Utilization of Critical Care Services among Patients Undergoing Total Hip and Knee Arthroplasty

Epidemiology and Risk Factors

Stavros G. Memtsoudis, M.D., Ph.D., F.C.C.P.,* Xuming Sun, M.S.,†
Ya-Lin Chiu, M.S.,† Michael Nurok, M.B., Ch.B., Ph.D.,‡ Ottokar Stundner, M.D.,§
Stephen M. Pastores, M.D., F.A.C.P., F.C.C.P., F.C.C.M.,‖ Madhu Mazumdar, Ph.D., M.A., M.S.#

ABSTRACT

Background: A paucity of data exist on the use of critical care services (CCS) among hip and knee arthroplasty patients. The authors sought to identify the incidence and risk factors for the use of CCS among these patients and compare the characteristics and outcomes of patients who require CCS to those who do not.

Methods: The authors analyzed hospital discharge data of patients who underwent primary hip or knee arthroplasty in approximately 400 United States hospitals between 2006 and 2010. Patient and healthcare system-related demographics for admitted patients requiring CCS were compared with those who did not. Differences in out-

What We Already Know about This Topic

- The number of total knee and hip arthroplasties performed has been steadily increasing. A paucity of data exist on the use of critical care services (CCS) among these patients.

What This Article Tells Us That Is New

- Among a very large cohort (n = 528,495) of patients undergoing total joint arthroplasty, 3% required CCS. Risk factors for requiring CCS are advanced age, use of general anesthesia, and occurrence of postoperative cardiopulmonary complications. CCS patients had higher mortality rates (2.5 *vs* 0.1%), longer hospital stays, higher costs, and were less likely to be discharged home (40 *vs*. 63%).

comes, including mortality, complications, disposition status, and hospital charges, were analyzed. Regression analysis was performed to identify risk factors for requiring CCS.

Results: A total of 528,495 patients underwent primary total hip (n = 172,467, 33%) and knee arthroplasty (n = 356,028, 67%). Of these, 3% required CCS. On average, CCS patients were older and had a higher comorbidity burden than did patients not requiring CCS. CCS patients experienced more complications, had longer hospital stays and higher costs, and were less likely to be discharged home than were non-CCS patients.

Risk factors with increased odds for requiring CCS included advanced age, use of general *versus* neuraxial anesthesia, and the presence of postoperative cardiopulmonary complications.

Conclusions: Approximately 1 of 30 patients undergoing total joint arthroplasty requires CCS. Given the large number of these procedures performed annually, anesthesiolo-

◇ This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 9A.

gists, orthopedic surgeons, critical care physicians, and administrators should be aware of the attendant risks this population represents and allocate resources accordingly.

THE number of total hip and knee arthroplasties performed annually in the United States has been steadily increasing and is expected to surpass 4 million by the year 2030.[1] Patients undergoing these procedures may share many characteristics of the general perioperative population, but they represent a group with a set of unique perioperative problems that require the attention of critical care practitioners.[2] In addition, evidence suggests a higher rate of perioperative complications resulting from increases in comorbidity burden among the predominantly elderly population undergoing these procedures.[3,4] These patient characteristics are likely to translate into a significant increase in the use of hospital resources. Using various national databases, we previously identified risk factors for mortality and complications among orthopedic patients undergoing total knee arthroplasty.[5,6] However, to date, limited data exist on the impact of the use of critical care services (CCS) among patients undergoing total hip and knee arthroplasties. With ever-increasing demands on the healthcare system, it is vital to promote the specialized training of physicians in the care of orthopedic patients and their needs, the appropriate allocation of resources and administrative planning, and the identification of risk factors that allow clinicians to pinpoint patients needing CCS. The purpose of this study was to analyze the epidemiology and identify risk factors for the use of CCS among patients who undergo total hip and knee arthroplasty using a nationwide database. We hypothesized that the demand for CCS after these procedures is significant and that a number of risk factors for using CCS could be identified.

