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Smoking increases the risk of postoperative wound complications: A propensity score-matched cohort study

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Abstract

Cigarette smoking is associated with surgical complications, including wound healing and surgical site infection. However, the association between smoking status and postoperative wound complications is not completely understood. Our objective was to investigate the effect of smoking on postoperative wound complications for major surgeries. Data were collected from the 2013 to 2018 participant use files of the American College of Surgeons National Surgical Quality Improvement Program database. A propensity score matching procedure was used to create the balanced smoker and nonsmoker groups. Multivariable logistic regression was used to calculate the odds ratios (ORs) with 95% confidence intervals (CIs) for postoperative wound complications, pulmonary complications, and in-hospital mortality associated with smokers. A total of 1 156 002 patients (578 001 smokers and 578 001 nonsmokers) were included in the propensity score matching analysis. Smoking was associated with a significantly increased risk of postoperative wound disruption (OR 1.65, 95% CI 1.56-1.75), surgical site infection (OR 1.31, 95% CI 1.28-1.34), reintubation (OR 1.47, 95% CI 1.40-1.54), and in-hospital mortality (OR 1.13, 95% CI 1.07-1.19) compared with nonsmoking. The length of hospital stay was significantly increased in smokers compared with nonsmokers. Our analysis indicates that smoking is associated with an increased risk of surgical site infection, wound disruption, and postoperative pulmonary complications. The results may drive the clinicians to encourage patients to quit smoking before surgery.

KEYWORDS
postoperative complications, propensity score, smoking, surgical site infection, wound dehiscence

Chuen-Chau Chang has equal contribution with the corresponding author.

Key Messages
- smoking increases the risk of postoperative surgical site infection and wound disruption
- smoking increases the risk of in-hospital mortality and pulmonary complications
- the length of hospital stays is higher among smokers than nonsmokers
- the negative effects of smoking on wounds occur regardless of the duration of surgery and anaesthetic technique

1 | INTRODUCTION

Smoking is recognised as a risk factor for perioperative cardiovascular, respiratory, and wound-related complications.[1,2] Wound-related complications can lengthen hospital stays, expand hospital resource utilisation, and affect patient recovery.[3,4] A brief statement about smoking impacting on wound healing was published by the American Society of Anesthesiologists' Task Force on Smoking Cessation.[5] The statement mentioned that smoking has a direct impact on postoperative outcomes, and patients receiving elective surgery should abstain from smoking for as long as possible before and after surgery. Recently, a consensus statement on perioperative smoking cessation by the Society for Perioperative Assessment and Quality Improvement (SPAQI) mentioned that smoking cessation should be done as soon as practicable with surgical scheduling.[6] Extended abstinence is associated with lower rates of wound healing complications.[7]

Normal wound healing is the foundation of successful surgery. A comprehensive review article mentioned that smoking is one of the risk factors associated with wound complications. Other risk factors include infection, malnutrition, immobilisation, diabetes, drugs (such as steroids), and radiation.[8] The interaction between smoking and postoperative wound complications (wound infection, wound disruption) has been analysed in studies related to many different surgical procedures, including breast cancer surgery,[9] ambulatory surgery,[10] gastrointestinal cancer, and thoracic surgery,[11] and colorectal surgery.[12] They found surgical site infection (SSI) and delayed wound healing more frequently in smokers. However, not all the studies have consistent results. For example, there were two cohort studies about plastic surgery, and no difference was observed in wound complications between smokers and nonsmokers.[13,14] Recently, various tobacco and nicotine products have been accessible on the market, and one in vitro study disclosed the divergent effects on wound healing.[15] Accordingly, in this study, we attempted to understand the current impact of smoking on wound complications in surgical cases.

We conducted this propensity score-matched study using the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database to investigate whether patients who were active smokers were more likely to have wound-related complications postoperatively. We hypothesized that the current smokers have an increased risk of wound complications compared with nonsmokers.

