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Impact of nicotine product use on outcomes of patients receiving cervical disc arthroplasty: a propensity score analysis of the united States nationwide inpatient sample 2005–2020

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Abstract

Background Nicotine product use, including cigarette smoking and other nicotine products, is a known risk factor for various health complications. While previous studies have examined its impact on spinal procedures, its specific effects on cervical disc arthroplasty (CDA) remain unclear. This study aims to investigate the association between nicotine product use and inpatient outcomes in patients undergoing CDA.

Methods Data from the 2005 to 2020 US Nationwide Inpatient Sample database of hospitalized adults ≥ 18 years old who underwent primary or revision CDA were extracted. Patients were divided into nicotine product users and non-users. Propensity score matching (PSM) was employed to balance the baseline characteristics between the groups. In-hospital mortality, unfavorable discharge, length of stay (LOS), and complications were compared between nicotine product users and non-users through logistic regression analyses.

Results After 1:1 PSM, 5,562 patients were included in the analysis. After adjustment, nicotine product users had a significantly elevated risk of overall complications (adjusted odds ratio [aOR] = 1.37, 95% confidence interval [CI]: 1.13–1.66, $p = 0.002$) and infection (aOR = 1.74, 95% CI: 1.17–2.58, $p = 0.006$). No significant association was observed between nicotine product use and the risk of unfavorable discharge or prolonged LOS (both, $p > 0.05$). In stratified analyses, male, but not female nicotine product users, had a greater risk of infection (aOR = 2.12, 95% CI: 1.22–3.70, $p = 0.008$). Nicotine product use was significantly associated with higher infection risk among individuals without diabetes, obesity, and chronic pulmonary disease ($p < 0.05$).

Conclusions Nicotine product use is associated with a higher risk of complications following CDA, particularly infections. The study highlights the importance of considering nicotine product use during preoperative assessments and postoperative care for patients undergoing CDA.

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Keywords Nicotine product use, Cervical disc arthroplasty (CDA), Nationwide inpatient sample (NIS), In-hospital outcome, Propensity score matching (PSM)

Background

Cervical disc degenerative disease is a prevalent health concern among older adults, characterized by the wear and tear of neck discs and associated with aging, genetics, occupational strain, prior neck injuries, osteoporosis, and smoking [1–3]. This condition impacts quality of life by causing chronic pain and limiting mobility, with treatment options ranging from pain management to surgical interventions [4].

Cervical disc arthroplasty (CDA) has emerged as a preferred alternative to fusion, as it preserves neck mobility and reduces adjacent segment degeneration [5]. CDA demonstrates outcomes comparable to or superior to anterior cervical arthrodesis, with a low complication rate of 1.5%. Common short-term complications include dysphagia, laryngeal nerve injury, Horner syndrome, and hematoma [6]. Reoperation rates range from 1.8 to 5.4% after 5 years [7].

Smoking is a significant global health concern, associated with 7.69 million deaths and 200 million disability-adjusted life-years in 2019 [8]. Beyond respiratory conditions, smoking contributes to cardiovascular disease, greater susceptibility to respiratory infections, and adverse surgical outcomes [9–11]. Although the general health risks of smoking and nicotine product exposure are well-documented, its specific impact on cervical disc degenerative disease, particularly following CDA, remains unclear.

Existing studies report mixed findings: smoking is associated with lower fusion rates and greater bone loss in hybrid cervical surgeries [12], while other studies suggest no significant differences in clinical outcomes between smokers and non-smokers after CDA [13]. Additionally, Lawand et al. explored non-tobacco nicotine use and its association with complications in anterior cervical discectomy and fusion, highlighting the diverse effects of nicotine products beyond traditional cigarette smoking [14]. These conflicting findings reveal a significant knowledge gap regarding smoking and nicothine product exposure's impact on postoperative outcomes in CDA patients.

Given the rising adoption of CDA and the increasing use of nicotine products, a comprehensive evaluation of this relationship is crucial. Therefore, this study investigates the specific impact of nicotine product use on CDA outcomes using a large, nationally representative dataset from the United States.

Methods

Data source

Data for this study were extracted from the 2005 to 2020 Nationwide Inpatient Sample (NIS), a database developed by the Healthcare Cost and Utilization Project (HCUP) in the US that is maintained by the Agency for Healthcare Research and Quality (AHRQ) [15]. Details of the dataset can be accessed at: https://hcup-us.ahrq.gov/nisoverview.jsp. The NIS database represents a 20% sample of inpatient admissions from 45 states and 1,051 hospitals that participated in collecting patient data at discharge. Principal and secondary diagnoses, principal and secondary procedures, admission date and diagnosis, discharge status, patient demographic data, and length of stay are included for each inpatient. Statistical weights that allow generalized estimates of national case volumes are also provided in the NIS.

Study design and ethical considerations

This was a population-based, retrospective study. This study complies with the terms of the NIS data-use agreement. The data utilized in this study were obtained through the Online HCUP Central Distributor. Given that this study solely involved the analysis of secondary data, there was no direct involvement of the general public or patients.

