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No Difference in Functional Outcome but Higher Revision Rate Among Smokers Undergoing Cervical Artificial Disc Replacement: Analysis of a Spine Registry

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ABSTRACT

Background: Smoking is a known predictor of negative outcomes in spinal surgery. However, its effect on the functional outcomes and revision rates after ADR is not well-documented. This study is a retrospective analysis of prospectively collected data at a major tertiary center. The objective was to elucidate the impact of smoking on functional outcomes in cervical artificial disc replacement (ADR).

Methods: Patients who underwent cervical ADR for myelopathy or radiculopathy from 2004 to 2015 with a minimum of 2 years of follow-up were included in the study. Patient function was assessed using Short Form-36 (SF-36), American Association of Orthopaedic Surgery (AAOS) cervical spine, and Japanese Orthopaedic Association (JOA) scoring systems preoperatively and at 2 years postoperatively. Incidence of further surgery on affected and adjacent segments was analyzed as well.

Results: A total of 137 patients were included in the study, consisting of 117 nonsmokers and 20 smokers. There were 60 patients who presented with myelopathy and 77 with radiculopathy. The mean age of smokers was 42.6 years, compared with 46.4 years in the nonsmoker group ($P < .01$). Statistical improvement was noted in postoperative range of motion, as well as AAOS, SF-36, and JOA scores in both groups, with no difference between groups at 2 years of follow-up. A total of 84.2% of nonsmokers and 87.5% of smokers reported as surgery having met their expectations. A total of 5 of 117 nonsmokers (5.1%) and 4 of 20 smokers (20%) needed revision surgery ($P = .018$). Three of the 4 smokers who required surgery for adjacent or multisegment disease, whereas only 2 of the nonsmokers needed an operation for adjacent segment disease.

Conclusions: Our analysis indicates that there is no difference in functional outcome or patient satisfaction between smokers and nonsmokers. Smokers have a higher chance of revision surgery after an artificial disc replacement compared with nonsmokers at 2 years.

Level of Evidence: 3.

Cervical Spine

Keywords: cervical spine, artificial disc replacement, smoking, functional outcome, fusion, anterior cervical discectomy and fusion, revision, myelopathy, radiculopathy, spine

INTRODUCTION

Cervical radiculopathy and cervical myelopathy can be caused by cervical disc prolapse or spondylotic changes.[1–4] Anterior surgical options include cervical discectomy/corpectomy with fusion or artificial disc replacement. The gold standard surgical treatment of radiculopathy and myelopathy has been fusion surgery.[5,6] Unfortunately, fusion has various shortcomings, including loss of range of motion and reoperation from adjacent segment disease.[7–10] Cervical artificial disc replacement (ADR) has been developed as an alternative to fusion surgery in young patients to preserve the range of motion and decrease the incidence of adjacent segment disease.[7,9,11,12]

Smoking is a known predictor of negative outcomes for most spine surgeries,[13–16] including anterior cervical discectomy and fusion (ACDF). However, there are limited data reporting the impact of smoking on cervical ADR surgery.

In this study, we aim to determine if smoking has a negative outcome in postoperative functional outcome in patients undergoing cervical ADR.

Table 1. Questions that were used from the American Association of Orthopaedic Surgery (AAOS) Cervical Spine Questionnaire.

Question 8	Did you return to full function after your most recent surgery? (Circle one response)						
	1 Yes	2 No					
Question 48	Has the surgery for your neck condition made your expectations? (Circle one response)						
	Yes, totally	Yes, almost totally	Yes, quite a bit	More or less	No, not quite	No, far from it	No, not at all
	1	2	3	4	5	6	7
Question 53	How would you rate the overall experience of your treatment for your neck or arm pain? (Circle one response)						
	Excellent	Very Good	Good	Fair	Poor	Terrible	
	1	2	3	4	5	6	

MATERIALS AND METHODS

Study Design and Setting

This was a retrospective analysis of prospectively collected data from the spine registry of a tertiary referral center specializing in spinal surgery. Institutional Review Board approval for SingHealth was granted for this study. No permission was required for the reproduction of copyrighted materials. No patient consent forms were required for this study.

