CME

The Impact of Sleep Apnea on Postoperative Utilization of Resources and Adverse Outcomes

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BACKGROUND: Despite the concern that sleep apnea (SA) is associated with increased risk for postoperative complications, a paucity of information is available regarding the effect of this disorder on postoperative complications and resource utilization in the orthopedic population. With an increasing number of surgical patients suffering from SA, this information is important to physicians, patients, policymakers, and administrators alike.

METHODS: We analyzed hospital discharge data of patients who underwent total hip or knee arthroplasty in approximately 400 U.S. Hospitals between 2006 and 2010. Patient, procedure, and health care system-related demographics and outcomes such as mortality, complications, and resource utilization were compared among groups. Multivariable logistic regression models were fit to assess the association between SA and various outcomes.

RESULTS: We identified 530,089 entries for patients undergoing total hip and knee arthroplasty. Of those, 8.4% had a diagnosis code for SA. In the multivariate analysis, the diagnosis of SA emerged as an independent risk factor for major postoperative complications (OR 1.47; 95% confidence interval [CI], 1.39–1.55). Pulmonary complications were 1.86 (95% CI, 1.65–2.09) times more likely and cardiac complications 1.59 (95% CI, 1.48–1.71) times more likely to occur in patients with SA. In addition, SA patients were more likely to receive ventilatory support, use more intensive care, stepdown and telemetry services, consume more economic resources, and have longer lengths of hospitalization.

CONCLUSIONS: The presence of SA is a major clinical and economic challenge in the postoperative period. More research is needed to identify SA patients at risk for complications and develop evidence-based practices to aid in the allocation of clinical and economic resources. (Anesth Analg 2014;118:407–18)

Sleep apnea (SA) is a major challenge in the postoperative period. As many as one-fourth of patients undergoing elective surgery may be affected.[1] The prevalence among orthopedic patients undergoing joint arthroplasty may be especially high, given that obesity is a widespread comorbidity in this patient population.[2] Despite the increasing level of concern that SA is associated with increased risk for postoperative complications,[2–7] there remains a paucity of population-based information available in the literature regarding postoperative outcomes. Most available data are from relatively small samples and academic institutions, thus limiting external validity and applicability. Large-scale observational studies, using secondary administrative databases, are increasingly being performed, because they provide more robust information on the impact of specific diseases in a more representative care setting.

Given the combination of a high prevalence of SA among orthopedic surgery patients[2] and the projection that by 2030 >4 million hip (THA) and knee (TKA) arthroplasties will be performed in the United States alone,[8] the joint replacement population is an especially important group of patients in need of further investigation.

Despite some data suggesting an increased risk for postoperative pulmonary complications associated with SA among orthopedic patients,[2] more detailed analysis of other important outcomes such as utilization of economic resources remains largely unexplored. Such information is important to assess and gain better insights into the clinical and economic impact of SA in patients undergoing surgery.

Therefore, we analyzed data on >500,000 patients from approximately 400 institutions. We hypothesized that THA

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and TKA patients with SA (1) were more likely to experience postoperative complications and (2) consumed greater hospital resources, as represented by an increased likelihood for a longer length of hospital stay and greater use of economic resources.

METHODS

Database and Study Design

For this study, data from Premier Perspective, Inc.'s (Charlotte, NC) collected between 2006 and 2010 were used. This retrospective administrative database contains discharge information from approximately 400 hospitals[9,10] and is compliant with the Health Insurance Portability and Accountability Act. Because data are de-identified, the study was exempt from review by the Hospital for Special Surgery IRB. Before distribution, rigorous quality assurance and data validation procedures are used by the provider to assure the accuracy of entries. This database has been used for other studies by our group.[11,12]

Study Population

The study population consisted of all patients in the Premier Perspective database, undergoing primary THA and TKA, as identified by International Classification of Diseases-9th revision-Clinical Modification codes (ICD-9-CM) 81.51 and 81.54, respectively.

Study Variables

The presence of SA was determined by the presence of respective ICD-9 codes. Appendix 1 lists specific diagnosis codes included and their individual prevalence.

Patient, procedure, and health care-related characteristics analyzed were age, sex, race (Caucasian, African-American, Hispanic, other), admission type (emergent, elective, other), hospital size (<300, 300–499, ≥500 beds), hospital location (urban, rural), hospital teaching status, anesthesia type (general, neuraxial, neuraxial-general, unknown), indication for surgery (osteoarthritis, rheumatoid arthritis, other), type of surgery (THA, TKA), year of surgery, and comorbidity prevalence (myocardial infarction [MI], cerebrovascular disease, peripheral vascular disease, renal disease, chronic obstructive pulmonary disease [COPD], uncomplicated and complicated diabetes mellitus, uncomplicated and complicated systemic hypertension, ["complicated" as defined by the absence or presence of disease-related end organ complications], cancer, obesity, and pulmonary hypertension). Overall, comorbidity burden was assessed with the Deyo adaptation of the Charlson comorbidity index method for use with administrative data for surgical outcomes.[13] In brief, the Deyo Index comprises a number of comorbidities. Each comorbidity is assigned a severity weight, and its presence contributes to an overall score. A higher score correlates with increased risk of adverse outcomes.

Individual major postoperative complications studied were pulmonary embolism, deep venous thrombosis, cerebrovascular events, pulmonary complications, sepsis, cardiac complications (excluding MI), MI, pneumonia (including ventilator-associated pneumonia and aspiration pneumonitis), infectious complications, acute renal failure, gastrointestinal complications, and mortality. To evaluate these major complications, a combined outcome variable ("combined complications") was created to indicate having at least one of the complications listed above. A case with "pulmonary complications" had at least 1 indication of pulmonary compromise, pneumonia, or pulmonary embolism. For "cardiac complications," cases had an indication of cardiac complications (except MI) or MI.

In addition, utilization of critical care, stepdown and telemetry services (each defined by specific billing records for these services representing distinctly different levels of care), blood transfusions, postoperative mechanical ventilation, and noninvasive ventilation were studied. Utilization of economic resources in U.S. dollars and length of hospitalization were compared as continuous variables. Due to their skewed distributions, they were also dichotomized such that entries exceeding the 75th percentile were defined as increased length of hospitalization or increased use of economic resources, respectively. This approach was used by our group in various other publications.[11,12] Furthermore, using this cutoff was not influenced by the length of hospitalization or patient costs of SA patients. To account for potential bias in choosing a cutoff for dichotomization, sensitivity analyses using cutoffs ranging from 50% to 90% were performed in the univariable analysis, and similar results were found. ICD-9 CM codes and billing data provided by the Premier database were used to define the presence of comorbidities, complications, and other outcomes and are listed in Appendix 2.

Statistical Analysis

The primary goal of our analysis was to compare different outcomes between patients with and without SA. All statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC).