Study population

Hospitalized adults ≥ 18 years old who underwent either primary or revision CDA were included. Exclusion criteria were: (1) Cervical fracture; (2) Without recorded age and sex; and (3) Without sample weight value, outcomes of interest, and covariates. All diagnoses and procedures were identified by the International Classification of Diseases, Ninth Revision, and Tenth Revision, Clinical Modification (ICD-9-CM and ICD-10-CM) codes, as detailed in Supplemental Table S1.

Main outcomes and variables

The outcomes of interest were in-hospital mortality, non-routine discharge (i.e., discharged to long-term care facilities), prolonged length of stay (LOS) (defined as ≥ 75th LOS in the study sample), and complication rates. Complications included dysphagia, dysphonia, acute myocardial infarction (AMI), venous thromboembolism (VTE), cerebrovascular accident (CVA), pneumonia, sepsis, infection, respiratory failure, acute kidney injury (AKI), wound complications, complications of the nervous system, and complications of the digestive system.

Demographic variables included patient age, sex, ethnicity (grouped into White, Black, Hispanic, and others), household income, insurance status (primary payer), and weekend admission. Admission type (emergency or elective) and year of admission were also included. Household income quartiles were obtained from the NIS, estimated from the household income of residents in the patient's ZIP Code (https://hcup-us.ahrq.gov/db/vars/zipinc_qrtl/nisnote.jsp). Nicotine product use, ho spital volume, and other relevant medical comorbidities were identified using ICD-9 and ICD-10 codes. Charlson Comorbidity Index (CCI) was calculated from individual comorbidities to represent patients' overall severity of comorbid conditions [16]. Finally, hospital-related characteristics (bed size, location/teaching status, and hospital region) were also obtained as part of the comprehensive data available for all participants.

Statistical analysis

The HCUP-NIS database includes a 20% sample of US annual inpatient admissions, weighted samples (before 2011 using TRENDWT and after 2012 using DISCWT), stratum (NIS_STRATUM), and cluster (HOSPID) were used to produce national estimates for all analyses. The SURVEY procedure in SAS performs analysis for sample survey data. Patient descriptive statistics are presented as number (n) and weighted percentage (%), or mean and standard error (SE). Categorical data were analyzed by the PROC SURVEYFREQ statement and continuous data were analyzed by the PROC SURVEYREG statement. To minimize confounding, propensity score matching (PSM) was performed using a 1:1 ratio, with age (continuous), sex, ischemic heart disease, hypertension, diabetes, obesity, and chronic pulmonary disease as the matching variables. The matching process followed a one-to-many approach [17]. PSM was chosen to minimize selection bias by balancing baseline characteristics before regression analysis, enhancing internal validity for a more accurate assessment of nicotine exposure and CDA outcomes. Logistic regression was then applied to the matched cohort for adjusted associations.

The method prioritizes "best" matches first and then proceeds with "next-best" matches until no more can be made. Logistic regressions were performed using the PROC SURVEYLOGISTIC statement to determine the associations between study variables, in-hospital mortality, unfavorable discharge, prolonged LOS, and any complications, and results were reported as odds ratio (OR) and 95% confidence interval (CI). Multivariable regression was adjusted for variables that were significant ($p < 0.05$) in the univariate analysis. Prolonged LOS was defined as a LOS ≥ 75th percentile of the study population. We applied the Benjamini-Hochberg (BH) procedure to control the false discovery rate (FDR). All p-values were 2-sided, and values of $p < 0.05$ were considered statistically significant. All statistical analyses were performed using the statistical software package SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Patient selection

The patient selection process is depicted in Fig. 1. A total of 9,800 patients ≥ 18 years old who received primary or secondary CDA were identified in the 2005 to 2020 NIS database. Patients with missing information on sex, in-hospital mortality, and sample weight were excluded ($n = 45$), as were 31 patients with fractures. Finally, 9,724 patients were included in the study, representing 47,978 hospitalized patients in the entire US after weighting, of which 2,781 were nicotine product users. After 1:1 PSM, 5,562 patients were included in the analysis, representing 27,438 hospitalized patients in the US.

Patient characteristics before and after PSM

Patient demographic characteristics, major comorbidities, and hospital-related characteristics are summarized in Table 1. Before PSM, the mean age of the study population was 47.5 years, 51.8% were females, and 79.8% were White. Compared to non-users of nicotine products, the nicotine product user group was notably younger, predominantly male and White, had lower income and were less frequently recipients of a fusion procedure. Additionally, the mean CCI was higher in the nicotine product user group compared to the non-user group. Specifically, 23.0% of nicotine product users had a CCI of 1 compared to 16.0% of non-users, while 5.7% of nicotine product users had a CCI of 2 compared to 4.0% of non-users, and 3.3% of nicotine product users had a CCI of 3 + compared to 1.9% of non-users ($p < 0.001$). Nicotine product users had a higher proportion of ischemic heart disease, hypertension, diabetes, obesity, and chronic pulmonary disease.

After PSM, significant differences between the 2 groups remained concerning race, income, insurance status/primary payer, year of admission, location/teaching status of the hospital, and hospital region (Table 1).

Inpatient outcomes after PSM

The outcomes after PSM are summarized in Table 2. Compared to non-users of nicotine products, those who used nicotine products had a significantly higher percentage of any complications (9.6% vs. 7.0%, $p < 0.001$), as well as cardio-cerebrovascular events (i.e., AMI or CVA) (0.6% vs. 0.3%, $p = 0.026$), and infection (2.9% vs. 1.5%, $p < 0.001$).