Participants, and Inclusion and Exclusion Criteria

All patients who underwent cervical ADR between 2004 and 2015 for either cervical radiculopathy or myelopathy were considered for the study. Patients who did not have a 2-year follow-up or who had concurrent ACDF were excluded. Patients with previous spinal tumor pathologies, spinal infections, acute spinal trauma, or infections were also excluded. All patients were actively treated with nonoperative management (physiotherapy, analgesia, and activity modification) for a minimum of 3 months without any relief of their radicular or myelopathic symptoms before undergoing surgery. All patients were actively counseled to cease smoking while undergoing treatment. All patients were operated on by experienced fellowship-trained spine surgeons.

Variables and Bias

Parameters included patient demographics, comorbidities, clinical diagnosis, operative details, and length of stay. Preoperative and postoperative, objective clinical assessment was done by experienced independent physiotherapists using the American Association of Orthopaedic Surgery (AAOS) scores, Neck Disability Index (NDI) score, 36-item Short Form Health Survey (SF-36) scores, numerical pain rating scale (NPRS), and the Japanese Orthopaedic Association (JOA) score for severity of cervical myelopathy, as well as questions from the AAOS Cervical Instrument questionnaire (Table 1). All data were collected prospectively at 6 months and at 2 years after surgery and were reviewed retrospectively for this study. Other parameters of complications, readmission rates, and revision surgeries were also noted.

Patients were divided into 2 groups: smokers and nonsmokers. Patients were classified as smokers if they were actively smoking at the time of their surgery. Patients who had never smoked before and ex-smokers, including those who had quit smoking before their surgery, were considered to be nonsmokers. Patient statistics were analyzed according to these 2 subgroups. Revision surgery rates for both groups were analysed in our study. The main indication for revision surgery was the presence of debilitating radicular or myelopathic symptoms at the previously operated level or adjacent level(s) that persisted or worsened for at least 6 months during the postoperative follow-up period.

Statistical Methods

Statistical analysis was performed with SPSS version 17.0 (IBM, New York, NY). The Pearson χ^2 test was used to compare categoric data (smoking status, sex, presence of comorbidities, diagnosis of radiculopathy or myelopathy), whereas the independent t test was used to compare continuous variables (length of operation, hospitalization, duration to return to work). Analysis of variance was used to elucidate any significant differences in SF-36, JOA, AAOS, or NPRS scores, as well as differences in scoring from the AAOS cervical instrumentation questionnaire. Independent t test was used for comparison. A significant value was defined as $P < .05$.

RESULTS

Participants and Descriptive Data

A total of 231 patients underwent cervical ADR at our institution during the time period. A total of 36 patients underwent concurrent ACDF and were excluded, and 58 patients did not have at least 2