Materials and Methods

Data Source

Annual data files from 2006 to 2010 were obtained from Premier Perspective (Premier Inc., Charlotte, NC), an administrative database developed for the measurement of health care use and quality. Information was obtained on all discharges from approximately 400 acute care hospitals located in all United States regions.** Data included are compliant with the Health Insurance Portability and Accountability Act[7]; thus, this project was exempt from requirements for consent by the Institutional Review Board at the Hospital for Special Surgery, New York, New York. Before making it available to researchers, data in this database undergo rigorous quality assurance and data validation checks. Confidence in the validity of information provided by Premier Inc. is evident in the use of this database to answer a wide variety of healthcare-related questions across a number of medical specialties.[8-10]

** Premier Inc. Premier Perspective Database. http://www.premierinc.com/quality-safety/tools-services/prs/data/perspective.jsp. Accessed November 7, 2011.

Study Sample

The study sample consisted of all data in the Premier database for each year between 2006 and 2010. Patient records with an International Classification of Diseases-ninth revision-Clinical Modification (ICD-9-CM) procedure code for primary lower extremity joint arthroplasty were identified using codes for primary hip (81.51) and knee (81.54) replacement. Admissions during which CCS were delivered were identified by the presence of appropriate billing records (*i.e.*, utilization of critical care facilities and provision of critical care). We compared the characteristics of patients requiring CCS with those who did not require CCS. Patient- and health-care system-related characteristics between the two groups were analyzed. Demographic data included age, sex, race (white, black, Hispanic, other), and admission type (emergent, required immediate medical intervention as a result of severe, life-threatening or potentially disabling conditions; elective, condition permitted adequate time to schedule intervention; urgent, required immediate attention for the care and treatment to first available accommodation; admitted from trauma center [*i.e.*, government licensed or designated hospital] or verified by American College of Surgeons and involving a trauma activation; and others). Healthcare system-related variables included hospital size (bed size of less than 299, 300–499, more than 500), geographic location (rural, urban [*i.e.*, location in a metropolitan statistical area]), and teaching status (teaching, nonteaching). The prevalence of comorbidities and overall comorbidity burden was assessed using the method described by Deyo *et al.*[11] In addition, because obesity is not considered in the Deyo index, we included this diagnosis in our analysis (using appropriate ICD-9 codes) because of the important role it may play in perioperative outcomes.[12] Procedure-specific variables included the type of surgery (total knee or hip arthroplasty), type of anesthesia (general, neuraxial [spinal and/or epidural], general/neuraxial, other [including peripheral nerve blocks/catheters, monitored anesthesia care], and missing), surgical pathology (osteoarthritis, rheumatoid arthritis, trauma, and other [infectious, internal derangements]), and comorbidities based on ICD-9-CM diagnosis codes or billing records.

For each group, the proportions of patients experiencing major complications were computed by identifying cases that had ICD-9-CM diagnosis codes listed consistent with such diagnosis (appendix). The complications analyzed included postoperative cerebral infarction, pulmonary compromise, sepsis, shock, acute myocardial infarction, cardiac complications (except myocardial infarction), pneumonia, pulmonary embolism, acute renal failure, gastrointestinal complications, hemorrhage, and wound complications. The incidence of multiple complications was also computed by group. In-hospital and 30-day mortality rates were determined. These two outcome variables are provided in the database and thus were included in the analysis. In addition, the incidences of blood product transfusion and mechanical

ventilation were recorded. Differences in length of hospital stay, disposition status (home [discharge to home or self-care, routine discharge] *versus* transfer to other facility) and hospital charges were analyzed. Variable definitions for discharge status were adopted from the Centers for Medicare and Medicaid Services (Baltimore, MD) manual, and details can be found online.††

Statistical Analysis

The primary endpoint of our analysis was the use of CCS. All statistical analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC). The weighting procedure developed by Centers for Medicare and Medicaid Services and made available by Premier was used to derive nationally representative estimates from the available data. This scheme is updated annually to allow accurately for the projection of data. Missing data were minimal (less than 0.4%) and affected only the weighting variable. To facilitate analysis of weighted data, SAS procedures SURVEYMEANS, SURVEYFREQ, SURVEYREG, and SURVEYLOGISTIC were used for descriptive analyses and final modeling efforts. In the descriptive univariate analysis, frequencies and percentages were shown for categorical variables; means (standard errors) or medians (interquartile ranges) were shown for categorical variables, as appropriate. Chi-square test or two-sample t test was performed to evaluate the association of two categorical variables or a continuous variable between two groups, respectively.