Patient- and Health Care-Related Characteristics by Presence of SA

Groups with and without SA diagnosis were compared regarding patient and health care-related characteristics in the univariable analysis. Means (standard deviation [SD]) and percentages were described for continuous and categorical variables, respectively. Length of stay and economic resource utilization exhibited a skewed distribution and were presented using median and interquartile ranges. Due to the large sample size, a significant difference of P (< 0.05) for differences between 2 groups using traditional t tests, Wilcoxon rank sum tests, or χ^2 tests were very likely to be detected but may not be clinically meaningful. Therefore, standardized difference (STD) was calculated to measure group balance.[14] A STD <0.1 for a continuous and 10% for a categorical variable indicated a negligible difference in the mean or proportion of a variable between groups.[15] Due to the large sample size, the SEs of STDs were very small; therefore, and to support clarity of presentation, they were not shown. Percentage of missing data was reported for all study variables, stratified by presence of a SA diagnosis.

Logistic Regression Analyses

Univariable and multivariable logistic regression analyses were performed to evaluate the association between patients with and without SA. Separate models were fitted for the binary outcomes: combined complications, pulmonary complications, cardiac complications, mortality, mechanical ventilation, noninvasive ventilation, use of blood product transfusion, intensive care utilization, stepdown/telemetry service utilization, increased length of hospitalization, and increased economic resource utilization. Covariates included for controlling purposes comprised age, gender, race, admission type, hospital size, hospital teaching status, hospital location, anesthesia type, indication for surgery, type of surgery, year of surgery, and individual comorbidities. The association between each covariate and outcome variable was performed by univariable analysis. Almost all associations had $P < 0.05$ and were entered into the multivariable model. Few covariates (e.g., gender and hospital characteristic) had $P > 0.05$ for the outcomes of mortality, and cardiac complication, but were included in the model due to the consensus that they were of clinical importance.[16]

In addition to the above-mentioned main effects, we evaluated the interaction terms of SA with age, gender, year, COPD, diabetes, obesity, hypertension, and complicated hypertension for each of the outcomes. These interaction terms were selected based on (1) clinical relevance; (2) STD >10% between SA versus non-SA status; and (3) sufficient frequency (> 5% prevalence of comorbidities in SA) to achieve adequate power and obtain valid estimates. All interaction effects were included in each model, and a backward approach was used for testing the significance of interaction effects while keeping all main effects in the model. The significance of interaction effects was measured using a P of 0.004 (Bonferroni-corrected $P = 0.05/11$ outcomes)[17] to adjust for multiple outcomes. If an interaction effect had a $P < 0.004$, but the corresponding coefficient was very small (e.g., < 0.001), we considered it quantitatively unimportant and removed it from the model. For models with significant interaction terms, the interpretation of SA effect would be conditioned on the terms interacted with.

Missing data were excluded from analyses, but because 27.6% of cases had "unknown" anesthesia, they were treated as a separate category and modeled as a sensitivity analysis.

Crude and adjusted odds ratios (OR), Bonferroni-corrected 95% confidence intervals (CI) and P values were reported due to multiple comparisons. Two-sided $P < 0.05$ (conventional threshold of significance) was used to determine significance of variables. Ninety-five percent CIs of estimates were reported to enable readers to interpret the significance of the findings; this was done to alleviate the potentially undue effect a very large sample size might have on the P values.

Diagnostic of Models

To evaluate independence of individual predictor variables, the value inflation factor was calculated for each predictor variable to determine whether multicollinearity was present. The final models were validated using the Hosmer-Lemeshow (H-L) test.[18] It evaluated adequate calibration of a logistic regression model so that the probability predictions from the model reflected the true occurrence of events in the data. The area under the receiver-operating characteristic curve[19] (c-statistic) was used to measure the level of model discrimination between observed data at different levels of the outcome. Discrimination was classified as perfect, excellent, very good, good, moderate, and poor if the area under curves were 1.0, 0.9 to 0.99, 0.8 to 0.89, 0.7 to 0.79, 0.6 to 0.69, or <0.6, respectively.[20] To evaluate whether populations differed among outcomes, the amount of patients with multiple outcomes was determined. Statistical analyses were performed using SAS software version 9.3 (SAS Institute, Cary, NC).

Sensitivity Analysis Based on Propensity Score Matching

The OR from a matched sample using the propensity score method was performed as a sensitivity of the results to different statistical approaches. All covariates used in the primary analysis above were included in the multivariable logistic regression with the outcome variable of SA versus non-SA to calculate propensity scores. One SA patient (case) was matched with 3 non-SA patients (controls) for statistical efficiency.[21] The matched pairs were generated by comparing the predicted propensity scores between cases and controls using the SAS macro %onetomanymatch with 8 to 1 digit match without replacement.[22] Based on the matched sample, the effect of SA on outcomes was tested for significance using the Cochran-Mantel-Haenszel (CMH) test. To account for matching samples, common odds ratio, an overall OR across pairs of matching samples, and Bonferroni-corrected 95% CIs were estimated. For comparison purposes, multivariable models with main effects only were performed and reported.

RESULTS

Characterization by Presence of SA

We identified 530,089 entries for patients undergoing THA and TKA between 2006 and 2010. Overall, 8.4% had a diagnosis code for SA. The prevalence of SA increased from 6.2% in 2006 to 10.3% in 2010 (Fig. 1). Compared with non-SA

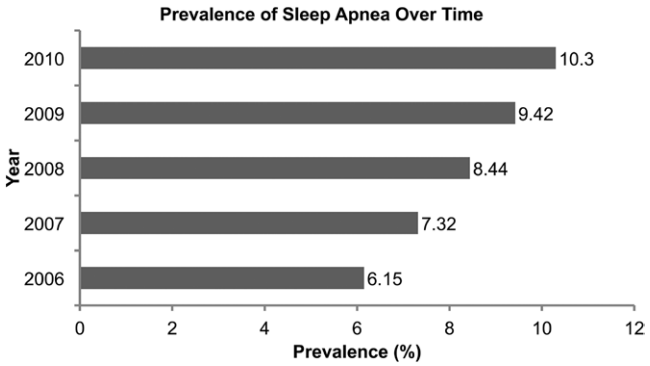

Figure 1. Figure 1 displays the prevalence of sleep apnea over time.