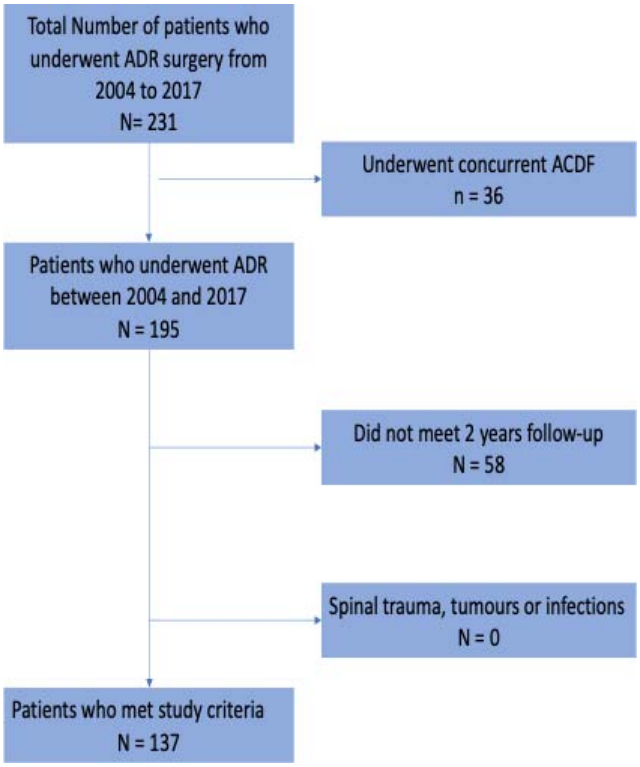

Figure 1. Methodology of patient selection. A total of 137 of 231 patients were included; 36 were excluded because of concurrent fusion, and 58 did not meet the 2-year follow-up requirement. No patients had trauma, tumors, or infections.

years of follow-up and were excluded from the study, leaving 137 patients who were included in the study. This gives an effective follow-up of 70% at 2 years. The patient selection process is illustrated in Figure 1.

Of the 137 patients that were included in the study, there were 117 nonsmokers and 20 smokers. The mean follow-up duration was 74 months and 17 days (2270 days).

Our results showed that the smoker group consisted of younger patients, with a mean age of 42.6 years compared with nonsmokers, whose mean age was 46.4 years ($P < .01$). Smokers were also much more likely to be male ($P = .002$). Both groups were otherwise well matched in terms of body mass index, number of spinal levels operated on, comorbidities, and preoperative subjective scores (Tables 2 and 3). Of the 137 patients, 77 (56.2%) had radiculopathy as their primary diagnosis, whereas the remaining 60 (43.8%) had myelopathy as a primary diagnosis. In the nonsmoking group, 65 patients (55.6%) had radiculopathy and 52 (44.4%) had myelopathy, whereas in the smoking group, 12 patients (60%) experienced radiculopathy and 8 (40%) had myelopathy.

Outcome Data and Main Results

There was no difference in the preoperative scores between the 2 groups (Table 3) except for SF-36

Table 2. Patient demographics and immediate perioperative parameters.

Baseline	Nonsmokers (n = 117)	Smokers (n = 20)	*P* Value
Age, y	46.4 ± 8.60	42.6 ± 10.81	.01
Number of males (%)	50 (42.7)	16 (80)	.002
Body mass inde at baseline	24.68 ± 4.04	23.79 ± 3.57	.509
Previous spine surgery, n (%)	9 (7.69)	1 (5)	
Adjacent segment fusion	6	1	
Adjacent segment ADR	2	0	
Same-level ADR	1	0	>.05
Radiculopathy, n (%)	65 (55.6)	12 (60)	.711
Myelopathy, n (%)	52 (44.4)	8 (40)	
ADR levels, n (%)			.413
1	82 (70.1)	13 (65)	
2	31 (26.5)	5 (25)	
3	4 (3.4)	2 (10)	
Diabetes, n (%)	10 (8.55)	0 (0)	.174
Ischemic heart disease, n (%)	6 (5.13)	0 (0)	.300
Stroke, n (%)	0 (0)	0 (0)	N/A
Arthritis, n (%)	12 (10.3)	2 (10)	.972
Asthma, n (%)	10 (8.55)	1 (5)	.590
Depression, n (%)	3 (2.56)	0 (0)	.469
Hypertension, n (%)	31 (26.5)	6 (30)	.744
Psoriasis, n (%)	1 (0.85)	0 (0)	.678
Length of procedure, min	130.03 ± 39.45	142.90 ± 43.39	.187
Length of hospital stay, days	2.84 ± 1.25	2.60 ± 1.04	.418
Return to work, days	69.357 ± 59.80	57.615 ± 30.87	.491
Duration of follow-up, days	2226.03 ± 1018.38	2527.05 ± 887.51	.216

Abbreviations: ADR, artificial disc replacement; N/A, xxxx.