2 | METHOD

2.1 | Data collection

This retrospective cohort study used the ACS NSQIP database to collect raw data from major surgical procedures. This database contains demographic data, comorbidities, perioperative surgical data, surgical outcomes, and complications.[16] Data were prospectively collected in a standardised way, and the accuracy and reproducibility were established.[17] This study was evaluated and approved by the Institutional Review Board of Taipei Medical University as exempt (TMU-JIRB202110058). The study was performed in line with the STROCSS guidelines for cohort studies.[18] The protocol was also submitted to the international clinical trial registry (clinicaltrial.gov – registration number NCT05142956).

2.2 | Study population

We used the 2013 to 2018 NSQIP participant user file to identify all codes and output variables required for surgical cases. Only patients with complete information for baseline parameters and without preoperative open wound infections were included. A total of 4 176 663 patients were initially chosen. (Figure 1).

Patients were stratified based on their smoking status as current smokers or nonsmokers. Current smokers were defined as patients who self-reported smoking cigarettes within 1 year before surgery. Outcome variables included postoperative complications (wound complications,

FIGURE 1 Flow of patients from initial identification in the database through to final cohort. ACS-NSQIP, The American College of Surgeons National Surgical Quality Improvement Program
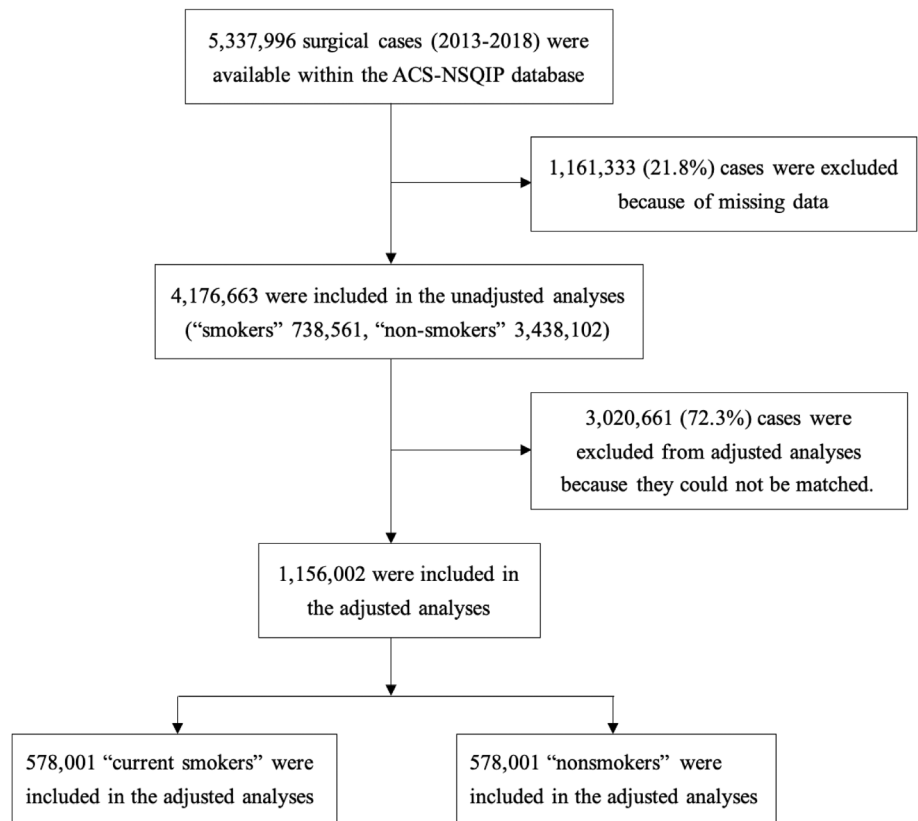
ventilator>48 hours, reintubation), length of hospital stay, and in-hospital mortality. Wound complications include SSI and wound disruption within 30 days after the primary procedure. SSIs were defined as a patient with at least one instance of a superficial SSI, deep SSI, or organ space SSI.