Table 1. Patient and Healthcare System-Related Characteristics

Patient and health care system-related demographics					
	No SA diagnosis		SA diagnosis		
N	485,843		44,246		
%	91.6%		8.4%		
Year of procedure[b]	*N*	%	*N*	%	STD (%)
2006	91,731	18.9	6007	13.6	14.42
2007	97,545	20.1	7709	17.4	6.80
2008	102,177	21.0	9419	21.3	0.63
2009	111,892	23.0	11640	26.3	7.61
2010	82,498	17.0	9471	21.4	11.25
Type of procedure[b]					
THA	162,011	33.3	10,939	24.7	19.08
TKA	323,832	66.7	33,307	75.3	
Type of anesthesia					
N	36,702	7.6	3332	7.5	0.09
G	269,495	55.5	24,798	56.0	1.16
N + G	44,762	9.2	4659	10.5	4.41
Unknown	134,884	27.8	11,457	25.9	4.22
Deyo index category[ab]					
0	315,316	64.9	20,662	46.7	37.28
1	80,419	16.6	8894	20.1	9.18
2	68,275	14.1	9531	21.5	19.67
> 3	21,833	4.5	5159	11.7	26.53
Average deyo index[ab] (SD, range)	0.59 (0.92–0–10)		1.00 (1.12–0–8)		40.11
Average age (y)[b] (SD)	66.16 (11.32)		63.36 (9.56)		26.72
Gender[b]					
Female	304,459	62.7	20,419	46.1	33.63
Male	181,384	37.3	23,827	53.9	
Race					
White	360,840	74.3	34,231	77.4	7.23
Black	32,844	6.8	3353	7.6	3.17
Hispanic	11,191	2.3	741	1.7	4.50
Other	80,968	16.7	5921	13.4	9.20
Admission type					
Emergent	11,430	2.4	978	2.2	0.95
Urgent	19,433	4.0	1821	4.1	0.59
Elective	453,700	93.4	41,373	93.5	0.50
Other	1280	0.3	74	0.2	2.08
Hospital size (no. of beds)					
< 299	158,567	32.6	12,991	29.4	7.09
300–499	189,123	38.9	19,102	43.2	8.64
> 500	138,153	28.4	12,153	27.5	2.16
Hospital location					
Rural	49,240	10.1	4203	9.5	2.14
Urban	436,603	89.9	40,043	90.5	
Hospital teaching status					
Nonteaching	286,759	59.0	24,537	55.5	7.21
Teaching	199,084	41.0	19,709	44.5	
Indication					
RA	15,980	3.3	1217	2.8	3.15
OA	451,184	92.9	41,984	94.9	8.44
Other	18,679	3.8	1045	2.4	8.56

Patient and health care system-related variables for patients without and with a diagnosis of sleep apnea.

SA = sleep apnea; STD = standardized difference; SD = standard deviation; THA = total hip arthroplasty; TKA = total knee arthroplasty; OA = osteoarthritis; RA = rheumatoid arthritis.

[a]The Deyo index was validated for the outcomes of complications, mortality, blood transfusion, use of hospital resources, and other adverse events on a cohort of surgical patients.[13] (Deyo Index = 1*Myocardial Infarction + 1*Cerebrovascular Disease + 1*Peripheral Vascular Disease + 2*Renal Disease + 1*COPD + 1*Diabetes + 2*Complicated Diabetes + 1*Dementia + 1*Rheumatoid Disease +1* Mild Liver Disease + 1*Severe Liver Disease + 6*AIDS + 1*Plegia + 1*Cancer).

[b]Variables met the standardized difference >10% threshold.

patients, individuals with SA were on average younger (SA: 63.4 ± 9.6 years vs non-SA: 66.2 ± 11.3 years, STD = 26.7%), more frequently male (53.9% vs 37.3%, STD = 33.63%), carried a higher overall Deyo comorbidity burden (1.00 ± 1.12 vs 0.59 ± 0.92, STD = 40.1%) and had a higher prevalence of most individual comorbidities (Table 1, Table 2).

Table 2. Prevalence of Comorbidities

Prevalence of comorbidities					
	No SA diagnosis		SA diagnosis		
Comorbidity	***N***	**%**	***N***	**%**	**STD (%)**
Myocardial infarction	17,069	3.5	2433	5.5	9.58
Cerebrovascular disease	1136	0.2	98	0.2	0.26
Peripheral vascular disease	8187	1.7	1057	2.4	4.98
Renal disease	243	0.1	23	0.1	0.09
COPD[a]	64,816	13.3	11,051	25.0	29.89
Diabetes[a]	79,444	16.4	12,980	29.3	31.30
Complicated diabetes[a]	4610	0.9	1108	2.5	11.96
Cancer	8556	1.8	782	1.8	0.05
Obesity[a]	75,644	15.6	18,708	42.3	61.65
Hypertension[a]	293,277	60.4	30,862	69.8	19.78
Complicated hypertension[a]	17,576	3.6	2764	6.2	12.16
Pulmonary hypertension[a]	2476	0.5	765	1.7	11.61

Prevalence of preexisting comorbidities for patients without and with diagnosis of sleep apnea.
SA = sleep apnea; STD = standardized difference; COPD = chronic obstructive pulmonary disease.
[a]Variables met the standardized difference >10% threshold.

Table 3. Incidence of Postoperative Complications and Resource Utilization

Incidence of postoperative complications and resource utilization (univariate analysis)						
	No SA diagnosis		SA diagnosis			
Event	***N***	**%**	***N***	**%**	**STD (%)**	***P***
Pulmonary embolism	1908	0.4	267	0.6	2.99	<0.0001
Deep venous thrombosis	2665	0.5	266	0.6	0.70	0.15
Cerebrovascular accident	560	0.1	46	0.1	0.34	0.50
Pulmonary complications	2672	0.6	839	1.9	12.27	<0.0001
Sepsis	697	0.1	91	0.2	1.49	0.0011
Cardiac complications (non-MI)	29,847	6.1	4110	9.3	11.81	<0.0001
Pneumonia	3987	0.8	591	1.3	4.99	<0.0001
All infectious complications	19,738	4.1	1899	4.3	1.15	0.02
Acute renal failure	6741	1.4	1245	2.8	9.96	<0.0001
Gastrointestinal complications	3571	0.7	507	1.1	4.26	<0.0001
Acute MI	1280	0.3	114	0.3	0.11	0.82
30-day mortality	716	0.1	85	0.2	0.79	<0.0001
ICU utilization	14,647	3.0	2713	6.1	14.96	<0.0001
Stepdown and telemetry use	26,847	5.5	4108	9.3	14.39	<0.0001
Mechanical ventilation	1622	0.3	2183	4.9	29.03	<0.0001
Noninvasive ventilation	400	0.1	1665	3.8	27.05	<0.0001
Transfusion	93,958	19.3	6394	14.5	13.07	<0.0001
Median length of stay	3 (IQR: 3–4) d		3 (IQR: 3–4) d		5.53	<0.0001
Mean length of stay	3.52 (SD = 1.96)		3.63 (SD = 1.96)			<0.0001
Median economic resource utilization	$15,005 [IQR:12,314–18,677]		$15,514 [IQR:12,760–19,336]		6.45	<0.0001
Mean economic resource utilization	$16,457 (SD = $9360)		$17,035 (SD = $8555)			<0.0001

The incidence of selected outcomes for patients without and with diagnosis of sleep apnea.
SA = sleep apnea; STD = standardized difference; IQR = interquartile range; MI = myocardial infarction.