Table 3. Preoperative and postoperative functional Short Form-36 (SF-36) scores.[a]

	Baseline		6 mo		2 y	
Clinical Outcomes	**Nonsmokers**	**Smokers**	**Nonsmokers**	**Smokers**	**Nonsmokers**	**Smokers**
Physical function	68.66 ± 21.90[b]	54.25 ± 33.49[b]	78.75 ± 19.57	79.12 ± 16.22	81.67 + 20.08	81.88 ± 22.79
Role functioning (physical)	31.03 ± 41.91	18.75 ± 37.06	60.27 ± 43.95	50.00 ± 47.60	68.06 + 41.27	78.13 ± 37.50
Bodily pain	37.56 ± 27.18	41.70 ± 26.50	65.68 ± 26.16	63.29 ± 24.07	66.89 + 26.53	59.75 ± 24.71
General health	65.14 ± 24.49	59.45 ± 26.89	69.27 ± 22.07	66.29 ± 28.44	67.84 ± 23.45	63.69 ± 24.28
Vitality	48.49 ± 24.15	50.25 ± 19.90	60.49 ± 22.08	53.53 ± 23.77	64.26 ± 19.95	57.19 ± 23.31
Social functioning	64.55 ± 36.23	63.13 ± 36.15	85.50 ± 23.64	81.62 ± 20.31	86.69 ± 24.18	87.50 ± 30.28
Role functioning (emotional)	63.50 ± 44.17	50.00 ± 45.24	80.95 ± 36.82	62.75 ± 48.42	86.11 ± 33.53	72.92 ± 42.55
Mental health	67.28 ± 21.98	62.80 ± 21.60	74.83 ± 17.91	72.00 ± 20.30	78.67 ± 17.47	71.50 ± 16.32

[a]$P > .05$ for all of the above parameters.
[b]Except baseline SF-36 physical functioning.

physical functioning, where the nonsmoker group had better preoperative scores than the smoker group (68.66 vs 54.25, $P = .014$). Patients in both groups showed significant improvements in all aspects of functional scores, with no statistical difference at 6 months or 2 years of follow-up between groups (Figures 2–5). At 6 months, 61.1% of nonsmokers and 52.9% of smokers reported a return to full function, whereas the numbers at 2 years were 69.4% and 58.9%, respectively (Figure 6). At the 2-year follow-up mark, 84.2% of nonsmokers and 87.5% of smokers answered question 48 of the AAOS cervical instrument score with a score of at least 4 out of 7 (Figure 7). A total of 85.2% of nonsmokers and 75% of smokers reported their overall result as *good*, *very good*, or *excellent* (Figure 8). At the 2-year mark, 124 patients (90.5%) answered questions 48 and 53, whereas 125 patients (91.2%) answered question 8. The differences in results between the 2 groups were not statistically significant. There was also no difference in the length of hospital stay and return to work.

Revision Surgery and Further Intervention

Our study had 9 patients who required revision surgery. Smokers had a higher incidence of revision surgery, with 4 of 20 (20%) compared with 5 of 117 nonsmokers (4.3%; $P = .018$). The time to revision surgery was not statistically different between smokers and nonsmokers (43.8 vs 40.9 months). The mean age of the revision groups was 40.36 years for nonsmokers and 47.1 years for smokers ($P > .05$). The postoperative functional scores and incidence of comorbidities were not statistically different between the 2 groups.

For patients who required revision surgery, 3 of the patients who were smokers underwent revision