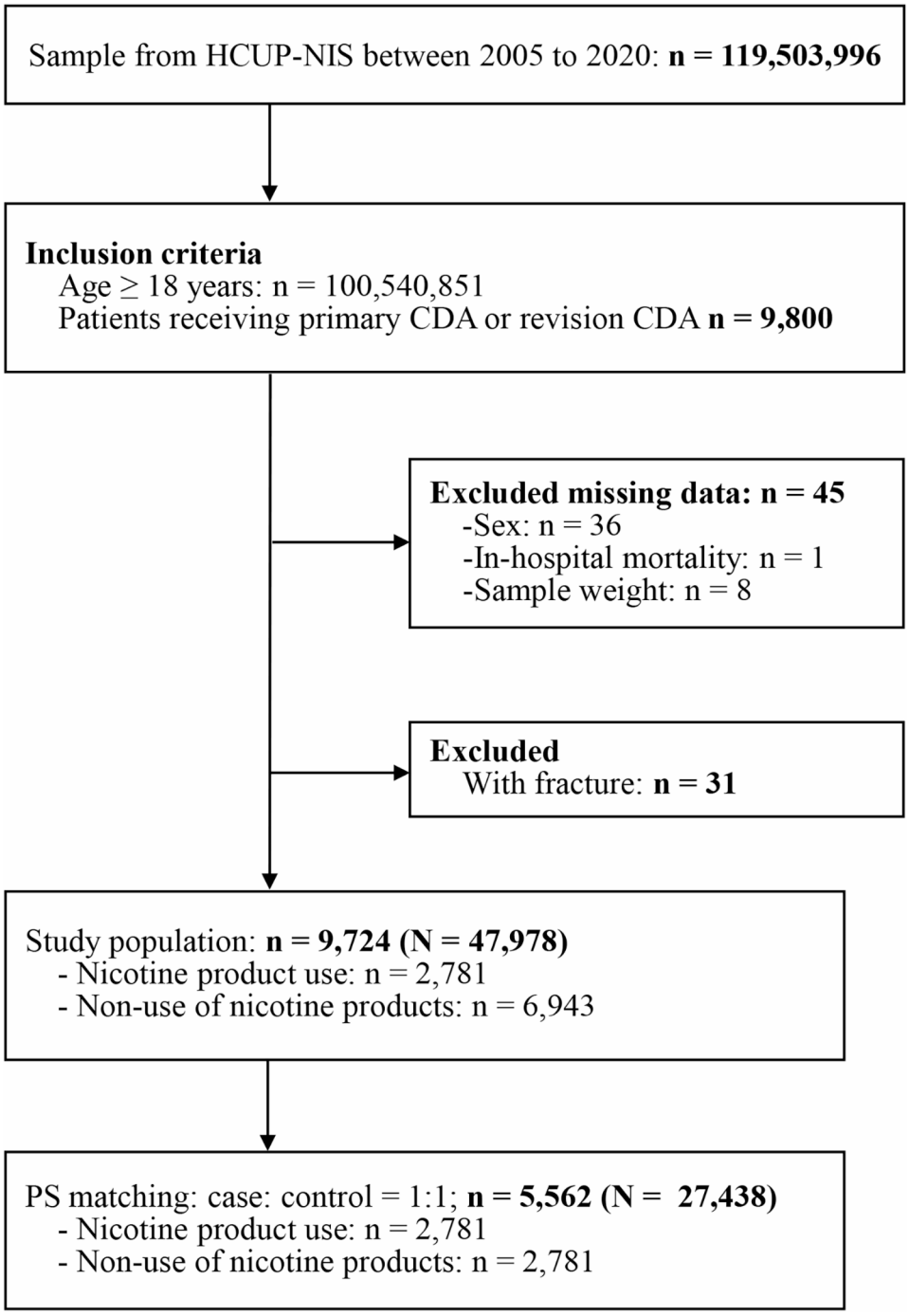

Fig. 1 Flow diagram of patient selection

Associations between nicotine product use and inpatient outcomes

Table 3 shows the associations between nicotine product use and outcomes. After adjustment in the multivariable analysis, we found that nicotine product users had a significantly higher risk for any complications (adjusted odds ratio [aOR] = 1.37, 95% CI: 1.13–1.66, $p = 0.002$) compared to non-users. In addition, nicotine product users also had a significantly higher risk of infection (aOR = 1.74, 95% CI: 1.17–2.58, $p = 0.006$) compared to non-users. Nicotine product use was not significantly associated with unfavorable discharge or prolonged LOS (both, $p > 0.05$) (Table 3).