Multiple multivariate regression models were created to identify predictors for requirement of CCS (outcome). The goal of the first model was to identify if demographic variables were predictors for CCS. Variables included in the first model were patient, healthcare system-related, and procedure-specific demographics, as described. In addition, the average comorbidity index and the year of discharge were added to account for comorbidity burden and temporal changes. In the second model, the average comorbidity index was substituted by its component comorbidities and obesity to identify if specific diseases were associated with CCS. In the third model, postoperative complications were entered to assess their impact on CCS use.

For building a parsimonious model with strong predictive covariates only, we took the following steps[13]: First, clinical judgment and significance at a P value at a 15% level in the univariate analysis were used to choose variables for the process of multivariable modeling. This cutoff (as supposed to $P \leq 0.05$) was chosen according to recommendations in the literature. Second, additional variable selection and internal validation of the predictive performance of the model was achieved through a two-step, nonparametric bootstrapping process.[14] In the bootstrap procedure, which has been rec-

ommended as a method of internal validation,[15] the original set of data of size N becomes a parent population from which the whole samples are randomly drawn with replacement. In the first step of internal validation, the bootstrapping technique was used for variable selection. One hundred bootstrap samples were created, and a stepwise procedure was applied to each sample using a forward selection method (with a selection entry level of 0.20) by using the LOGISTIC procedure because SURVEYLOGISTIC did not allow for a forward selection procedure. From this analysis, we calculated the percentage of samples for which each variable was included in the model from the 100 samples. For variables that failed the 80% cutoff of being included in the model from the 100 samples, if the frequency of pairwise combinations of being included in the model from the 100 samples was greater than 90%, we included the one with the largest frequency in the model. Finally, the model was run using the SURVEYLOGISTIC procedure with the variables included above to obtain the appropriate estimates of the variance for the weighted data while keeping variables with a P value <0.05 in the model.

All P values reported were from two-tailed tests. The conventional threshold of statistical significance (*i.e.*, P value <0.05) was used to determine significance of variables, but 95% confidence intervals (CI) were reported to enable readers to interpret the significance of the findings in light of the potential undue effect a very large sample size might have on the P values. Multicollinearity was evaluated by the value inflation factor. The conventional criterion of absence of multicollinearity (*i.e.*, value inflation factor less than 10) was used. The final models were reported with the measure of model calibration, the Hosmer-Lemeshow (H-L) test statistic,[16] and the measure of model discrimination, the c-statistic.[17] C-statistic values between 0.7 and 0.8 are considered indicative of acceptable discrimination.[13] The H-L test statistic evaluates whether a logistic regression model is calibrated adequately so that the probability predictions from the model reflect the true occurrence of events in the data. Although nonsignificant P values for this test are considered indicative of a well-calibrated model, caution needs to be taken when interpreting significant P values for the H-L test statistic in the setting of large sample size studies.[18] In this context and in application to data in the critical care setting, it has been suggested that models with a significant H-L test statistic should not be viewed as suspect of bad fit or not useful.[18]

Results

During the 5-yr study period (2006–2010), 528,495 patients underwent total hip or knee arthroplasties. This represents an estimated 4,440,974 procedures performed in the United States during this time frame (table 1). Of these, approximately 3% required CCS. Patients requiring CCS were on average older and predominantly male. Black and Hispanic patients received CCS less frequently than did

†† Department of Health and Human Services (DHHS). Publication 100-04 Medicare Claims Processing (Transmittal 171). https://www.cms.gov/transmittals/downloads/R1718CP.pdf. Accessed February 9, 2012.

Table 1. Patient, Healthcare System-related and Procedure-related Characteristics