Missing data were limited to the categories of anesthesia type, race, admission type, and payor type (28.7%, 19.4%, 0.3%, and 2.8%, respectively).

SA patients exhibited a higher incidence of major postoperative complications including pulmonary, cardiac (non-MI), and renal outcomes. Analysis of the various subtypes of pneumonia yielded a higher incidence of postprocedural aspiration pneumonia and/or Mendelson's syndrome (as defined by ICD-9 code 997.39) in the SA group, compared with the no SA group (0.9% vs 0.6%, $P < 0.0001$). SA patients more frequently used critical care, telemetry, and stepdown unit services, and more commonly received postoperative mechanical ventilation and noninvasive ventilatory support. SA patients received fewer postoperative blood transfusions compared with non-SA patients. Appendix 3 details the incidence of individual cardiac complications, which suggests that the higher incidence of atrial fibrillation among SA patients was responsible for the increased rates in this complication category. Median length of hospitalization and economic resource utilization was

Table 4. Results from the Logistic Regression Models–SA Diagnosis Versus Non-SA Diagnosis

Results from the logistic regression models–SA diagnosis versus Non-SA diagnosis

Outcome	Crude odds ratio (corrected 95% CI)[abc]	Adjusted odds ratio (corrected 95% CI)[ac]	Significant interaction term with SA (P^d)	c-statistic
Combined complications	1.53 (1.47–1.60)	1.47 (1.39–1.55)	None	0.69
Pulmonary complications	2.19 (2.00–2.40)	1.86 (1.65–2.09)	None	0.69
Cardiac complications	1.56 (1.48–1.65)	1.59 (1.48–1.71)	None	0.74
Mortality	1.27 (0.82–1.98)	1.27 (0.74–2.19)	None	0.74
Mechanical ventilation	11.94 (10.64–13.40)	See table 5	Complicated hypertension ($P < 0.0001$) COPD ($P < 0.0001$)	0.83
Noninvasive ventilation	37.13 (30.64–45.00)	See table 5	Complicated hypertension ($P < 0.0001$), COPD ($P < 0.0001$)	0.88
Blood product transfusion	0.71 (0.68–0.74)	0.88 (0.83–0.93)	None	0.67
ICU utilization	2.06 (1.92–2.21)	See table 5	Gender ($P = 0.0002$), year ($P = 0.0007$)	0.73
Telemetry/stepdown unit utilization	1.76 (1.66–1.86)	See table 5	Year ($P = 0.0008$), complicated hypertension ($P < 0.0001$), obesity ($P < 0.0001$)	0.68
Length of stay >75th percentile	1.09 (1.05–1.13)	See table 5	Obesity ($P = 0.0006$)	0.65
Utilization of economic resources >75th percentile	1.22 (1.18–1.26)	1.14 (1.09–1.19)	None	0.60

Multivariable regression for various outcomes. Present diagnosis of sleep apnea (SA) is the effect variable. Reference = no sleep apnea diagnosis.
ICU = intensive care unit; CI = confidence interval.
[a]All 95% CIs and the associated *P* values were both Bonferroni corrected for multiple comparisons
[b]All corrected *P* were <0.0001 except for mortality ($P > 0.99$).
[c]All corrected *P* were <0.0001 except for mortality ($P > 0.99$).
[d]*P* were raw *P* values from multivariate regressions and compared with threshold 0.05/11 = 0.004 to determine the statistical significance.

similar among groups. Table 3 lists postoperative complication and resource utilization rates.

Logistic Regression Analyses

Table 4 details the results of the univariable and multivariable logistic regression analysis. Table 5 details the effect of SA for the models with significant interaction modifications.

Postoperative Complication Outcomes

No significant interaction terms were found for the models analyzing outcomes of combined complications, pulmonary complications, cardiac complications, and mortality. A diagnosis of SA emerged as an independent risk factor for the outcome of combined complications, as well as pulmonary and cardiac complications separately, but not for mortality.

Hospital Resource Utilization Outcomes

Significant interaction terms were detected for the models assessing outcome of mechanical ventilation (e.g., complicated hypertension, COPD), noninvasive ventilation (e.g., complicated hypertension, COPD), utilization of critical care (e.g., gender, year), stepdown/telemetry services (e.g., year, complicated hypertension, obesity), and prolonged length of stay (e.g., obesity). None were found for the outcomes of the need for blood transfusion and increased economic resource. The details of ORs conditioned on the modifications are shown in Table 5, and the SA effect on outcomes will have to be interpreted in the context of these modifications. When considering interaction terms, SA was associated with increased odds for mechanical ventilation, noninvasive ventilatory support, utilization of intensive care unit, stepdown and telemetry services as well as prolonged length of stay and increased economic resources.

In the sensitivity analysis including "unknown" anesthesia as a separate category, the results were similar.

Model Diagnostics

The value inflation factors were all <10, indicating that no multicollinearity was present. The ranges of c-statistics were 0.7 to 0.9 except for the model evaluating increasing economic resource utilization (c = 0.6), indicating good to very good discrimination for most outcomes. The percentage of patients with multiple outcomes was 0.44% and 22.89% for postoperative complications and resource utilization outcomes, respectively. Among all outcomes, 26.54% of patients had at least 2 of any of the outcomes evaluated, indicating differences between outcome populations.

Sensitivity Analysis Based on Propensity Score Matching

Of 32,789 SA patients in the sample, 28,177 were successfully matched to non-SA patients. The propensity score-matched samples were well balanced (STD< 10%) between groups in terms of demographic variables and comorbidities (Appendices 4, 5). The common ORs were similar to the ORs found in the analysis with main effects only (Appendix 6).

DISCUSSION

In this study, we were able to show that SA was associated with higher rates and odds of postoperative complications, utilization of resources, and length of stay.