Table 1 Characteristics of the study population

	Before PSM				After PSM			
Characteristics	**All patients (*n* = 9,724)**	**Nicotine product use (*n* = 2,781)**	**Non-use of nicotine products (*n* = 6,943)**	**p-value**	**All patients (*n* = 5,562)**	**Nicotine product use (*n* = 2,781)**	**Non-use of nicotine products (*n* = 2,781)**	**p-value**
Demography								
Age, years	47.5 ± 0.1	47.1 ± 0.2	47.7 ± 0.2	**0.028**	46.9 ± 0.2	47.1 ± 0.2	46.7 ± 0.2	0.154
18–29	301 (3.1)	76 (2.7)	225 (3.2)	**0.002**	165 (3.0)	76 (2.7)	89 (3.2)	0.170
30–39	2,018 (20.8)	651 (23.4)	1,367 (19.7)		1,290 (23.2)	651 (23.4)	639 (23.0)	
40–49	3,552 (36.6)	983 (35.3)	2,569 (37.0)		1,993 (35.8)	983 (35.3)	1,010 (36.3)	
50–59	2,593 (26.6)	725 (26.1)	1,868 (26.9)		1,477 (26.6)	725 (26.1)	752 (27.0)	
60–69	934 (9.6)	259 (9.3)	675 (9.7)		481 (8.7)	259 (9.3)	222 (8.0)	
70+	326 (3.4)	87 (3.1)	239 (3.5)		156 (2.8)	87 (3.1)	69 (2.5)	
Sex				**< 0.001**				0.315
Male	4,686 (48.2)	1,435 (51.6)	3,251 (46.8)		2,834 (51.0)	1,435 (51.6)	1,399 (50.3)	
Female	5,038 (51.8)	1,346 (48.4)	3,692 (53.2)		2,728 (49.0)	1,346 (48.4)	1,382 (49.7)	
Race				**< 0.001**				**< 0.001**
White	7,150 (79.8)	2,129 (83.0)	5,021 (78.6)		4,163 (81.1)	2,034 (79.2)	2,129 (83.0)	
Black	647 (7.2)	160 (6.2)	487 (7.6)		349 (6.8)	189 (7.4)	160 (6.2)	
Hispanic	641 (7.2)	139 (5.4)	502 (7.9)		339 (6.6)	200 (7.8)	139 (5.4)	
Other	518 (5.8)	136 (5.3)	382 (6.0)		279 (5.4)	143 (5.6)	136 (5.3)	
Missing	768	217	551		432	217	215	
Income				**< 0.001**				**< 0.001**
Q1	1,718 (18.3)	586 (21.7)	1,132 (16.9)		1,048 (19.5)	586 (21.7)	462 (17.3)	
Q2	2,245 (23.9)	712 (26.5)	1,533 (22.9)		1,316 (24.5)	712 (26.5)	604 (22.5)	
Q3	2,536 (27.0)	755 (27.9)	1,781 (26.6)		1,495 (27.7)	755 (27.9)	740 (27.5)	
Q4	2,889 (30.8)	644 (23.9)	2,245 (33.6)		1,521 (28.3)	644 (23.9)	877 (32.7)	
Missing	336	84	252		182	84	98	
Insurance status / Primary Payer				**< 0.001**				**< 0.001**
Medicare / Medicaid	1,838 (19.0)	737 (26.6)	1,101 (15.9)		1,154 (20.8)	737 (26.6)	417 (15.0)	
Private including HMO	6,038 (62.2)	1,514 (54.5)	4,524 (65.3)		3,368 (60.6)	1,514 (54.5)	1,854 (66.8)	
Self-pay / No charge / Other	1,830 (18.8)	524 (18.9)	1,306 (18.8)		1,030 (18.5)	524 (18.9)	506 (18.2)	
Missing	18	6	12		10	6	4	
Admission type				0.721				0.549
Elective	8,616 (88.8)	2,470 (89.0)	6,146 (88.8)		4,953 (89.3)	2,470 (89.0)	2,483 (89.5)	
Emergent	1,080 (11.2)	304 (11.0)	776 (11.2)		594 (10.7)	304 (11.0)	290 (10.5)	
Missing	28	7	21		15	7	8	
Receiving cervical spine fusion				**< 0.001**				0.056
No	8,026 (82.8)	2,363 (85.2)	5,663 (81.8)		4,670 (84.2)	2,363 (85.2)	2,307 (83.2)	
Yes	1,698 (17.2)	418 (14.8)	1,280 (18.2)		892 (15.8)	418 (14.8)	474 (16.8)	
Year of Admission				**< 0.001**				**< 0.001**
2005–2008	1,300 (12.7)	330 (11.3)	970 (13.2)		724 (12.4)	330 (11.3)	394 (13.4)	
2009–2012	2,426 (24.8)	651 (23.2)	1,775 (25.5)		1,369 (24.4)	651 (23.2)	718 (25.7)	
2013–2016	2,865 (29.9)	795 (28.9)	2,070 (30.2)		1,640 (29.9)	795 (28.9)	845 (30.8)	
2017–2020	3,133 (32.7)	1,005 (36.6)	2,128 (31.1)		1,829 (33.3)	1,005 (36.6)	824 (30.1)	
Major comorbidities								
Ischemic heart disease	381 (3.9)	141 (5.1)	240 (3.4)	**< 0.001**	268 (4.8)	141 (5.1)	127 (4.6)	0.364
Atrial fibrillation	94 (1.0)	25 (0.9)	69 (1.0)	0.740	53 (0.9)	25 (0.9)	28 (1.0)	0.786
Hypertension	2862 (29.4)	898 (32.3)	1964 (28.2)	**< 0.001**	1,791 (32.2)	898 (32.3)	893 (32.0)	0.801
Diabetes	966 (10.0)	315 (11.4)	651 (9.4)	**0.002**	618 (11.1)	315 (11.4)	303 (10.9)	0.537
Obesity	1,123 (11.6)	370 (13.4)	753 (10.9)	**< 0.001**	736 (13.3)	370 (13.4)	366 (13.1)	0.728
Chronic pulmonary disease	1,233 (12.7)	520 (18.8)	713 (10.2)	**< 0.001**	1,041 (18.7)	520 (18.8)	521 (18.7)	0.893
Chronic kidney disease	113 (1.2)	35 (1.3)	78 (1.1)	0.548	69 (1.3)	35 (1.3)	34 (1.2)	0.924
Rheumatic disease	137 (1.4)	46 (1.7)	91 (1.3)	0.184	90 (1.6)	46 (1.7)	44 (1.6)	0.809
Any malignancy	36 (0.4)	13 (0.5)	23 (0.3)	0.245	19 (0.3)	13 (0.5)	6 (0.2)	0.091