2.3 | Statistical analysis

We used propensity score analysis to control for confounding factors in this study. Propensity score matching was applied to match several parameters to make the two groups more comparable.[19] For the primary analysis, we determined the relationship between smoking and postoperative morbidity after propensity score matching current smokers to nonsmokers with the available confounding variables (sex, age, American Society of Anesthesiologists (ASA), preoperative functional status, race, body mass index (BMI), medical conditions, preoperative steroid use, surgical specialty, types of anaesthesia, operation time and wound classification). Matched cohort analysis was performed by using a 1:1 (nonsmoker: smoker) greedy nearest neighbour matching without replacement. To optimise matching for selective variables, we used a calliper width of 0.1 standard deviations of the logit of the propensity score. Therefore, the closest

match between subjects from each cohort (based on propensity score) and patients (who were within the calliper range) was matched together. The propensity score for each group was estimated using a logistic model based on the baseline variables. An absolute standardised difference of <0.1 for each baseline factor was considered a negligible difference between matched groups, which implies there was balance and good quality matching.[19]

Odds ratios (ORs) and 95% confidence intervals (CIs) for wound complications, in-hospital mortality, ventilator >48 hours, and reintubation for matched current smokers and nonsmokers were analysed with multivariable logistic regression models adjusted for sex, age, ASA, functional status, race, BMI, medical conditions, surgical specialty, wound classification, type of anaesthesia, and operation time. The length of hospital stay was analysed using paired t tests. All P values were 2-sided, and a P value <.05 was considered significant for the propensity score matching analysis.

The association between smoking status and postoperative wound complications was further explored by stratified analysis, and adjusted ORs with 95% CIs were calculated in the multivariate logistic regressions by sex, age, duration of surgery, and anaesthetic techniques. SAS software (version 9.4, SAS Institute Inc., Cary, North Carolina) was used for data analyses.

TABLE 1 Characteristics of smokers and nonsmokers before matching

	Non-smoker (N = 3 438 102)		Smoker (N = 738 561)		
	n	(%)	n	(%)	P-value
Gender					<.0001
Female	1 989 602	(57.9)	367 644	(49.8)	
Male	1 448 500	(42.1)	370 917	(50.2)	
Age, years					<.0001
20-29	167 026	(4.9)	47 079	(6.4)	
30-39	271 569	(7.9)	83 258	(11.3)	
40-49	435 781	(12.7)	122 394	(16.6)	
50-59	657 254	(19.1)	205 016	(27.8)	
60-69	864 608	(25.2)	181 065	(24.5)	
70-79	680 470	(19.8)	82 083	(11.1)	
≥80	361 394	(10.5)	17 666	(2.4)	
ASA physical status					<.0001
I	206 577	(6.0)	19 872	(2.7)	
II	1 472 463	(42.8)	286 437	(38.8)	
III	1 535 166	(44.7)	363 816	(49.3)	
IV	218 593	(6.4)	66 372	(9.0)	
V	5303	(0.2)	2064	(0.3)	
Functional status prior to surgery					<.0001
Independent	3 331 971	(96.9)	719 138	(97.4)	
Dependent	106 131	(3.1)	19 423	(2.6)	
Race					<.0001
Asian	104 535	(3.0)	10 237	(1.4)	
Black	339 066	(9.9)	98 489	(13.3)	
Other/unknown	485 885	(14.1)	92 924	(12.6)	
White	2 508 616	(73.0)	536 911	(72.7)	
BMI					<.0001
<18.5	51 655	(1.5)	25 960	(8.3)	
18.5-24.9	777 999	(22.6)	213 738	(28.9)	
25-29.9	1 067 718	(31.1)	219 895	(29.8)	
30-34.9	756 430	(22.0)	144 413	(19.6)	
35-39.9	411 987	(12.0)	73 626	(10.0)	
>=40	372 313	(10.8)	60 929	(8.3)	
Medical conditions					
Hypertension	1 760 483	(51.2)	343 150	(46.5)	<.0001
Diabetes	620 768	(18.1)	121 649	(16.5)	<.0001
COPD	125 168	(3.6)	86 292	(11.7)	<.0001
Ventilator dependent	10 136	(0.3)	3877	(0.5)	<.0001
CHF	34 184	(1.0)	8262	(1.1)	<.0001
Disseminated cancer	93 291	(2.7)	20 287	(2.8)	.1095
Bleeding disorders	154 969	(4.5)	44 311	(6.0)	<.0001
Dialysis	52 500	(1.5)	10 509	(1.4)	<.0001
Acute renal failure	13 334	(0.4)	3394	(0.5)	<.0001