—	No CCS	CCS	P Value
N	511,238	17,257	
Weighted N	4,306,727	134,247	
%	97	3	
Comorbidity burden			
Deyo Index, median (IQ 25–75)	0 (0–0.74)	0.5 (0–1.8)	<0.001
Deyo Index Category, N (%)			
0	279,108 (55)	6,564 (36)	<0.001
1	138,319 (27)	4,595 (27)	
2	51,824 (10)	2,522 (15)	
3	41,987 (8)	3,576 (22)	
Age			
Average age, yr (SE)	66 (0.02)	69 (0.13)	<0.001
Age category, N (%)			
<45	15,367 (2.9)	417 (2.1)	<0.001
45–54	65,452 (13)	1,786 (9)	
55–64	143,683 (28)	3,981 (22)	
65–74	162,756 (32)	5,124 (30)	
>75	123,980 (25)	5,949 (37)	
Sex, N (%)			
Female	313,765 (61)	10111 (58)	<0.001
Male	197,473 (39)	7,146 (42)	
Race, N (%)			
White	379,523 (72)	13625 (73)	<0.001
Black	35,281 (6)	881 (5)	
Hispanic	11,673 (2.7)	260 (1.9)	
Other	84,761 (19)	2,491 (20)	
Admission type, N (%)			
Emergent	11,181 (2.3)	1,211 (9)	<0.001
Urgent	20,234 (3.8)	770 (4.9)	
Elective	478,074 (93)	15,217 (86)	
Trauma center	422 (0.1)	33 (0.2)	
Other	1,327 (0.3)	26 (0.2)	
Hospital size (Beds), N (%)			
<299	165,318 (36)	5,324 (40)	<0.001
300–499	198,629 (42)	8,890 (46)	
>500	147,291 (21)	3,043 (14)	
Hospital location, N (%)			
Rural	49,721 (4.6)	1,677 (5.7)	<0.001
Urban	461,517 (95)	15,580 (94)	
Hospital teaching status, N (%)			
Nonteaching	303,577 (78)	8,133 (68)	<0.001
Teaching	207,661 (22)	9,124 (32)	
Procedure type, N (%)			
THA	165,710 (32)	6,757 (40)	<0.001
TKA	345,528 (68)	10,500 (60)	
Surgical pathology, N (%)			
Rheumatoid arthritis	16,589 (3.2)	566 (3.3)	0.63
Osteoarthritic	490,450 (96)	15,685 (91)	<0.001
Infectious/Internal derangements	4,118 (0.8)	136 (0.7)	0.0384
Trauma	14,444 (2.8)	1,913 (12)	<0.001
Number of diagnoses, N (%)			
0	11,895 (2.3)	517 (2.8)	<0.001
1	468,383 (92)	14,628 (85)	
2	29,837 (6)	1,959 (12)	
3	1,096 (0.2)	150 (0.9)	
≥4	27 (0.01)	*	
Anesthesia type, N (%)			
General	281,290 (53)	11,514 (62)	<0.001
Neuraxial	39,347 (8)	689 (5)	
Genera/Neuraxial	48,367 (10)	1,029 (7)	
Other	8,189 (1.1)	81 (0.4)	
Missing	134,045 (28)	3,944 (26)	

Patient, healthcare system-related, and procedure-related variables for patients requiring and not requiring critical care services (CCS) after hip and knee arthroplasty.

* Less than N = 10.

IQ 25–75 = interquartiles 25–75%; SE = standard error; THA = total hip arthroplasty; TKA = total knee arthroplasty.
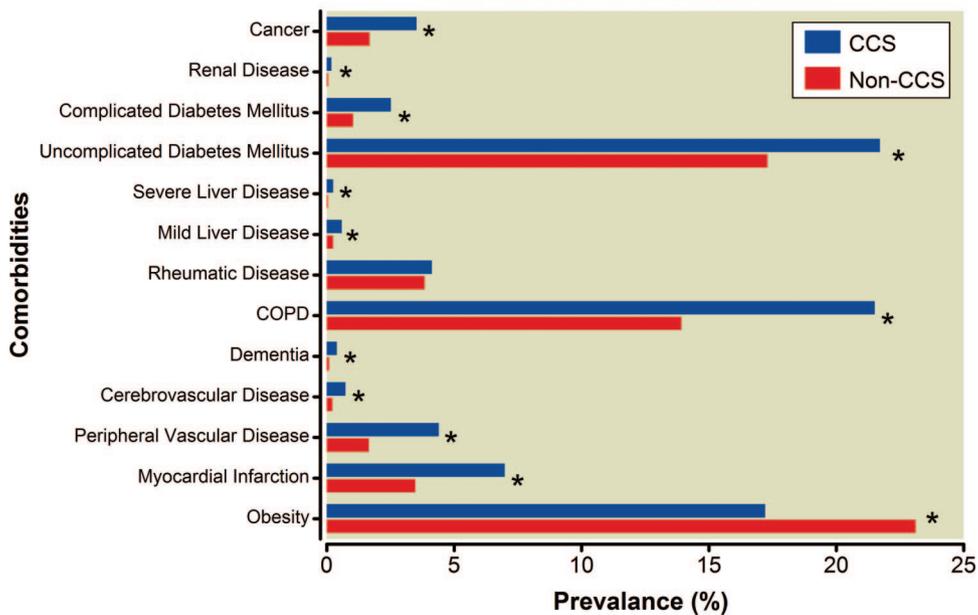
Fig. 1. The prevalence of comorbidities among patients requiring and not requiring critical care services (CCS) after hip and knee arthroplasty. For all comparisons, $P < 0.001$, except for rheumatic disease, for which $P = 0.0972$. *$P < 0.001$. COPD = chronic obstructive pulmonary disease.