Table 1 (continued)

	Before PSM				After PSM			
Characteristics	**All patients (*n* = 9,724)**	**Nicotine product use (*n* = 2,781)**	**Non-use of nicotine products (*n* = 6,943)**	**p-value**	**All patients (*n* = 5,562)**	**Nicotine product use (*n* = 2,781)**	**Non-use of nicotine products (*n* = 2,781)**	**p-value**
Charlson comorbidity index				**< 0.001**				0.118
0	7,316 (75.2)	1,893 (67.9)	5,423 (78.1)		3,827 (68.8)	1,893 (67.9)	1,934 (69.6)	
1	1,754 (18.0)	639 (23.0)	1115 (16.0)		1,264 (22.7)	639 (23.0)	625 (22.4)	
2	435 (4.5)	159 (5.7)	276 (4.0)		316 (5.7)	159 (5.7)	157 (5.7)	
3+	219 (2.3)	90 (3.3)	129 (1.9)		155 (2.8)	90 (3.3)	65 (2.3)	
Hospital bed size				0.334				0.558
Small	1,887 (19.3)	511 (18.4)	1,376 (19.7)		1,057 (18.9)	511 (18.4)	546 (19.5)	
Medium	2,615 (27.0)	771 (27.7)	1,844 (26.7)		1,518 (27.4)	771 (27.7)	747 (27.1)	
Large	5,189 (53.7)	1,492 (54.0)	3,697 (53.5)		2,969 (53.7)	1,492 (54.0)	1,477 (53.4)	
Missing	33	7	26		18	7	11	
Location / Teaching status				**< 0.001**				**< 0.001**
Rural	342 (3.6)	126 (4.5)	216 (3.2)		200 (3.6)	126 (4.5)	74 (2.7)	
Urban nonteaching	3,545 (36.4)	923 (33.1)	2,622 (37.8)		1,975 (35.5)	923 (33.1)	1,052 (37.8)	
Urban teaching	5,804 (60.0)	1,725 (62.3)	4079 (59.1)		3,369 (60.9)	1,725 (62.3)	1,644 (59.4)	
Missing	33	7	26		18	7	11	
Hospital region				**< 0.001**				**< 0.001**
Northeast	1,633 (16.9)	471 (17.0)	1,162 (16.8)		930 (16.8)	471 (17.0)	459 (16.6)	
Midwest	1,861 (19.2)	634 (22.9)	1,227 (17.7)		1,124 (20.3)	634 (22.9)	490 (17.7)	
South	3,305 (33.8)	913 (32.7)	2,392 (34.2)		1,875 (33.5)	913 (32.7)	962 (34.4)	
West	2,925 (30.2)	763 (27.5)	2,162 (31.2)		1,633 (29.4)	763 (27.5)	870 (31.4)	

Abbreviations: PSM, propensity score matching; AMI, acute myocardial infarction; CVA, cerebral vascular accident; VTE, venous thromboembolism

Continuous data are presented as mean ± SE; categorical data are presented as unweighted counts (weighted percentage)

p-values < 0.05 are shown in bold

Associations between nicotine product use and outcomes stratified by sex, diabetes, obesity, and chronic pulmonary disease

We further carried out stratified analysis by sex, diabetes, obesity, and chronic pulmonary disease. Similar to the results observed in the general population, nicotine product use did not impact the risk of unfavorable discharge or prolonged LOS among any subgroup of patients (all, $p > 0.05$). Concerning complication rates, compared to non-users, men who used nicotine products had a significantly higher risk for any complications (aOR = 1.45, 95% CI: 1.08–1.94, $p = 0.015$) and infection (aOR = 2.12, 95% CI: 1.22–3.70, $p = 0.008$) after surgery, where this association was not observed in women.

For the risk of any complication, nicotine product users had a significantly higher risk among individuals without diabetes (aOR = 1.38, 95% CI: 1.10–1.74, $p = 0.006$), without obesity (aOR = 1.37, 95% CI: 1.08–1.73, $p = 0.009$), and without chronic pulmonary disease (aOR = 1.40, 95% CI: 1.09–1.79, $p = 0.007$).

For the risk of infection, nicotine product users had a significantly higher risk among individuals without diabetes (aOR = 2.01, 95% CI: 1.23–3.28, $p = 0.005$), without obesity (aOR = 1.82, 95% CI: 1.14–2.90, $p = 0.012$), and without chronic pulmonary disease (aOR = 1.93, 95% CI: 1.20–3.10, $p = 0.007$) (Table 4).