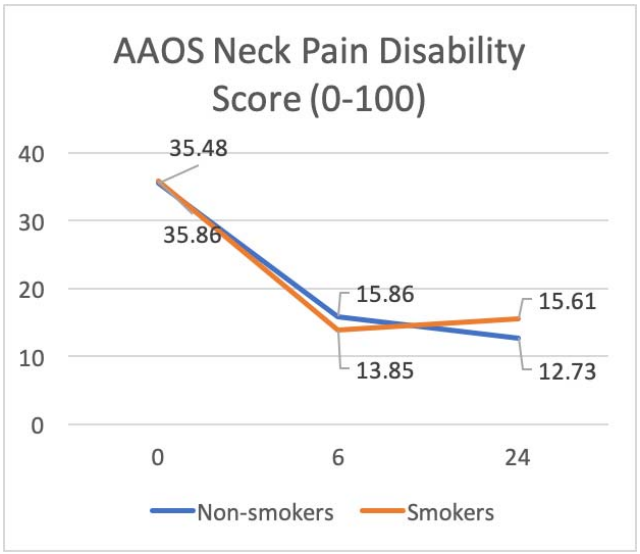

Figure 2. The American Association of Orthopaedic Surgery (AAOS) Neck Pain Disability Score before surgery, and at 6 months and 2 years postoperatively. Patients had a significant improvement in both groups, with no statistical difference between smokers and nonsmokers.

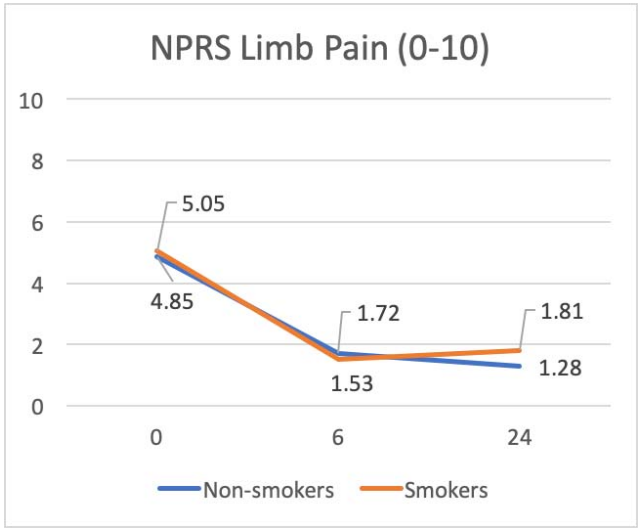

Figure 3. The Numeric Pain Rating Scale (NPRS) Limb Pain Score at baseline, 6 months and 2 years postoperatively. Patients had a significant improvement in both groups, with no statistical difference between smokers and nonsmokers.

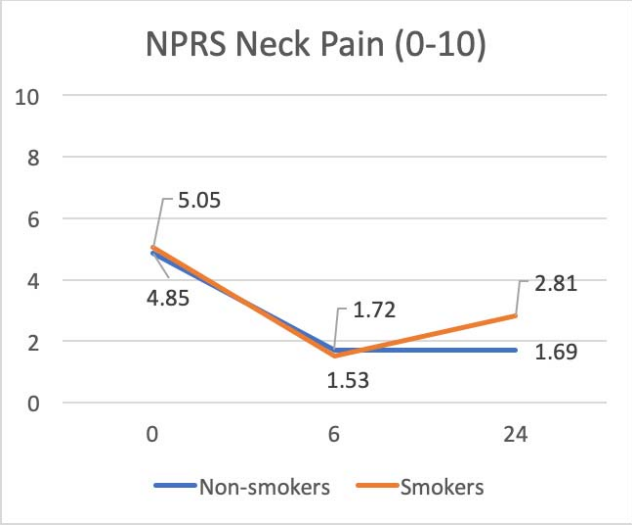

Figure 4. The Numeric Pain Rating Scale (NPRS) Neck Pain Score at baseline, 6 months and 2 years postoperatively. Patients had a significant improvement in both groups, with no statistical difference between smokers and nonsmokers.

surgery at the index level (posterior surgery), with all requiring multilevel posterior decompression. The other patient who was a smoker had an ACDF for adjacent segment disease. Three of the nonsmokers had surgery involving the index level, with 2 posterior surgeries and 1 revision of the artificial disc to an anterior fusion. For the other 2 nonsmoking patients, 1 had a posterior decompression and fusion and the other had radiofrequency ablation and facet blocks.

There were 5 cases of bony overgrowth around or directly posterior to the artificial disc replacement.