TABLE 1 (Continued)

	Non-smoker (N = 3 438 102)		Smoker (N = 738 561)		
	n	(%)	n	(%)	P-value
Steroid use	146 133	(4.3)	26 922	(3.7)	<.0001
Surgical specialty					<.0001
Cardiac surgery	17 822	(0.5)	4443	(0.6)	
General surgery	1 599 183	(46.5)	334 228	(45.3)	
Gynaecology	249 211	(7.3)	43 395	(5.9)	
Neurosurgery	189 245	(5.5)	52 154	(7.1)	
Orthopaedics	795 346	(23.1)	125 315	(17.0)	
Otolaryngology	64 051	(1.9)	15 443	(2.1)	
Plastics	76 482	(2.2)	10 893	(1.5)	
Thoracic	42 668	(1.2)	16 586	(2.3)	
Urology	216 202	(6.3)	41 693	(5.7)	
Vascular	187 892	(5.5)	94 411	(12.8)	
Wound classification					<.0001
Clean	1 874 424	(54.5)	396 204	(53.7)	
Clean/contaminated	1 167 239	(34.0)	229 838	(31.1)	
Contaminated	224 660	(6.5)	53 906	(7.3)	
Dirty/infected	171 779	(5.0)	58 613	(7.9)	
Types of anaesthesia					<.0001
General	3 031 846	(88.2)	679 661	(92.0)	
Other	406 256	(11.8)	58 900	(8.0)	
Operation time (h)					<.0001
<2	2 260 547	(65.8)	466 965	(63.2)	
2-4	869 634	(25.3)	193 589	(26.2)	
>=4	307 921	(9.0)	78 007	(10.6)	

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease.

3 | RESULTS

There were 5 337 996 surgical cases identified within the ACS NSQIP database during 2013 to 2018. We excluded 21.8% of patients with missing data. Among the remaining 4 176 663 patients, 738 561 (17.7%) were current smokers and 3 438 102 (82.3%) were nonsmokers. We successfully matched 578 001 current smokers and 578 001 nonsmokers for a total of 1 156 002 patients. Figure 1 shows details of the numbers of exclusions.

Table 1 summarises the baseline data of each cohort (nonsmokers and smokers). Baseline variables, including sex, age, ASA classification, functional status, race, BMI, comorbidities, surgical specialties, wound classification, anaesthesia technique, and operation time were different between two groups (p value <.01) except that disseminated cancer before surgery (p value .1095) was comparable between the two

groups. Smokers had higher proportions of ASA class III and IV, chronic obstructive pulmonary disease (COPD), ventilator dependency, congestive heart failure (CHF), bleeding disorders, acute renal failure, and wounds with higher contamination levels than nonsmokers.

The characteristics of smokers and nonsmokers after propensity score matching are summarised in Table 2. Our sample had 48.2% male patients. There were 43.8% patients with ASA class II and 48.1% patients with ASA class III. Regarding functional status prior to surgery, most cases were independent (99.0%). Among these patients, 39.7% cases had a BMI above 30. Regarding medical conditions, 44.3% of the population had a history of hypertension, and 14.4% of patients had a history of diabetes. General surgery accounted for 45.6% of all surgical specialties. Most patients (92.4%) underwent general anaesthesia.