white patients and those of other races. Higher rates of CCS were used among patients after nonelective admission, in hospitals of smaller size, and in rural areas and teaching settings (table 1). Patients using CCS were affected more frequently by all individual comorbidities studied, except for obesity (fig. 1), which was also reflected by a higher overall comorbidity index (table 1). Those with nonosteoarthritic surgical indication and receiving general anesthesia compared with neuraxial anesthesia also required CCS more frequently (table 1). Patients requiring CCS had higher in-hospital and 30-day mortality rates, and received mechanical ventilation and blood product transfusions more frequently (table 2) than did non-CCS patients. The median length of hospital stay was 1 day longer for patients requiring CCS than for non-CCS patients (4 [3–7] vs. 3 [2–3] days, $P < 0.001$), whereas the rate of discharge to home compared with

Table 2. Incidence of Selected Outcomes after Hip and Knee Arthroplasty

—	No CCS	CCS	P Value
In-hospital death, N (%)	243 (0.1)	340 (2.2)	<0.001
30-day mortality, N (%)	408 (0.1)	390 (2.5)	<0.001
Discharge to home, N (%)	321,618 (63)	7,466 (40)	<0.001
Mechanical ventilation, N (%)	2,098 (0.4)	1,698 (11)	<0.001
Blood product transfusion, N (%)	95,220 (19)	4,958 (33)	<0.001

CCS = critical care services.

other facilities was significantly lower (40% vs. 63%, $P < 0.001$) (table 2). The median patient charges were significantly higher for CCS than non-CCS patients ($51,673 [$35,524,79,432] vs. $41,251 [$31,550,54,186], $P < 0.001$). Admitted patients requiring CCS were associated with an increased incidence of major in-hospital complications compared with non-CCS patients (fig. 2). The most commonly encountered events were cardiac and pulmonary complications. Overall, 9% of subjects had one complication, and 1.2% had more than one complication. Among patients not requiring CCS, 8% had one complication, whereas 0.7% had more than one complication. In those requiring CCS, 0.8% had one complication, whereas 98% had multiple complications.