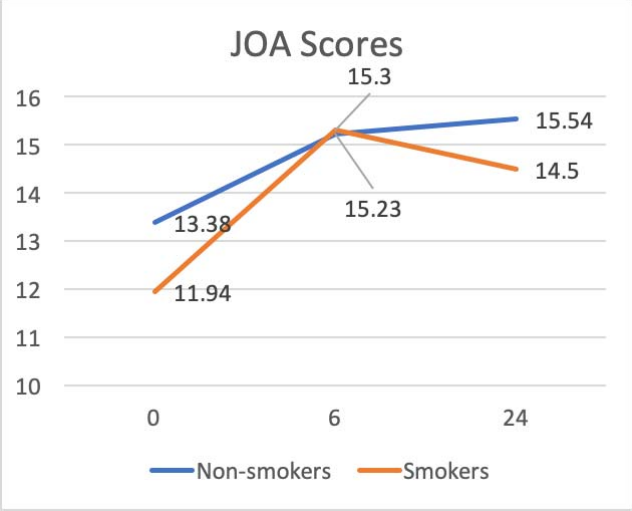

Figure 5. Japanese Orthopaedic Association (JOA) Cervical Myelopathy Scores at baseline, 6 months and 2 years postoperatively. Patients had a significant improvement in both groups, with no statistical difference between smokers and nonsmokers.

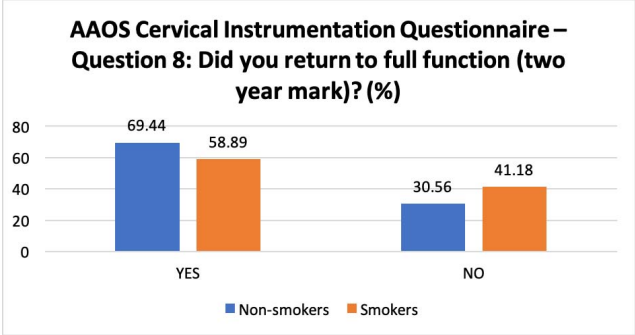

Figure 6. American Association of Orthopaedic Surgery (AAOS) Cervical Instrumentation Questionnaire—question 8. Both smokers and nonsmokers reported similar rates of return to full function, with no statistical difference between smokers and nonsmokers.

Three of the patients were smokers, all of whom underwent posterior decompression surgery (2 patients had laminectomy and fusion, whereas the other patient had a laminoplasty). The remaining 2 cases of heterotopic ossification around the disc were nonsmokers. One patient had posterior decompression with fusion, whereas the other patient had disc removal and conversion to partial corpectomy and fusion. Figure 9 is a sagittal computed tomography scan showing bony overgrowth with stenosis around the artificial disc of the patient, and Figure 10 shows the postoperative X-rays after anterior revision was performed. The surgical approach to revision surgeries was based on surgeon preference.

DISCUSSION

The adverse impact of smoking on surgical outcomes in multiple specialty fields is well documented. Smoking is associated with higher rates of perioperative mortality, cardiac and respiratory complications, delayed wound healing, increased

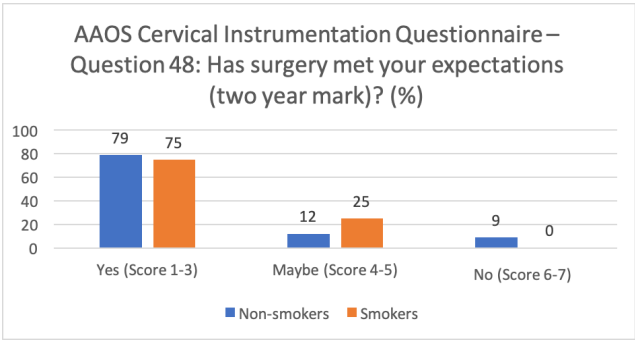

Figure 7. American Association of Orthopaedic Surgery (AAOS) Cervical Instrumentation Questionnaire—question 48. Both smokers and nonsmokers reported surgery meeting their expectations at the 2-year mark, with no statistical difference between smokers and nonsmokers.