Table 5. Effect of SA Versus Non-SA from Logistic Regression Models with Significant Interaction Terms of SA Diagnosis Versus Non-SA Diagnosis

Effect of SA versus Non-SA from logistic regression models with significant interaction terms of SA Diagnosis versus Non-SA diagnosis					
Interaction terms[b]			**Adjusted OR (95% CI)[a]**	**Adjusted *P*[a]**	**c-statistic**
Mechanical ventilation					
Complicated hypertension = no	COPD = no		13.80 (11.53–16.52)	<0.0001	
	COPD = yes		8.01 (6.19–10.36)	< 0.0001	0.83
Complicated hypertension = yes	COPD = no		5.30 (3.62–7.74)	< 0.0001	
	COPD = yes		3.07 (2.04–4.64)	< 0.0001	
Noninvasive ventilation					
Complicated hypertension = no	COPD = no		46.12 (33.88–62.77)	< 0.0001	
	COPD = yes		16.20 (10.95–23.97)	< 0.0001	0.88
Complicated hypertension = yes	COPD = no		15.62 (8.53–28.60)	< 0.0001	
	COPD = yes		5.49 (2.92–10.30)	< 0.0001	
ICU utilization					
Male	2006		1.86 (1.49–2.30)	< 0.0001	
	2007		1.82 (1.49–2.23)	< 0.0001	
	2008		2.05 (1.70–2.48)	< 0.0001	
	2009		1.37 (1.13,1.67)	< 0.0001	
	2010		1.37 (1.09–1.72)	0.0005	0.73
Female	2006		2.28 (1.82–2.84)	< 0.0001	
	2007		2.23 (1.82–2.73)	< 0.0001	
	2008		2.52(2.09–3.04)	< 0.0001	
	2009		1.69 (1.38–2.05)	< 0.0001	
	2010		1.68 (1.34–2.11)	< 0.0001	
Telemetry/stepdown unit utilization					
Complicated hypertension = no	Obesity = no	2006	1.81 (1.47–2.23)	< 0.0001	
		2007	1.49 (1.24–1.78)	< 0.0001	
		2008	1.40 (1.19–1.65)	0.0584	
		2009	1.73 (1.52–1.96)	0.0213	
		2010	1.54 (1.33–1.78)	0.0268	
	Obesity = yes	2006	2.17 (1.73–2.72)	< 0.0001	
		2007	1.78 (1.47–2.17)	< 0.0001	
		2008	1.68 (1.41–2.00)	0.0689	
		2009	2.07 (1.79–2.39)	0.0262	
		2010	1.85 (1.58–2.16)	0.0309	0.68
Complicated hypertension = yes	Obesity = no	2006	1.25 (0.91–1.73)	> 0.99	
		2007	1.03 (0.76–1.39)	> 0.99	
		2008	0.97 (0.73–1.29)	0.1853	
		2009	1.19 (0.91–1.57)	0.17	
		2010	1.07 (0.80–1.41)	0.1773	
	Obesity = yes	2006	1.50 (1.08–2.08)	0.0047	
		2007	1.23 (0.91–1.67)	0.2089	
		2008	1.16 (0.87–1.55)	0.1901	
		2009	1.43 (1.08–1.89)	0.1731	
		2010	1.28 (0.96–1.69)	0.1801	
Increased length of hospitalization					
Obesity = no			1.12 (1.06–1.18)	< 0.0001	
Obesity = yes			1.23 (1.15–1.31)	< 0.0001	0.65

Multivariable regression for outcomes with significant interactions. Present diagnosis of sleep apnea (SA) is the effect variable. (Reference = no sleep apnea diagnosis).

COPD= chronic obstructive pulmonary disease.

[a]All 95% CIs and the associated *P* were both Bonferroni corrected for multiple comparisons.

[b]All interaction terms had $P < 0.001$.

We observed that SA was associated with a 47% increased odds for the combined outcome of postoperative major morbidity. Increased odds for adverse outcomes among SA patients have been described,[2–7] but information on a wide range of outcomes beyond pulmonary complications in the setting of orthopedic surgery remains rare. While the exact mechanisms by which SA confers increased odds for complications remains unknown, a number of abnormalities have been described among SA patients that may lower the clinically relevant injury threshold for various organ systems to exhibit signs of dysfunction. For example, SA is associated with higher baseline levels of systemic and pulmonary inflammation,[23] decreased pharyngeal sphincter function,[24] and increased

sensitivity to the respiratory-depressant effects of opioids.[25] These and other pathologic states may contribute to the increased susceptibility of SA patients to perioperative insults, such as transfusion and ventilator-related lung injury, and aspiration. However, it must be noted that not all our findings corroborate with available literature. For example, we did not find differences in the rates of cerebrovascular disease and complications between the 2 groups. Previous research has suggested that the presence of SA may indeed increase the risk for stroke,[26] without allowing for inferences to be made in the postoperative setting. A factor to be considered when interpreting our findings is the fact that only patients with a known diagnosis of SA are included in our cohort and that use of positive airway pressure therapy, which may reverse some of the pathophysiology predisposing to long-term adverse outcomes, may be more likely used in this population.

In addition, we identified lower rates of blood transfusions among SA patients in our study. Feasible explanations for this finding are not obvious but warrant further inquiry. One possibility includes higher starting hematocrit levels frequently found in SA patients.[27]

Recent literature has further suggested a lack of evidence for increased mortality among SA patients.[28,29] While speculative, an increase in vigilance among clinicians may indeed lead to better detection of complications in this patient group perceived to be at risk, thus allowing for interventions to avoid this extreme outcome despite higher complication rates.

In addition to the increased odds for adverse medical outcomes, we were able to show an effect of the presence of SA on increased resource utilization. The argument can be made that at least some of the increased utilization of services is not an indication of higher morbidity but reflects planned use of monitored settings and perioperative positive airway pressure equipment in an attempt to reduce complications. However, despite the recommendation by the American Society of Anesthesiologists task force on perioperative care of patients with obstructive sleep apnea that patients with SA be observed in a monitored setting postoperatively and treated with positive pressure ventilation in certain cases,[30] little data are available on the use of resources such as telemetry, stepdown, and intensive care units. If the utilization of these resources would have to be interpreted in this context, the conclusion to be drawn would point toward a surprisingly low use of perioperative monitoring and use of ventilatory assistance. Indeed, there remains a paucity of data regarding the adoption of guidelines for the perioperative care in current practice. Interestingly, a single published inquiry into the existence of perioperative policies among anesthesia departments in Canada concluded that only 28% had such provisions.[31] While lack of proof that these interventions lead to improved outcomes among SA patients may be 1 reason, the additional use of economic resources associated with implementation of these practices on a wider level certainly is a contributing factor. It is therefore not surprising that in our study SA was associated with higher odds for this outcome.