On multivariate regression analyses, independent risk factors for requiring CCS included total hip versus knee arthroplasty, advanced age, male sex, race other than black or Hispanic, emergent admission status, small hospital size, institutional designation as a teaching hospital, surgical pathologies other than osteoarthritis and rheumatoid arthritis, and the use of general compared with neuraxial anesthesia (table 3). In addition, the likelihood of requiring CCS services decreased over time by 36% in 2010 versus 2006 (table 3). An increase of every point in Deyo index was associated with a 25% increase in the odds for the requirement of CCS (table 3). Comorbidities associated with the highest risk for need for CCS included renal disease, severe liver disease, poorly controlled diabetes mellitus, and those affecting the central nervous system (table 4). Pulmonary compromise was identified as the complication with the highest odds for the requirement of CCS (OR 18.44; CI 16.55; 20.55, $P < 0.001$) (table 5).
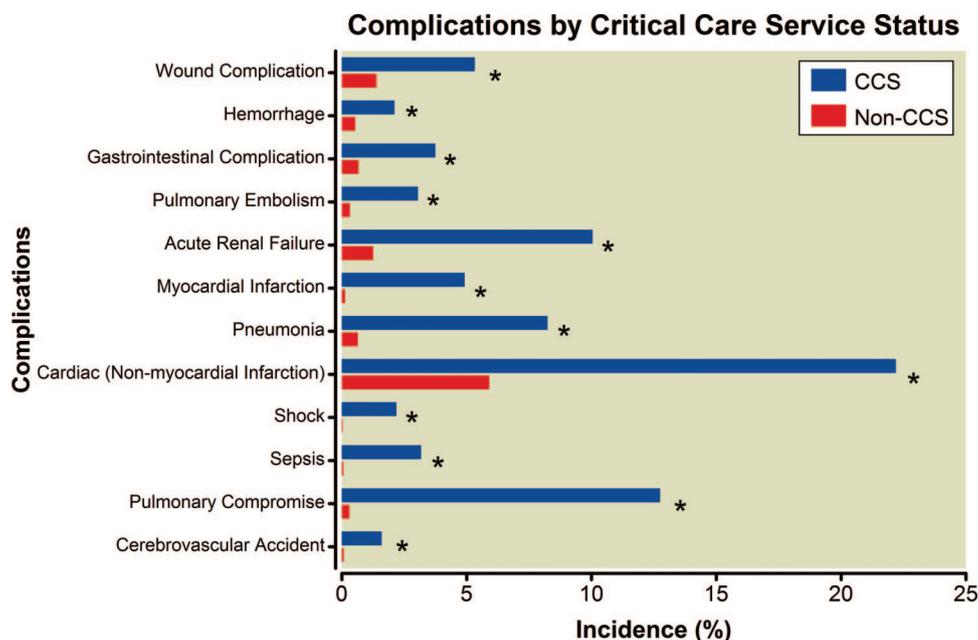
Fig. 2. The incidence of complications among patients requiring and not requiring critical care services (CCS) after hip and knee arthroplasty. For all comparisons, $P < 0.001$. *$P < 0.001$. CCS = critical care services.

Multicollinearity was absent after removing surgical pathology (value inflation factor in the range of 1–8); however, the OR estimates from all three models were similar with or without the variable of surgical pathology. Thus, the models were retained. The c-statistics for the three regression models were 0.72, 0.71, and 0.79, respectively, indicating acceptable discrimination. The H-L test showed significant P values for all three models; however, significance of the H-L test is known to not be indicative of bad calibration in the context of a large sample size, such as in the current study. Therefore, we are not considering our model suspect of suboptimal calibration.

Discussion

In the current study, we found that approximately 3% of patients undergoing primary total knee or hip arthroplasty required CCS. Compared with non-CCS patients, patients using CCS experienced more complications, received more blood transfusions and mechanical ventilation, had higher mortality rates, and incurred higher costs. In addition, these patients had longer hospital lengths of stay and were less frequently discharged to home after hospitalization. Risk factors with increased odds for requiring CCS included advanced age, hip *versus* knee surgery, surgical indications other then osteoarthritis and rheumatoid arthritis, use of general *versus* neuraxial anesthesia, emergent admission, increasing comorbidity burden, and the presence of postoperative cardiopulmonary complications. Our results suggest that it is possible to characterize the extent of CCS use among patients undergoing lower extremity joint arthroplasty and identify a subset of patients at risk for need of CCS. Increased attention

and surveillance of the patients with risk factors may diminish the need for CCS.

The reasons for the higher rates and risk for use of CCS among hip *versus* knee recipients are unclear. However, they may be partly explained by the differential intraoperative pathophysiology between the two procedures. Cardiopulmonary effects associated with the embolization of marrow and cement debris during the reaming and implantation process have been suggested to be dose dependent.[19,20] In this context, the amount of material gaining access to the vascular system after hip arthroplasty is arguably greater than that with knee procedures given the larger volume of the femoral canal requiring instrumentation. Another reason for this finding may be associated with differences in the prevalence of patients undergoing surgery for traumatic indications. Although accounted for in our regression analysis, it is widely known that hip fracture patients have the highest perioperative morbidity and mortality rates among all orthopedic patients.[21]