TABLE 2 Characteristics of smokers and nonsmokers after matching

	Non-smoker (N = 578 001)		Smoker (N = 578 001)		
	n	(%)	n	(%)	ASD
Sex					
Female	299 215	(51.8)	299 215	(51.8)	.00
Male	278 786	(48.2)	278 786	(48.2)	.00
Age, years					
20-29	36 948	(6.4)	36 948	(6.4)	0.00
30-39	67 674	(11.7)	67 674	(11.7)	0.00
40-49	98 358	(17.0)	98 358	(17.0)	0.00
50-59	155 131	(26.8)	155 131	(26.8)	0.00
60-69	140 590	(24.3)	140 590	(24.3)	0.00
70-79	65 826	(11.4)	65 826	(11.4)	0.00
≥80	13 474	(2.3)	13 474	(2.3)	0.00
ASA physical status					
I	16 675	(2.9)	16 675	(2.9)	0.00
II	252 972	(43.8)	252 972	(43.8)	0.00
III	277 918	(48.1)	277 918	(48.1)	0.00
IV	30 312	(5.2)	30 312	(5.2)	0.00
V	124	(0.0)	124	(0.0)	0.00
Functional status prior to surgery					
Independent	572 353	(99.0)	572 353	(99.0)	0.00
Dependent	5648	(1.0)	5648	(1.0)	0.00
Race					
Asian	7519	(1.3)	7519	(1.3)	0.00
Black	70 206	(12.2)	70 206	(12.2)	0.00
Other/unknown	72 821	(12.6)	72 821	(12.6)	0.00
White	427 455	(74.0)	427 455	(74.0)	0.00
BMI					
<18.5	11 850	(2.1)	11 850	(2.1)	0.00
18.5-24.9	157 118	(27.2)	157 118	(27.2)	0.00
25-29.9	179 456	(31.1)	179 456	(31.1)	0.00
30-34.9	119 536	(20.7)	119 536	(20.7)	0.00
35-39.9	60 350	(10.4)	60 350	(10.4)	0.00
>=40	49 691	(8.6)	49 691	(8.6)	0.00
Medical conditions					
Hypertension	258 317	(44.7)	253 446	(43.9)	0.01688
Diabetes	84 548	(14.6)	82 024	(14.2)	0.01187
COPD	41 417	(7.2)	41 446	(7.2)	0.00020
Ventilator dependent	244	(0.0)	304	(0.1)	0.00319
CHF	2588	(0.5)	3234	(0.6)	0.01273
Disseminated cancer	12 866	(2.2)	12 978	(2.3)	0.00121
Bleeding disorders	21 886	(3.8)	27 756	(4.8)	0.04981
Dialysis	3628	(0.6)	3640	(0.6)	0.00020
Acute renal failure	620	(0.1)	791	(0.1)	0.00654

TABLE 2   (Continued)

	Non-smoker (N = 578 001)		Smoker (N = 578 001)		
	n	(%)	n	(%)	ASD
Steroid	15 915	(2.8)	15 946	(2.8)	0.00028
Surgical specialty					
Cardiac surgery	2907	(0.5)	2907	(0.5)	0.00
General surgery	263 388	(45.6)	263 388	(45.6)	0.00
Gynaecology	40 432	(7.0)	40 432	(7.0)	0.00
Neurosurgery	44 745	(7.7)	44 745	(7.7)	0.00
Orthopaedics	107 017	(18.5)	107 017	(18.5)	0.00
Otolaryngology	11 896	(2.1)	11 896	(2.1)	0.00
Plastics	7486	(1.3)	7486	(1.3)	0.00
Thoracic	10 952	(1.9)	10 952	(1.9)	0.00
Urology	36 082	(6.2)	36 082	(6.2)	0.00
Vascular	53 096	(9.2)	53 096	(9.2)	0.00
Wound classification					
Clean	327 777	(56.7)	327 777	(56.7)	0.00
Clean/contaminated	199 815	(34.6)	199 815	(34.6)	0.00
Contaminated	33 688	(5.8)	33 688	(5.8)	0.00
Dirty/infected	16 721	(2.9)	16 721	(2.9)	0.00
Types of anaesthesia					
General anaesthesia	533 845	(92.4)	533 845	(92.4)	0.00
Other	44 156	(7.6)	44 156	(7.6)	0.00
Operation time (h)					
<2	367 465	(63.6)	367 465	(63.6)	0.00
2-4	152 741	(26.4)	152 741	(26.4)	0.00
>=4	57 795	(10.0)	57 795	(10.0)	0.00

Abbreviations: ASA, American Society of Anesthesiologists; ASD, absolute standardised difference; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease.