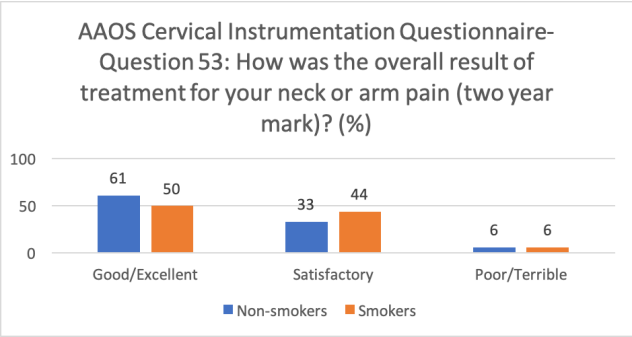

Figure 8. American Association of Orthopaedic Surgery (AAOS) Cervical Instrumentation Questionnaire—question 53. Both smokers and nonsmokers reported satisfactory outcomes for their neck and arm pain at the 2-year mark, with no statistical difference between smokers and nonsmokers.

incidences of wound infection, and septicaemia, as well as prolonged hospital stay and increased cost to the health care system.[13–17] Some studies show that smoking in ACDF and corpectomy has been associated with higher postoperative infection rates, pseudoarthrosis, postoperative dysphagia, poorer neural recovery, and overall outcome and patient satisfaction.[15,18–21]

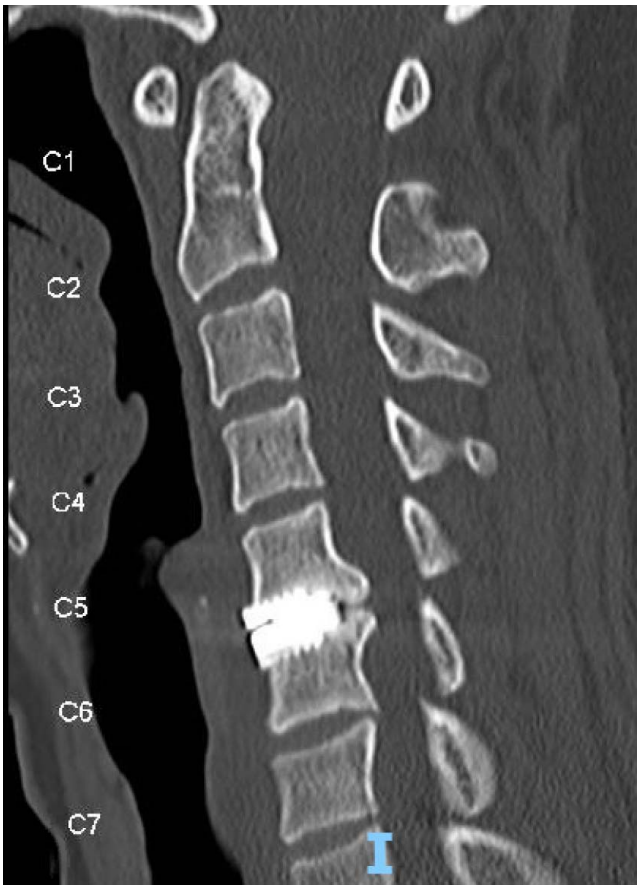

Figure 9. Sagittal computed tomography scan of a nonsmoking patient showing bony overgrowth around the artificial disc.