Our study is subject to a number of limitations. As a consequence of retrospective database analysis, clinically important covariates are not obtainable. However, a very large sample size provides access to outcomes as seen in actual practice. A further limitation is the reliance on ICD-9 coding for the diagnosis of SA. Thus, it is not possible to correlate the diagnosis with the severity of SA. This also applies to the severity of various other comorbidities. It is also almost certain that the true incidence of SA is higher than that reported here, as only patients with a preoperative diagnosis code for SA would have been entered. This potential misclassification may have lead to an underestimation of the effects of SA on outcomes. As mentioned previously, we were unable to determine whether the utilization of higher levels of care and noninvasive ventilation were the result of a complication and thus represented treatment or whether they were used in a prophylactic manner. The inability to determine causal relationships makes it impossible to study whether these interventions are capable of modifying outcomes in our sample. Thus, the value of these data lies in the estimation of the magnitude of utilization of these resources. Furthermore, because cause and effect or mechanisms of adverse events cannot be established from these data, we are unable to conclusively explain some of the findings. It is also likely that postoperative complications impact on the outcomes of mortality and resource utilization. However, the goal of this analysis was to study the impact of factors that are known preoperatively and may be considered before surgery commences. Finally, all comorbidities and complications are based on the ICD-9-CM coding system or billing codes (Appendix 1). Although rigorous quality checks are being performed by the vendor before release, coding errors or inconsistencies remain a possibility. A problem encountered for some outcomes, such as thromboembolic events for example, is the fact that there is no differential coding for an old versus new diagnosis, and therefore, we cannot conclusively determine whether such diagnoses were preexisting. Unfortunately, a present-on-admission variable, as introduced by many databases to facilitate this kind of interpretation, is not available for >70% of entries within our dataset, making it highly unreliable. However, there is no indication that this potential bias would affect one of the groups more than the other.

In conclusion, the preexisting comorbidity is associated with higher ORs of perioperative complications (adjusted OR: 1.47; CI, 1.39–1.55), utilization of economic resources (adjusted OR: 1.14; CI, 1.09–1.19) and prolonged length of stay (adjusted OR 1.12 for nonobese SA patients; CI, 1.06–1.18) among THA and TKA recipients. Despite a higher rate of advanced monitoring among SA patients, the overall utilization of stepdown, telemetry, or intensive care units was still <17%, at least partially putting into question the adoption of guidelines and perioperative protocols for the treatment of SA. The subject of outcomes among SA patients requires further study to identify patients at risk and determine ways to prevent complications using evidence-based and accountable approaches.

Appendix 1. Diagnosis Codes, Prevalence, and Percent of Total for Sleep Apnea Cohort

Sleep apnea diagnosis codes		
Diagnosis code	**Description**	**% of SA diagnoses[a]**
327.23	Obstructive sleep apnea (adult) (pediatric)	59.43
780.57	Unspecified sleep apnea	39.00
786.03	Apnea	0.60
780.51	Insomnia with sleep apnea, unspecified	0.35
780.53	Hypersomnia with sleep apnea, unspecified	0.24
327.24	Idiopathic sleep-related nonobstructive alveolar hypoventilation	0.17
327.26	Sleep-related hypoventilation/hypoxemia in conditions classifiable elsewhere	0.11
327.27	Central sleep apnea in conditions classified elsewhere	0.07
327.20	Organic sleep apnea, unspecified	0.02
327.21	Primary central sleep apnea	0.02

[a]Please note that percentages add up to >100% as a small fraction of patients carried >1 sleep apnea diagnosis.

Appendix 3. The Incidence of Individual Cardiac Outcomes for Patients Without and With Diagnosis of Sleep Apnea

Incidence of selected cardiac complications/outcomes					
	No SA diagnosis		**SA diagnosis**		
Event	***N***	**%**	***N***	**%**	**STD (%)**
Conduction disorders	10,433	2.15	1155	2.61	3.04
Atrial fibrillation and flutter	27,357	5.63	3854	8.71	11.94
Ventricular fibrillation and flutter	80	0.02	10	0.02	0.50
Cardiac arrest	269	0.06	57	0.13	2.44
Functional disturbances after cardiac surgery	5	0.001	0	0	0.45
Cardiogenic shock	96	0.02	13	0.03	0.58
Cardiac complications not elsewhere classified	3849	0.79	419	0.95	1.67

SA = sleep apnea; STD = standardized difference.

Appendix 2. International Classification of Diseases-9th Revision-Clinical Modification Diagnosis Codes for Major Complications and Comorbidities

Complications	
Event	**ICD-9-CM diagnosis codes**
Pulmonary embolism	415.1
Deep vein thrombosis	451.1, 451.2, 451.8, 451.9, 453.2, 453.4, 453.8, 453.9
Cerebrovascular event	433.01, 433.11, 433.21,433.31, 433.81, 433.91, 434.01, 434.11, 434.91, 997.02
Pulmonary compromise	514, 518.4, 518.5, 518.81, 518.82
Sepsis	038, 038.0, 038.1x, 038.2, 038.3, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9, 790.
Cardiac (nonmyocardial infarction)	426.0, 427.41, 427.42, 429.4, 997.1, 427.4, 427.3, 427.31, 427.32
Acute myocardial infarction	410.XX
Pneumonia	481, 482.00–482.99, 483,485, 486, 507.0, 997.31, 997.39
All infections	590.1, 590.10, 590.11,590.8590.81, 590.2, 590.9, 595.0, 595.9, 599.0, 567.0 480, 480.0, 480.1, 480.2, 480.8, 480.9, 481, 482.0, 482.1, 482.2, 482.3, 482.30, 482.31, 482.32, 482.39, 482.4, 482.40, 482.41, 482.42, 482.49, 482.5, 482.8, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 483, 483.0, 483.1, 483.8, 485, 486, 487, 997.31, 038, 038.0, 038.1, 038.10, 038.11, 038.12, 038.19, 038.2, 038.3, 038.4, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9, 790.7, 998.0, 958.4, 998.5, 998.59, 998.89, 785, 785.50, 785.52, 785.59, 999.39, 999.31, 999.3
Acute renal failure	584, 584.5, 584.9
Gastrointestinal complication	997.4, 560.1, 560.81, 560.9, 536.2, 537.3
Mechanical ventilation	93.90, 96.7, 96.70, 96.71, 96.72, (CPT Code) 94002, 94656, 94003, 94657
Blood transfusion	99.0, 99.01, 99.02, 99.03, 99.04, 99.05, 99.06, 99.07, 99.08, 99.09, (HCPCS codes) P9010, P9011, P9012, P9016, P9017, P9019, P9020, P9021, P9022, P9023, P9031, P9032, P9033, P9034, P9035, P9036, P9037, P9038, P9039, P9040
Noninvasive ventilation	93.90, 93.91
Comorbidities	
Event	ICD-9-CM diagnosis codes
Myocardial infarction	412.XX
Peripheral vascular disease	441.X, 785.4, V43.4, 38.48
Cerebrovascular disease	430.X-438.X
Dementia	290.XX
COPD	490, 491.X, 492.X, 493.X, 495.X, 500–505, 506.4
Rheumatic disease	710.0, 710.1, 710.4, 714.0, 714.1, 714.2, 714.81, 725
Peptic ulcer disease	531–534
Mild liver disease	571.2, 571.4X, not 571.42, 571.5, 571.6
Diabetes	250.0, 250.1, 250.2, 250.3, 250.7
Diabetes with complications	250.4, 250.6
Hemiplegia or paraplegia	344.1, 342.X
Renal disease	582.X, 583.X, 585, 586, 588
Malignancy	140–239.99
Moderate or severe liver disease	456.0–456.29, 572.2–572.8
Aids	042
Hypertension	401.1, 401.9, 642.0X
Complicated hypertension	401.0, 402.X-405.X, 642.1, 642.2, 642.7, 642.9
Pulmonary hypertension	416.X
Obesity	278.0, 278.00, 278.01, 649.1, V85.3, V85.4, V85.54, 792.91
Sleep apnea	786.03, 780.51, 780.53, 780.57, 327.20–327.27, 327.29