Table 3 shows the risk of postoperative outcomes with current smoking from the propensity score matching analysis. Smoking was associated with a significantly increased risk of postoperative SSI (OR 1.31, 95% CI 1.28-1.34) and wound disruption (OR 1.65, 95% CI 1.56-1.75). Current smokers had higher risk of in-hospital mortality (OR 1.13, 95% CI 1.07-1.19) and pulmonary complications, including reintubation (OR 1.47, 95% CI 1.40-1.54) and ventilator >48 hours (OR, 1.44; 95% CI, 1.37-1.52), than nonsmokers. The length of hospital stays was significantly higher among current smokers than nonsmokers ($P < .0001$).

Table 4 presents the risk of postoperative wound complications associated with current smoking and stratification by sex, age, duration of surgery, and anaesthetic technique. Current smokers were associated with a higher risk of postoperative wound complications in both the male (OR, 1.27; 95% CI, 1.23-1.31) and female groups (OR, 1.40; 95% CI, 1.36-1.44), and the increased risk was more prominent in the female group. Current smokers were related to an increased risk of postoperative wound complications in all age groups. The positive relationship between current smokers and major postoperative wound complications was apparent regardless of the duration of surgery or anaesthetic technique.

4 | DISCUSSION

In recent years, there have been expanding studies about the adverse impact of smoking on wound healing.[1,2,20-23] Wound complications, such as SSI and surgical wound

TABLE 3 Risk of postoperative mortality and wound complications in patients with current smoking

Postoperative outcomes	Non-smoker (N = 578 001)		Smoker (N = 578 001)		Outcome risk	
	Events	%	Event	%	OR	(95% CI)[a]
In-hospital mortality	2705	0.4	3067	0.5	1.13	(1.07-1.19)
SSI	14 887	2.6	19 262	3.3	1.31	(1.28-1.34)
Superficial SSI	7610	1.3	10 228	1.8	1.35	(1.31-1.39)
Deep SSI	1886	0.3	2892	0.5	1.53	(1.45-1.63)
Organ space SSI	5819	1.0	6770	1.2	1.17	(1.13-1.21)
Wound disruption	1784	0.3	2944	0.5	1.65	(1.56-1.75)
Ventilator >48 hours	2516	0.4	3577	0.6	1.44	(1.37-1.52)
Reintubation	3136	0.5	4552	0.8	1.47	(1.40-1.54)
Length of hospital stay, days[b]	2.88 ± 4.85		3.04 ± 4.96		$p < .0001$	

Abbreviations: CI, confidence interval; OR, odds ratio; SSI, surgical site infection (superficial, deep, and organ space).
[a]Adjusted for all covariates listed in Table 2.
[b]Mean ± SD.

dehiscence, are associated with an increased risk of unplanned reoperation, readmission, and extended length of stay.[24-26] Wound complications will also impact patient quality of life and health care budgets.[27] Most importantly, this behavioural risk factor may be preventable.[23] Our study adds to existing evidence and improves our understanding of healing complications and major complications in smoking surgical cases according to the recent NSQIP database. Among the surgical cases in the database, approximately 17.7% were current smokers, which declined from 26.5% between 2005 and 2008 and was larger than the 15.5% in 2016 among U.S. adults.[1,28] The results of this propensity score matching study showed a higher risk of wound complications and pulmonary complications along with an increased risk of in-hospital mortality and extended length of hospital stays in current smokers.

We found that current smokers who underwent surgery had approximately 30% increased odds of developing SSI and 65% increased odds of developing wound disruption. Prior studies have consistently found that current smokers have an increased risk of wound complications in nonspecific operations. A meta-analysis by Grønkjær et al, which includes 107 studies found that smokers undergoing surgery had significantly increased odds of wound complications over nonsmokers.[2] Turan et al, used the NSQIP dataset from 2005 to 2008 to survey the association between smoking status and perioperative outcomes. Current smokers had significantly higher odds of wound disruption and superficial and deep incisional infections.[1] An observational, matched case-control study by Nolan et al found that current smoking status was related to higher odds of SSI.[22] Our data are consistent with these findings, and the benefits of using NSQIP data include a recent and satisfactory number of surgical

cases, modifications for probable confounders, and the use of a clear definition of smoking status.