The finding that patients undergoing hip or knee arthroplasty in smaller and academic teaching hospitals had higher CCS use may be attributable to varying criteria for admission to an intensive care unit and patient acuity. In rural hospitals, it is likely that the admission criteria to an intensive care unit are less stringent than in larger hospitals. Academic teaching hospitals may receive a more complex or a sicker patient population, which may explain the increased use of CCS in our study. Patients identified as black or Hispanic had lower rates of CCS use. Discrepancies of care among orthopedic patients of different race have been described previously[22] and according to our findings seem to extend to the provision of CCS. Among other reasons, this may be attributable to lower insurance rates in this population and concomitant

Table 3. Multivariate Regression for Outcome of Need for Critical Care Services (Characteristics)

Variable	Effect		Odds Ratio (95% CI)	P Value
Procedure type (reference: THA)	TKA		0.78 (0.75, 0.81)	<0.001
Age category (reference: <45 yr)		45–54	1.14 (1.01, 1.29)	0.0358
		55–64	1.23 (1.09, 1.38)	<0.001
		65–74	1.49 (1.33, 1.68)	<0.001
		>75	2.27 (2.02, 2.56)	<0.001
Sex (reference: Male)	Female		0.82 (0.79, 0.85)	<0.001
Race (reference: White)	Black		0.76 (0.70, 0.82)	<0.001
	Hispanic		0.82 (0.79, 0.85)	0.0038
	Other		1.12 (1.07, 1.18)	<0.001
Admission type (reference: emergent)	Urgent		0.50 (0.44, 0.56)	<0.001
	Routine		0.43 (0.39, 0.47)	<0.001
	Other		0.54 (0.37, 0.79)	0.0014
	Missing		0.29 (0.20, 0.44)	<0.001
Hospital bed size (reference: <299)		300–499	0.83 (0.80, 0.86)	<0.001
		>500	0.35 (0.33, 0.37)	<0.001
Hospital teaching status (reference: nonteaching)	Teaching		2.45 (2.36, 2.54)	<0.001
Discharge year (reference: 2006)		2007	0.89 (0.85, 0.95)	<0.001
		2008	0.78 (0.74, 0.83)	<0.001
		2009	0.65 (0.62, 0.69)	<0.001
		2010	0.64 (0.61, 0.68)	<0.001
Surgical pathology (reference: osteoarthritis)	Rheumatoid arthritis		1.26 (0.99, 1.62)	0.07
	Infection/Internal derangement		3.18 (1.92, 5.30)	<0.001
	Trauma		2.09 (1.85, 2.38)	<0.001
	Other		1.64 (1.49, 1.80)	<0.001
	Multiple diagnoses		1.69 (1.59, 1.80)	<0.001
Anesthesia type (reference: general)	Neuraxial		0.55 (0.51, 0.60)	<0.001
	General/Neuraxial		0.66 (0.62, 0.71)	<0.001
	Other		0.28 (0.21, 0.36)	<0.001
	Missing		0.80 (0.77, 0.84)	<0.001
Comorbidity burden (continuous scale)	Deyo Category		1.25 (1.24, 1.26)	<0.001

THA = total hip arthroplasty; TKA = total knee arthroplasty.

underuse of hospital resources in general, which has been shown to affect CCS resource use.[23]

In our study, patients undergoing general anesthesia had a higher incidence of CCS use than did those undergoing neuraxial anesthesia alone or general with neuraxial anesthesia. The reasons neuraxial anesthesia may improve outcomes are complex and speculative[24]; however, neuraxial anesthesia has been associated with decreased morbidity and mortality among orthopedic patients in the past.[25] Positive effects of neuraxial techniques on the pulmonary system recently have

Table 4. Multivariate Regression for Outcome of Need for Critical Care Services (Comorbidities) after Hip and Knee Arthroplasty

Effect	Odds Ratios (95% CI)	P Value
Myocardial infarction	1.60 (1.48, 1.72)	<0.001
Peripheral vascular disease	1.86 (1.67, 2.05)	<0.001
Cerebrovascular disease	2.11 (1.65, 2.68)	<0.001
Dementia	2.16 (1.53, 3.05)	<0.001
COPD	1.56 (1.50, 1.63)	<0.001
Rheumatic disease	0.56 (0.50, 0.63)	<0.001
Mild liver disease	1.70 (1.26, 2.28)	<0.001
Severe liver disease	2.79 (1.65, 4.70)	<0.001
Uncomplicated diabetes mellitus	1.24 (1.18, 1.29)	<0.001
Complicated diabetes mellitus	2.06 (1.83, 2.33)	<0.001
Renal disease	3.26 (2.09, 5.08)	<0.001
Cancer	1.67 (1.51, 1.84)	<0.001
Obesity	1.72 (1.65, 1.80)	<.0001

COPD = chronic obstructive pulmonary disease.