Discussion

This study investigated the impact of nicotine product use on the outcomes of US adults undergoing CDA. After PSM, nicotine product users exhibited significantly higher rates of complications post-surgery. In multivariable analysis, nicotine product users had a higher risk of having any complications, and a 74% higher risk of infection, compared to non-users. However, no significant correlation was observed between nicotine product use and the likelihood of unfavorable discharge or prolonged LOS. In the stratified analyses, consistent trends were noted. Male nicotine product users had a greater risk of having any complications, and twice the risk of infection post-surgery. However, this association was not present in female nicotine product users. Additionally, individuals without diabetes, obesity, and chronic pulmonary disease who used nicotine products had significantly higher risks of complications and infection compared to non-users.

Smoking is associated with worse outcomes of surgical procedures [18]. Our results align with previous studies that document the adverse effects of smoking

Table 2 In-hospital outcomes of the study population after PSM

	All patients (*n* = 5,562)	Nicotine product use (*n* = 2,781)	Non-use of nicotine products (*n* = 2,781)	*p*-value
Outcomes				
In-hospital mortality	5 (0.1)	3 (0.1)	2 (0.1)	0.555
Unfavorable discharge[a]	141 (2.6)	78 (2.8)	63 (2.3)	0.158
Prolonged LOS[a, b]	726 (13.0)	380 (13.7)	346 (12.4)	0.163
Any complications	485 (8.7)	278 (10.0)	207 (7.4)	**< 0.001**
Dysphagia	223 (4.0)	118 (4.2)	105 (3.8)	0.324
Dysphonia	12 (0.2)	6 (0.2)	6 (0.2)	0.975
AMI or CVA	24 (0.4)	16 (0.6)	8 (0.3)	**0.026**
VTE	16 (0.3)	9 (0.3)	7 (0.3)	0.623
Pneumonia	22 (0.4)	14 (0.5)	8 (0.3)	0.125
Sepsis	18 (0.3)	9 (0.4)	9 (0.3)	0.793
Infection	120 (2.2)	79 (2.9)	41 (1.5)	**< 0.001**
SSI	4 (0.1)	1 (0.03)	3 (0.1)	0.316
UTI	36 (0.7)	20 (0.7)	16 (0.6)	0.432
Hemorrhage/hematoma	19 (0.3)	10 (0.4)	9 (0.3)	0.768
Respiratory failure/Mechanical ventilation	69 (1.2)	41 (1.5)	28 (1.0)	0.075
AKI	22 (0.4)	8 (0.3)	14 (0.5)	0.166
Wound complication	9 (0.2)	6 (0.2)	3 (0.1)	0.295
Nervous system complication	21 (0.4)	12 (0.4)	9 (0.3)	0.493
Digestive system complication	5 (0.1)	2 (0.1)	3 (0.1)	0.742

Abbreviations: AMI, acute myocardial infarction; AKI, acute kidney injury; CVA, cerebrovascular accident; VTE, venous thromboembolism; SSI, surgical site infection; UTI, urinary tract infection; PSM, propensity score matching; LOS, length of hospital stay

Categorical variables are presented as unweighted counts (weighted percentages)

[a] Excluding patients who died in the hospital. [b] LOS > 75th percentile: 2 days

p-values < 0.05 shown in bold

Table 3 Associations between smoking and inpatient outcomes

Outcomes	Nicotine product use	OR (95% CI)	*p*-value	aOR (95% CI)	*p*-value
Unfavorable discharge[a, e]	Yes vs. No	1.26 (0.91–1.73)	0.160	1.27 (0.86–1.87)	0.239
Prolonged LOS[b, e, f]	Yes vs. No	1.11 (0.96–1.30)	0.164	1.07 (0.90–1.28)	0.449
Any complications[c]	Yes vs. No	1.39 (1.17–1.67)	**< 0.001**	1.37 (1.13–1.66)	**0.002**
Infection[d]	Yes vs. No	1.96 (1.36–2.83)	**< 0.001**	1.74 (1.17–2.58)	**0.006**

Abbreviations: LOS, length of hospital stay; OR, odds ratio; aOR, adjusted OR; CI, confidence interval; CCI, Charlson comorbidity index

p-values < 0.05 are shown in bold

[a] Adjusted for variables that were significant ($p < 0.05$) in the univariate analysis (except for CCI), including age (continuous), race, insurance status / primary payer, admission type, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, hospital bed size, and location / teaching status

[b] Adjusted for significant variables ($p < 0.05$) in the univariate analysis (except for CCI), including age (continuous), race, income, insurance status / primary payer, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, obesity, chronic pulmonary disease, chronic kidney disease, any malignancy, hospital bed size, and location / teaching status

[c] Adjusted for significant variables ($p < 0.05$) in the univariate analysis (except for CCI), including age (continuous), race, insurance status / primary payer, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, obesity, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, and location / teaching status

[d] Adjusted for variables that were significant ($p < 0.05$) in the univariate analysis (except for CCI), including age (continuous), income, insurance status / primary payer, admission type, hypertension, diabetes, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, and location / teaching status