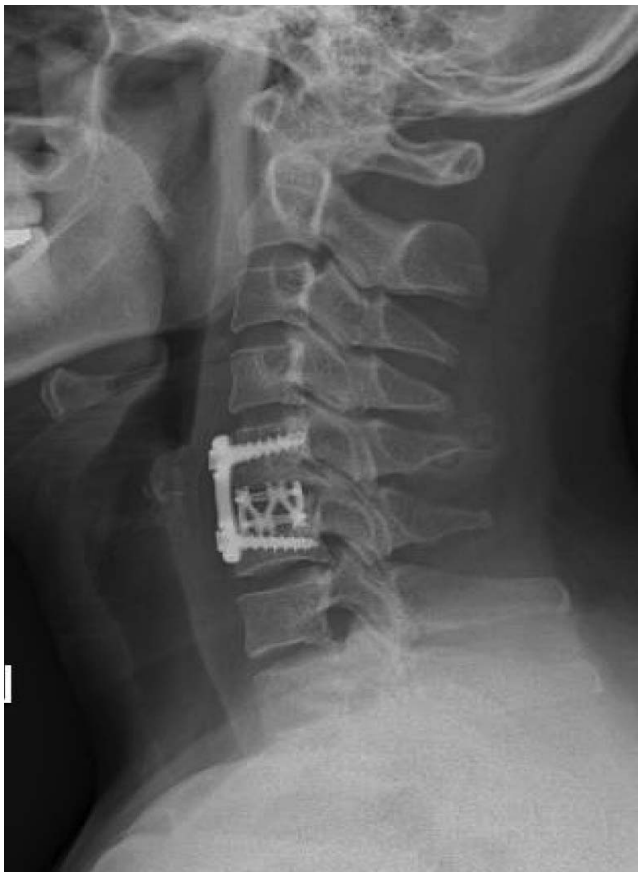

Figure 10. Postoperative X-ray of the same patient showing anterior cervical fusion with a plate and cage after removal of the artificial disc.

However, there are other studies that show there is no difference in patient outcomes, fusion rates, adjacent segment disease, or revision surgeries with smoking in patients undergoing ACDF.[22–24] Despite the diverse array of studies analyzing the impact of smoking and spine surgery, there are no studies to date documenting the impact of smoking on outcomes after cervical ADR.

Key Results and Interpretation

Our study shows that there is no difference in the functional outcome of patients postoperatively at up to 2 years between smokers and nonsmokers who undergo ADR. This is different from the results of smokers who undergo anterior cervical fusion surgery, where smokers tend to have an inferior outcome.[25–27] One reason for this may be that the smokers are disadvantaged for fusion surgery because they have a tendency to form a fibrous union rather than form a solid bony fusion. This disadvantage is removed during ADR, where the desired result is preservation of motion rather than fusion.

However, it must be noted that smokers who undergo ADR tend to have a higher revision rate compared with nonsmokers. Most of the revisions involved the adjacent level or multiple segments. This is not surprising because smoking may have affected multiple levels, in which case after the index surgery, other levels also undergo degenerative changes requiring revision surgery. Smokers were also more likely to have clinically and radiologically significant bony stenosis around the artificial disc compared with nonsmokers necessitating revision surgery. Given that smokers generally have a poorer outcome with fusion surgery as well, it would be optimal if patients were able to stop smoking preoperatively and abstain thereafter. It is important for clinicians to have a discussion on smoking and the risks of both anterior cervical fusion surgery and ADR preoperatively.

There was no statistical difference in age, comorbidities, or functional status between smokers and nonsmokers who required revision surgery. Although this sample size is small, it potentially indicates that smoking in itself may be associated with higher rates of bony stenosis and therefore a higher incidence of revision surgery after ADR.

Limitations and External Validity

This study has some limitations. First, the population of smokers in this study is small. We did not look at the smoking history in detail, that is, the number of pack-years or when the patient quit smoking if he or she was an ex-smoker. Even though there is no difference in the functional outcome between smokers and nonsmokers at 2 years, a longer follow-up would provide useful information for both patients and the treating surgeon as to the long-term functional impact of smoking on ADR.

CONCLUSION

Our spine registry analysis has shown that smoking does not adversely affect functional outcomes in patients undergoing cervical ADR for myelopathy or radiculopathy. However, smokers have a higher incidence of postoperative bony stenosis and revision surgery than nonsmokers, and it often involves adjacent or multiple segments.

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