg Spine 2009;11:228-37.
4. Carreon L, Glassman SD, Campbell MJ. Treatment of anterior cervical pseudoarthrosis: Posterior fusion versus anterior revision. Spine J 2006;6:154-6.
5. McAnany SJ, Baird EO, Overley SC, Kim JS, Qureshi SA, Anderson PA. A meta-analysis of the clinical and fusion results following treatment of symptomatic cervical pseudarthrosis. Global Spine J 2015;5:148-55.
6. Lee NJ, Kim JS, Park P, Riew KD. A comparison of various surgical treatments for degenerative cervical myelopathy: A propensity score matched analysis. Global Spine J 2022;12:1109-18.
7. Yue JK, Upadhyayula PS, Deng H, Sing DC, Ciacci JD. Risk factors for 30-day outcomes in elective anterior versus posterior cervical fusion: A matched cohort analysis. J Craniovertebr Junction Spine 2017;8:222-30.
8. Badiee RK, Mayer R, Pennicooke B, Chou D, Mummaneni PV, Tan LA. Complications following posterior cervical decompression and fusion: A review of incidence, risk factors, and prevention strategies. J Spine Surg 2020;6:323-33.
9. Joo PY, Jayaram RH, McLaughlin WM, Ameri B, Kammien AJ, Arnold PM, *et al*. Four-level anterior versus posterior cervical fusions: Perioperative outcomes and five-year reoperation rates: Outcomes after four-level anterior versus posterior cervical procedures. N Am Spine Soc J 2022;10:100115.
10. Leckie S, Yoon ST, Isaacs R, Radcliff K, Fessler R, Haid R Jr., *et al*. Perioperative complications of cervical spine surgery: Analysis of a prospectively gathered database through the association for collaborative spinal research. Global Spine J 2016;6:640-9.
11. Zaki O, Jain N, Yu EM, Khan SN. 30- and 90-day unplanned readmission rates, causes, and risk factors after cervical fusion: A single-institution analysis. Spine (Phila Pa 1976) 2019;44:762-9.
12. Goel A, Shah A. Facetal distraction as treatment for single-and multilevel cervical spondylotic radiculopathy and myelopathy: A preliminary report. J Neurosurg Spine 2011;14:689-96.
13. Goel A. Facet distraction spacers for treatment of degenerative disease of the spine: Rationale and an alternative hypothesis of spinal degeneration. J Craniovertebr Junction Spine 2010;1:65-6.
14. Goel A. Interfacetal intra-articular spacers: Emergence of a concept. J Craniovertebr Junction Spine 2016;7:72-4.
15. Summerside E, Heller J, Glenn J, McCormack B, Menchetti PP. Tissue sparing posterior fixation as a treatment option for degenerative disc disease. In: Menchetti PP, editor. Cervical Spine: Minimally Invasive and Open Surgery. Cham: Springer International Publishing; 2022. p. 231-45.
16. McCormack BM, Dhawan R. Novel instrumentation and technique for tissue sparing posterior cervical fusion. J Clin Neurosci 2016;34:299-302.
17. Smith W, Gillespy M, Huffman J, Vong V, McCormack BM. Anterior cervical pseudarthrosis treated with bilateral posterior cervical cages. Oper Neurosurg (Hagerstown) 2018;14:236-42.
18. Haglund MM, McCormack BM, Williams DM, Lemons AC, Summerside EM. Long-term outcomes in patients treated with tissue-sparing posterior cervical fusion to revise a 1-level pseudarthrosis following ACDF. J Clin Neurosci 2024;119:85-92.
19. Laratta JL, Gupta K, Smith WD. Tissue-sparing posterior cervical fusion with interfacet cages: A systematic review of the literature. Global Spine J 2020;10:230-6.

20. Yazdanshenas H, Osias E, Hwang R, Park DY, Lord E, Shamie AN. Retrospective evaluation of cervical fusion with DTRAX (R) cervical cage. J Craniovertebr Junction Spine 2022;13:48-54.
21. Hoang L, Jasiukaitis P. Confirming a C5 palsy with a motor evoked potential trending algorithm during insertion of cervical facet spacers: A case study. Neurodiagn J 2022;62:206-21.
22. Garcia JH, Haddad AF, Patel A, Safaee MM, Pennicooke B, Mummaneni PV, *et al*. Management of malpositioned cervical interfacet spacers: An institutional case series. Cureus 2021;13:e20450.
23. Siemionow KB, Glowka P, Blok RJ, Gillespy MC, Gundanna MI, Smith WD, *et al*. Perioperative complications in patients treated with posterior cervical fusion and bilateral cages. J Craniovertebr Junction Spine 2017;8:342-9.
24. Wang SJ, Jiang SD, Jiang LS, Dai LY. Axial pain after posterior cervical spine surgery: A systematic review. Eur Spine J 2011;20:185-94.
25. Patel PD, Canseco JA, Houlihan N, Gabay A, Grasso G, Vaccaro AR. Overview of minimally invasive spine surgery. World Neurosurg 2020;142:43-56.
26. Youssef JA, Heiner AD, Montgomery JR, Tender GC, Lorio MP, Morreale JM, *et al*. Outcomes of posterior cervical fusion and decompression: A systematic review and meta-analysis. Spine J 2019;19:1714-29.
27. Nayak R, Razzouk J, Ramos O, Ruckle D, Chiu A, Parel P, *et al*. Reoperation and perioperative complications after surgical treatment of cervical radiculopathy: A comparison between three procedures. Spine (Phila Pa 1976) 2023;48:261-9.
28. Nichols NM, Jamieson A, Wang M, Chou D, Mummaneni PV, Tan LA. Characterizing the fusion order and level-specific rates of arthrodesis in 3-level anterior cervical discectomy and fusion: A radiographic study. J Clin Neurosci 2020;81:328-33.
29. Wewel JT, Kasliwal MK, Adogwa O, Deutsch H, O'Toole JE, Traynelis VC. Fusion rate following three- and four-level ACDF using allograft and segmental instrumentation: A radiographic study. J Clin Neurosci 2019;62:142-6.
30. McClure JJ, Desai BD, Shabo LM, Buell TJ, Yen CP, Smith JS, *et al*. A single-center retrospective analysis of 3-or 4-level anterior cervical discectomy and fusion: Surgical outcomes in 66 patients. J Neurosurg Spine 2020;34:45-51.