Appendix 4. Patient and Healthcare System-Related Characteristics Based on the Propensity Scoring Matched Samples

Patient and healthcare system-related demographics (based on propensity matching)

	No SA diagnosis		SA diagnosis		STD (%)
	N	%	*N*	%	
Total	84,531	75	28,177	25	
Average age (year) (SD)	63.63 (10.56)		63.70 (9.56)		0.63
Gender					
Female	13,203	15.6	4071	14.5	2.16
Male	71,328	84.4	24,106	85.6	
Race					
White	68,623	81.2	22,331	79.3	4.84
Black	5834	6.9	2250	8.00	4.13
Hispanic	1321	1.6	498	1.8	1.60
Other	8753	10.4	3098	11.00	2.07
Average Deyo index[a] (SD)	0.82 (1.04)		0.87 (1.05)		4.36
Deyo index category					
0	45,444	53.8	14,452	51.3	4.95
1	16,042	19.00	5659	20.1	2.79
2	16,588	19.6	5708	20.3	1.59
≥ 3	6457	7.6	2358	8.4	2.69
Type of procedure					
THA	71,328	84.4	24,106	85.6	2.46
TKA	13,203	15.6	4071	14.5	
Type of anesthesia					
N	8342	9.9	2874	10.2	1.10
G	64,747	76.6	21,397	75.9	1.55
N + G	11,442	13.5	3906	13.9	0.95
Year of procedure					
2006	11,886	14.1	4064	14.4	1.04
2007	15,122	17.9	5103	18.1	0.58
2008	17,690	20.9	5913	21.00	0.14
2009	22,472	26.6	7341	26.1	1.21
2010	17,361	20.5	5756	20.4	0.27
Admission type					
Emergent	1867	2.2	694	2.5	1.68
Urgent	3095	3.7	1175	4.2	2.62
Elective	79,321	93.8	26,253	93.2	2.70
Other	248	0.3	55	0.2	1.99
Indication					
RA	2151	2.5	829	2.9	2.43
OA	80,487	95.2	26,588	94.4	3.85
Other	1893	2.2	760	2.7	2.95
Hospital size (beds)					
< 299	25,619	30.3	8610	30.6	0.54
300–499	34,874	41.3	11,602	41.2	0.16
≥ 500	24,038	28.4	7965	28.3	0.38
Hospital location					
Rural	71,328	84.4	24,106	85.6	2.48
Urban	13,203	15.7	4071	14.5	
Hospital teaching status					
Nonteaching	71,328	84.4	24,106	85.6	1.25
Teaching	13,203	15.6	4071	14.5	

THA = total hip arthroplasty; TKA = total knee arthroplasty; OA = osteoarthritis; RA = rheumatoid arthritis.

[a]The Deyo index was validated for the outcomes of complications, mortality, blood transfusion, use of hospital resources, and other adverse events on a cohort of surgical patients.[13]

Appendix 5. Comorbidity Incidence Based Propensity Scoring Matched Samples

Incidence of Comorbid Disease (based on propensity matching)

	No SA diagnosis		SA diagnosis		STD
Comorbidity	*N*	%	*N*	%	(%)
MI	3611	4.3	1386	4.9	3.09
Cerebrovascular disease	186	0.2	68	0.2	0.44
Peripherovascular disease	1580	1.9	595	2.1	1.74
Dementia	57	0.1	21	0.1	0.27
Renal disease	35	<0.1	15	0.1	0.54
Copd	17,087	20.2	5983	21.2	2.52
Diabetes	20,608	24.4	7140	25.3	2.22
Complicated diabetes	1366	1.6	490	1.7	0.96
Cancer	1354	1.6	500	1.8	1.34
Hypertension	58,936	69.7	19,330	68.6	2.42
Complicated hypertension	4181	5.0	1498	5.3	1.68
Pulmonary hypertension	695	0.8	243	0.9	0.44
Obesity	27,886	33.0	9561	33.9	2.00

SA = sleep apnea; STD = standardized difference; COPD = chronic obstructive pulmonary disease.

Appendix 6. Results Comparisons Between the Propensity Score Method-Based Sensitivity Analysis and Multivariable Logistic Regressions with Main Effects Only

	Propensity score-matched samples	Multivariable logistic regression with main effects only
Outcome	Common odds ratio (corrected 95% CI)[ab]	Adjusted odds ratio (corrected 95% CI)[ac]
Combined complications	1.45 (1.37–1.53)	1.47 (1.40–1.54)
Pulmonary complications	1.90 (1.68–2.15)	1.86 (1.68–2.06)
Cardiac complications	1.54 (1.43–1.66)	1.59 (1.49–1.69)
Mortality	1.20 (0.69–2.07)	1.27 (0.80–2.04)
Mechanical ventilation	10.84 (8.97–13.09)	10.26 (9.01–11.69)
Noninvasive ventilation	27.78 (20.02–38.56)	29.04 (23.55–35.80)
Blood product transfusion	0.91 (0.86–0.96)	0.88 (0.83–0.92)
ICU utilization	1.85 (1.69–2.03)	1.85 (1.71–2.00)
Telemetry/ stepdown unit utilization	1.69 (1.57–1.82)	1.64 (1.55–1.75)
Length of stay >75th percentile	1.18 (1.13–1.23)	1.16 (1.12–1.20)
Utilization of economic resources >75th percentile	1.13 (1.11–1.22)	1.13 (1.09–1.18)

Based on the matched sample, the effect of SA on outcomes was tested for significance using the Cochran-Mantel-Haenszel test common odds ratio (COR) Bonferroni-corrected 95% confidence intervals and *P* are reported.

[a]All 95% CIs and the associated *P* were both Bonferroni corrected for multiple comparisons.

[b]All corrected *P* were <0.0001 except for mortality ($P > 0.99$).

[c]All corrected *P* were <0.0001 except for mortality ($P = 0.43$).