[e] Excluding patients who died in the hospital

[f] LOS > 75th percentile: 2 days

on spinal surgery outcomes. For instance, Purvis et al. found that smoking status was significantly associated with increased complications in ACDF [19]. Similarly, Wen-Shen et al. [20] reported that smokers and non-smokers undergoing cervical artificial disc replacement had similar functional outcomes, but smokers had a significantly higher risk of requiring revision surgery 2 years after the initial procedure. A review of the literature by V Khurana concluded that smoking accelerates spondylosis and can lead to early surgery, delayed wound healing, increased rates of surgical site infections, failed fusion, re-operations, and chronic spine pain [21]. These studies collectively highlight the detrimental impact of smoking on surgical recovery, reinforcing the need for smoking

Table 4 Stratified associations between smoking and outcomes by sex, comorbid hypertension, diabetes, obesity, and chronic pulmonary disease

Subgroup	Nicotine product use	Unfavorable discharge [a, e]		Prolonged LOS [b, e, f]		Any complications [c]		Infection [d]	
		aOR (95% CI)	*p*-value	aOR (95% CI)	*p*-value	aOR (95% CI)	*p*-value	aOR (95% CI)	*p*-value
Sex									
Male	Yes vs. No	1.52 (0.88–2.64)	0.133	1.26 (0.96–1.65)	0.100	1.45 (1.08–1.94)	**0.015**	2.12 (1.22–3.70)	**0.008**
Female	Yes vs. No	0.98 (0.53–1.80)	0.945	0.93 (0.72–1.21)	0.589	1.26 (0.93–1.70)	0.137	1.35 (0.73–2.52)	0.344
Diabetes									
No	Yes vs. No	1.23 (0.77–1.96)	0.383	1.06 (0.87–1.30)	0.565	1.38 (1.10–1.74)	**0.006**	2.01 (1.23–3.28)	**0.005**
Yes	Yes vs. No	1.84 (0.72–4.68)	0.201	1.23 (0.75–2.03)	0.412	1.36 (0.82–2.26)	0.238	1.09 (0.45–2.63)	0.843
Obesity									
No	Yes vs. No	1.27 (0.81–1.99)	0.296	1.14 (0.93–1.41)	0.202	1.37 (1.08–1.73)	**0.009**	1.82 (1.14–2.90)	**0.012**
Yes	Yes vs. No	1.21 (0.42–3.51)	0.725	0.80 (0.49–1.30)	0.362	1.44 (0.88–2.36)	0.148	1.44 (0.56–3.72)	0.455
Chronic pulmonary disease									
No	Yes vs. No	1.43 (0.90–2.29)	0.130	1.10 (0.89–1.36)	0.361	1.40 (1.09–1.79)	**0.007**	1.93 (1.20–3.10)	**0.007**
Yes	Yes vs. No	0.85 (0.35–2.06)	0.719	0.98 (0.65–1.49)	0.929	1.27 (0.84–1.92)	0.265	1.33 (0.56–3.16)	0.524

Abbreviations: LOS, length of hospital stay; aOR, adjusted odds ratio; CI, confidence interval; CCI, Charlson comorbidity index

p-values < 0.05 are shown in bold

[a] Adjusted for variables that were significant ($p < 0.05$) in the univariate analysis (except for CCI and stratified variables), including age (continuous), race, insurance status / primary payer, admission type, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, hospital bed size, and location / teaching status

[b] Adjusted for significant variables ($p < 0.05$) in the univariate analysis (except for CCI and stratified variables), including age (continuous), race, income, insurance status / primary payer, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, obesity, chronic pulmonary disease, chronic kidney disease, any malignancy, hospital bed size, and location / teaching status

[c] Adjusted for significant variables ($p < 0.05$) in the univariate analysis (except for CCI and stratified variables), including age (continuous), race, insurance status / primary payer, admission type, receiving cervical spine fusion, ischemic heart disease, atrial fibrillation, hypertension, diabetes, obesity, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, and location / teaching status

[d] Adjusted for variables that were significant ($p < 0.05$) in the univariate analysis (except for CCI and stratified variables), including age (continuous), income, insurance status / primary payer, admission type, hypertension, diabetes, chronic pulmonary disease, chronic kidney disease, rheumatic disease, any malignancy, and location / teaching status

[e] Excluding patients who died in the hospital

[f] LOS > 75th percentile: 2 days

cessation interventions in surgical patients. Contrastingly, Tu et al. observed no significant differences in clinical outcomes between smokers and non-smokers undergoing CDA, suggesting that smoking did not negatively impact postoperative recovery [13]. However, their study was limited by a small sample size of smokers, potentially underestimating the true impact of smoking. Our study, utilizing a larger dataset, provides more robust evidence of the risks associated with nicotine product use in CDA patients, particularly in infection rates.

Our stratified analysis showed that nicotine product use is associated with an elevated infection risk in males but not females. Differences in nicotine product usage patterns between males and females, such as the frequency and intensity of use, may contribute to this discrepancy. If males, on average, use nicotine products more frequently or in higher doses than females, they could be at higher risk for nicotine-related complications, including infections [22]. Unfortunately, we did not have access to detailed information on nicotine product consumption, such as pack-years for cigarette smoking or equivalent metrics for other nicotine products, and thus could not perform further analysis.