The findings that current smokers have a higher risk of SSI and wound disruption can be explained by the pathophysiological mechanisms related to the toxic effects and oxidative destruction induced by smoking.[29] Regarding the mechanisms of increasing risk of wound disruption, cigarette smoke consists of a complex mixture of compounds, and the primary toxins related to delayed wound healing are nicotine and carbon monoxide.[30-32] Carbon monoxide has a greater affinity for haemoglobin than the affinity of oxygen for haemoglobin. Its presence negatively affects oxygen delivery to the tissues. Nicotine stimulates nicotinic acetylcholine receptors and triggers the secretion of neurotransmitters, such as serotonin, dopamine, noradrenaline, adrenaline, vasopressin, and serotonin.[33] These complex compounds have been proven to impact the wound healing course and tissue oxygenation.[29,34] Tissue hypoxia is one of the crucial mechanisms through which cigarette smoking disrupts wound healing. Oxygen is vital for the entire wound healing process, including cell migration to wound sites, bactericidal mechanisms, angiogenesis, and collagen metabolism.[35-37] In addition, nicotine-mediated vasoconstriction can temporarily reduce tissue blood flow. Some wounds with a vulnerable blood supply, such as intestinal anastomoses, tissue flaps, and ischemic tissues (eg, peripheral artery disease), may be susceptible to blood flow reduction caused by smoking. A systemic review by Sørensen LT demonstrated that smoking has an extensive impact on all phases of wound healing.[29]

The potential mechanisms of cigarette smoking on wound infection are multifactorial.[29,38] Impeded blood flow caused by a potent vasoconstrictor, nicotine, will

TABLE 4　Stratified analysis for the risk of postoperative wound complications associated with current smoking

		n	Wound complications			
			Events	Rate, %	OR	(95% CI)
Male	Control	278 786	8077	2.9	1.00	
	Current smoking	278 786	10 116	3.6	1.27	(1.23-1.31)
Female	Control	299 215	7946	2.7	1.00	
	Current smoking	299 215	10 932	3.7	1.40	(1.36-1.44)
Age, 20-29 years	Control	36 948	618	1.7	1.00	
	Current smoking	36 948	825	2.2	1.35	(1.21-1.50)
Age, 30-39 years	Control	67 674	1608	2.4	1.00	
	Current smoking	67 674	2102	3.1	1.32	(1.24-1.41)
Age, 40-49 years	Control	98 358	2703	2.8	1.00	
	Current smoking	98 358	3796	3.9	1.43	(1.36-1.51)
Age, 50-59 years	Control	155 131	4521	2.9	1.00	
	Current smoking	155 131	6305	4.1	1.43	(1.37-1.48)
Age, 60-69 years	Control	140 590	4325	3.1	1.00	
	Current smoking	140 590	5457	3.9	1.28	(1.23-1.34)
Age, ≥70 years	Control	79 300	2248	2.8	1.00	
	Current smoking	79 300	2563	3.2	1.15	(1.08-1.22)
<2 hours of surgery	Control	367 465	5268	1.4	1.00	
	Current smoking	367 465	7345	2.0	1.40	(1.35-1.45)
2-4 hours of surgery	Control	152 741	5683	3.7	1.00	
	Current smoking	152 741	7608	5.0	1.36	(1.32-1.41)
≥4 hours of surgery	Control	57 795	5072	8.8	1.00	
	Current smoking	57 795	6095	10.6	1.23	(1.18-1.28)
General anaesthesia	Control	533 845	15 575	2.9	1.00	
	Current smoking	533 845	20 425	3.8	1.33	(1.31-1.36)
Other anaesthesia	Control	44 156	448	1.0	1.00	
	Current smoking	44 156	623	1.4	1.41	(1.24-1.59)

Note: Wound complications included surgical site infection (superficial, deep, and organ space) and wound disruption.
Abbreviation: OR, odds ratio.