DISCLOSURES

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Attestation: Stavros G. Memtsoudis has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
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REFERENCES

1. Finkel KJ, Searleman AC, Tymkew H, Tanaka CY, Saager L, Safer-Zadeh E, Bottros M, Selvidge JA, Jacobsohn E, Pulley D, Duntley S, Becker C, Avidan MS. Prevalence of undiagnosed obstructive sleep apnea among adult surgical patients in an academic medical center. Sleep Med 2009;10:753–8
2. Memtsoudis S, Liu SS, Ma Y, Chiu YL, Walz JM, Gaber-Baylis LK, Mazumdar M. Perioperative pulmonary outcomes in patients with sleep apnea after noncardiac surgery. Anesth Analg 2011;112:113–21
3. Gupta RM, Parvizi J, Hanssen AD, Gay PC. Postoperative complications in patients with obstructive sleep apnea syndrome undergoing hip or knee replacement: a case-control study. Mayo Clin Proc 2001;76:897–905
4. Liao P, Yegneswaran B, Vairavanathan S, Zilberman P, Chung F. Postoperative complications in patients with obstructive sleep apnea: a retrospective matched cohort study. Can J Anesth 2009;56:819–28
5. Chung F, Yegneswaran B, Liao P, Chung SA, Vairavanathan S, Islam S, Khajehdehi A, Shapiro CM. Validation of the Berlin questionnaire and American Society of Anesthesiologists checklist as screening tools for obstructive sleep apnea in surgical patients. Anesthesiology 2008;108:822–30
6. Gali B, Whalen FX, Schroeder DR, Gay PC, Plevak DJ. Identification of patients at risk for postoperative respiratory complications using a preoperative obstructive sleep apnea screening tool and postanesthesia care assessment. Anesthesiology 2009;110:869–77
7. Kaw R, Pasupuleti V, Walker E, Ramaswamy A, Foldvary-Schafer N. Postoperative complications in patients with obstructive sleep apnea. Chest 2012;141:436–41
8. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89:780–5
9. Premier I. Premier Perspective Database. www.premierinc.com/quality-safety/tools-services /prs/data/perspective.jsp. Accessed May 1, 2013
10. US Department of Health and Human Services. OCR Privacy Brief: Summary of the HIPAA Privacy Rule. (Office for Civil Rights HCA, ed.). Washington, DC: Office for Civil Rights, HIPAA Compliance Assistance, 2003
11. Stundner O, Chiu YL, Sun X, Mazumdar M, Fleischut P, Poultsides L, Gerner P, Fritsch G, Memtsoudis SG. Comparative perioperative outcomes associated with neuraxial versus general anesthesia for simultaneous bilateral total knee arthroplasty. Reg Anesth Pain Med 2012;37:638–44
12. Memtsoudis SG, Sun X, Chiu YL, Nurok M, Stundner O, Pastores SM, Mazumdar M. Utilization of critical care services among patients undergoing total hip and knee arthroplasty: epidemiology and risk factors. Anesthesiology 2012;117:107–16
13. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol 1992;45:613–9
14. Austin PC. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. Stat Med 2009;28:3083–107
15. Normand ST, Landrum MB, Guadagnoli E, Ayanian JZ, Ryan TJ, Cleary PD, McNeil BJ. Validating recommendations for coronary angiography following acute myocardial infarction in the elderly: a matched analysis using propensity scores. J Clin Epidemiol 2001;54:387–98
16. Mickey RM, Greenland S. The impact of confounder selection criteria on effect estimation. Am J Epidemiol 1989;129:125–37
17. Bland JM, Altman DG. Multiple significance tests: the Bonferroni method. BMJ 1995;310:170
18. Hosmer DW, Lemeshow SA. Goodness-of-fit test for the multiple logistic regression model. Commun Stat 1980;A10:1043–69
19. Pepe MS. The Statistical Evaluation of Medical Tests for Classification and Precision. Oxford, UK: Oxford University Press, 2003:66–94
20. Merkow RP, Hall BL, Cohen ME, Dimick JB, Wang E, Chow WB, Ko CY, Bilimoria KY. Relevance of the c-statistic when evaluating risk-adjustment models in surgery. J Am Coll Surg 2012;214:822–30
21. Ury HK. Efficiency of case-control studies with multiple controls per case: continuous or dichotomous data. Biometrics 1975;31:643–9
22. Lori S. Performing a 1:N Case-Control Match on Propensity Score. SAS Proceedings 2010

23. Carpagnano GE, Lacedonia D, Foschino-Barbaro MP. Non-invasive study of airways inflammation in sleep apnea patients. Sleep Med Rev 2011;15:317–26
24. Sabaté JM, Jouët P, Merrouche M, Pouzoulet J, Maillard D, Harnois F, Msika S, Coffin B. Gastroesophageal reflux in patients with morbid obesity: a role of obstructive sleep apnea syndrome? Obes Surg 2008;18:1479–84
25. Blake DW, Chia PH, Donnan G, Williams DL. Preoperative assessment for obstructive sleep apnoea and the prediction of postoperative respiratory obstruction and hypoxaemia. Anesth Intensive Care 2008;36:379–84
26. Yaggi HK, Concato J, Kernan WN, Lichtman JH, Brass LM, Mohsenin V. Obstructive sleep apnea as a risk factor for stroke and death. N Engl J Med 2005;353:2034–41
27. Choi JB, Loredo JS, Norman D, Mills PJ, Ancoli-Israel S, Ziegler MG, Dimsdale JE. Does obstructive sleep apnea increase hematocrit? Sleep Breath 2006;10:155–60
28. Lockhart EM, Willingham MD, Abdallah AB, Helsten DL, Bedair BA, Thomas J, Duntley S, Avidan MS. Obstructive sleep apnea screening and postoperative mortality in a large surgical cohort. Sleep Med 2013;14:407–15
29. Mokhlesi B, Hovda MD, Vekhter B, Arora VM, Chung F, Meltzer DO. Sleep-disordered breathing and postoperative outcomes after elective surgery: analysis of the nationwide inpatient sample. Chest 2013;144:903–14
30. Gross JB, Bachenberg KL, Benumof JL, Caplan RA, Connis RT, Coté CJ, Nickinovich DG, Prachand V, Ward DS, Weaver EM, Ydens L, Yu S; American Society of Anesthesiologists Task Force on Perioperative Management. Practice guidelines for the perioperative management of patients with obstructive sleep apnea: a report by the American Society of Anesthesiologists Task Force on Perioperative Management of patients with obstructive sleep apnea. Anesthesiology 2006;104:1081–93; quiz 1117–8
31. Turner K, VanDenkerkhof E, Lam M, Mackillop W. Perioperative care of patients with obstructive sleep apnea-a survey of Canadian anesthesiologists. Can J Anesth 2006;53: 299–304