Our stratified analysis further revealed that the correlation between nicotine product use and infection risk was evident solely among individuals who did not have diabetes, obesity, or chronic pulmonary disease. This could be explained by the fact that these comorbidities may have a greater impact on post-surgical complications, potentially masking the effects of nicotine product use. While there is no literature regarding the impact of such comorbidities on CDA outcomes, some studies have examined

their impacts on the outcomes of ACDF. For example, Malik et al. [23] reported that metabolic syndrome was significantly associated with a prolonged length of stay ≥ 3 days (OR = 1.32) in patients undergoing ACDF, but was not associated with 30-day complications, reoperations, or re-admissions, non-home discharge, or death. Interestingly, Sielatycki et al. [24] reported that obesity did not influence the outcomes of patients undergoing elective ACDF.

There are multiple mechanisms through which nicotine product use may increase the risk of infections in patients undergoing surgery. Nicotine impairs the immune system, reducing its efficiency in combating infections [25]. Furthermore, it leads to the constriction of blood vessels and diminished blood flow to the surgical site which compromises the healing process due to reduced delivery of essential nutrients and immune cells to the area [25]. Notably, Liu et al. [26] compared postoperative wound healing between smokers, non-smokers, and persons who had stopped smoking. The results showed that wound healing problems and surgical site infections were significantly lower in non-smokers and persons who had stopped smoking than in active smokers. Our observation is generally consistent with these prior reports.

While our investigation identified nicotine product use as an adverse predictor of infections in patients undergoing CDA, we were unable to analyze the impact of preoperative nicotine cessation due to a lack of such data. Prior literature in the realm of spinal surgeries emphasizes nicotine cessation as a promising strategy for potentially mitigating various short-term adverse events [27–29]. However, a recent study shed light on a contrasting finding: patients undergoing smoking cessation therapy before single-level anterior cervical discectomy and fusion procedures exhibited heightened vulnerability to postoperative dysphagia and revision surgery compared to their smoking counterparts [30]. Despite mixed findings, our study suggests that clinicians should prioritize nicotine cessation for CDA patients, recommending a 4–6-week cessation period pre-surgery to reduce risks. Tailored postoperative care, including vigilant infection monitoring, is also crucial. Further research is needed to clarify the long-term benefits and specific impacts of nicotine cessation on CDA outcomes.

Strengths and limitations

This study leveraged the NIS database from 2005 to 2020, offering a vast and diverse patient base that enhances the applicability of its findings on the impact of nicotine product use on CDA outcomes across the US. By employing PSM, it adjusts for potential confounding factors as much as possible, providing a more balanced comparison of post-surgical complications, infections, and other outcomes. The inclusion of stratified analyses for various subgroups allows for more personalized insights into patient care. However, the retrospective nature of the study limits its ability to consider all potential confounding factors, and the reliance on ICD-coded conditions and procedures may introduce biases if any coding errors exist. While PSM reduces selection bias, it cannot fully eliminate confounders like disease severity, such as HbA1c differences in diabetic patients. Additionally, the database lacks granular clinical details, such as laboratory values and functional status, which may affect risk adjustment and outcome interpretation. In addition, the dataset does not include information on specific medication types for diabetic patients, limiting the ability to perform a subanalysis comparing first-line versus second-line treatments. A limitation is the inability to differentiate between deep and superficial infections. Additionally, the dataset lacks clinical information, such as the actual severity of the disease and surgical invasiveness (e.g., blood loss and operation time), and long-term outcomes. Complications were only captured during the hospitalization, and data on post-discharge events or follow-up are unavailable. Changes in surgical techniques over the study period could also influence results. Notably, the identification of nicotine product use through ICD codes fails to capture the intensity and duration of use, such as pack-years for cigarette smoking or equivalent measures for other nicotine products, which limits the understanding of nicotine product use's true impact on CDA outcomes. Finally, the absence of data on preoperative nicotine cessation efforts limits the ability to evaluate its potential benefits.

Despite these limitations, the study's comprehensive approach contributes to the literature and highlights the need for further research, including datasets with more granular clinical details and long-term follow-up, to better understand the implications of nicotine product use on CDA outcomes.

Conclusions

This population-based study demonstrates that nicotine product use significantly increases the risk of complications, particularly infections, following CDA, particularly among male nicotine product users and patients without coexisting conditions like diabetes, obesity, or chronic pulmonary disease. While nicotine product use did not influence the rates of unfavorable discharge or extended hospital stay, its impact on post-surgical outcomes still underscores the need for targeted interventions and risk stratification in surgical planning for nicotine product users.

Abbreviations

CDA	Cervical disc arthroplasty
PSM	Propensity score matching
LOS	length of stay

COPD	Chronic obstructive pulmonary disease
AMI	Acute myocardial infarction
VTE	Venous thromboembolism
CVA	Cerebrovascular accident
AKI	Acute kidney injury
CCI	Charlson Comorbidity Index

Supplementary Information

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Supplementary Material 1

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Author contributions
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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This was a population-based, retrospective study. This study complies with the terms of the NIS data-use agreement. The data utilized in this study were obtained through the Online HCUP Central Distributor. Given that this study solely involved the analysis of secondary data, there was no direct involvement of the general public or patients.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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