cause tissue hypoxia and acidosis.[39,40] Hypoxia will decrease the ability of neutrophils and macrophages to oxidative kill pathogens.[41-43] Prolonged acidosis increases the risk of infection.[44] In our study, smokers had a higher risk of deep SSI (OR 1.53, 95% CI 1.45-1.63) than superficial SSI (OR 1.35, 95% CI 1.31-1.39). However, there is not enough evidence to prove the mechanism of the association between smoking and SSI.[22] In a retrospective study of NSQIP dataset in 2011, current smoking was a risk factor for both superficial and deep/organ-space SSI but also varied in terms of magnitude and significance.[45] Therefore, different SSIs may have divergent disease processes, and cigarettes may have distinct impacts on them.

In addition to wound complications, our results show that smokers have an increased risk of pulmonary complications (ventilator >48 hours and reintubation). Smoking impedes the innate defence system of the lung, including damaging mucus transport, aggravating mucus production, and diminishing macrophage function.[46] These findings are consistent with previous studies, which identify smoking as a risk factor for postoperative pulmonary complications.[1,47,48] However, lifetime exposure to smoking is now considered more influential on the rate of postoperative pulmonary complications than current smoking status.[49]

This study using propensity score matching and multivariable logistic regression adds validity to the results. Propensity score matching techniques can control confounding variables by constructing propensity scores based on selected clinical characteristics and matching

subjects with similar propensity score values. Our selected variables included in the matching method were based on clinical factors that can influence wound healing or SSI. After matching, multivariate logistic regression techniques were used to diminish the risk of confounding other variables on the outcomes of concern.

Other than a traditional cigarette, it is worth noting that e-cigarettes, which are alternative nicotine options, are gaining popularity. The content and adverse effects of e-cigarettes are less well known. The major constituents of e-cigarettes include nicotine, glycerol, propylene glycol, and other flavourings. There is limited evidence comparing perioperative complications in e-cigarette consumers to traditional cigarette consumers. A case report by Fracol et al described an e-cigarette user who had significant mastectomy skin flap necrosis after a bilateral mastectomy.[34] Despite insufficient evidence, data suggest that e-cigarettes may have a significant adverse effect on wound healing.[50-52] Further investigations are needed to validate the effects of e-cigarettes on perioperative outcomes.

Although one strength of our study is its large sample size, our study has limitations. First, we could not identify the data on the duration of smoking cessation or pack-years of smoking from the NSQIP, which made it difficult to measure the transitory effect of smoking cessation or smoking status on postoperative outcomes. For example, patients who had quit smoking within 1 year of surgery were defined as current smokers by the NSQIP. This will cause underestimation of the smoking effect on postoperative complications. Second, there were residual confounders that were not adjusted for. Factors affecting surgical-wound healing include individual characteristics (aging, malnutrition, immobilisation, diabetes, chronic renal failure, obesity, alcoholism, and jaundice), anaesthetic characteristics (tissue perfusion, normovolaemia, body temperature, concentration of inspired oxygen, and analgesia), and surgical characteristics (site, duration, and complexity of surgery, suturing quality, hematoma, and prophylactic antibiotics).[53] Some of these factors were included in our propensity matching, but there were still other uncorrected factors. Third, propensity score matching still carries bias, as it cannot balance all selected factors, including duration and the severity of comorbidities.[54] Studies with more corrected confounding factors or prospective, randomised trials are needed to verify our results and provide adequate evidence of wound complications.

5 | CONCLUSION

Smoking status is related to increased perioperative risk for wound complications following major surgical procedures. The current literature review has shown that smoking harms wound healing. Our study adds to existing evidence and improves our understanding of healing complications in smoking surgical cases. Wound complications are associated with other adverse outcomes and have a significant impact on patient quality of life and health care budgets. Therefore, patients who smoke should be informed about the potentially increased risks of complications before surgery. Our results encourage smoking cessation prior to surgery, although the data do not allow us to evaluate the effects of smoking cessation.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP). Restrictions apply to the availability of these data, which were used under license for this study.

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