Table 5. Multivariate Regression for Outcome of Need for Critical Care Services (Complications) after Hip and Knee Arthroplasty

Effect	Odds Ratio (95% CI)	P Value
Cerebrovascular accident	8.09 (6.13, 10.68)	<0.001
Pulmonary compromise	18.44 (16.55, 20.55)	<0.001
Sepsis	6.12 (4.61, 8.13)	<0.001
Shock	14.28 (9.96, 20.49)	<0.001
Cardiac (nonmyocardial infarction)	2.58 (2.44, 2.74)	<0.001
Pneumonia	3.29 (2.91, 3.73)	<0.001
Myocardial infarction	9.36 (7.78, 11.26)	<0.001
Acute renal failure	2.85 (2.58, 3.14)	<0.001
Pulmonary embolism	4.90 (4.11, 5.84)	<0.001
Gastrointestinal complication	2.44 (2.06, 2.90)	<0.001
Hemorrhage	2.75 (2.34, 3.24)	<0.001

been suggested by van Lier *et al.* to result in decreased risk of pulmonary complications in patients with chronic obstructive pulmonary disease after abdominal surgery.[26] However, it remains a matter of controversy whether the benefit observed with neuraxial anesthesia is caused by avoidance or reduction of potentially adverse effects associated with general anesthesia (*i.e.*, mechanical ventilation and administration of larger amounts of opioids) or is the result of intrinsic benefit from regional anesthesia.[25] Our data suggest that the use of neuraxial anesthesia with or without general anesthesia was associated with a reduced risk for CCS need compared with general anesthesia alone, supporting the concept that neuraxial anesthesia may provide intrinsic beneficial attributes. When comparing the use of neuraxial anesthesia with general anesthesia *versus* general anesthesia alone, the odds for the use of CCS were reduced (OR 0.83 [CI 0.75, 0.93]), $P = 0.001$.

In general, the relatively high rate of CCS use after knee and hip arthroplasty may be explained by the unique pathophysiology related to these procedures. This is particularly important when cemented prosthesis are used, which may result in pulmonary microemboli, right heart dysfunction, and pulmonary hypertension. These effects likely explain the relationship of pulmonary complications with CCS use.[19,27] Given the increasing body of research providing data for risk stratification, many perioperative physicians have raised the question of the appropriateness of performing elective orthopedic procedures in high-risk patients. Although beyond the scope of this study, patient selection for hip and knee arthroplasty among an increasingly sicker and older population will remain an important but controversial topic. Our study certainly provides additional data that can be used to identify patients at risk for adverse outcome. In addition, we think our findings should be viewed in the context of a recent trend among perioperative researchers using databases to quantify perioperative complications and identify risk factors for adverse outcomes spanning from issues surrounding stroke risk[28] to intraoperative transfusion practices.[29]

Our study is limited by a number of factors that are mostly inherent to the analysis of secondary data from large administrative databases. Detailed clinical information (*i.e.*, blood loss, intraoperative details) cannot be captured, so the impact of such factors on outcome cannot be taken into consideration. In addition, complications were captured only if they occurred during the index admission; thus, our findings do not take into account postdischarge events. However, we did analyze and report 30-day mortality data. Unfortunately, mortality outcomes beyond this time point are not available. Causal relationships cannot be established using this data source, and reasons for our findings have to remain speculative. For example, transfusion practices vary widely, and the reason for administration of blood products cannot be discerned. In addition, the fact that teaching institutions and general anesthesia were associated with increased odds for CCS use may be associated with factors

indicating case severity that are not captured here. However, we conducted propensity score analysis to account for the likelihood that patients received general anesthesia or underwent surgery in teaching hospitals, and when such data were entered into our regression models, results did not change significantly.[30] In addition, the definitions of comorbidities, surgical pathology, and complications are based on the ICD-9 coding system and thus may be burdened with coding bias despite quality checks used by Premier Inc. This is in contrast to the more robust and discrete outcome of mortality. Thus, the true incidence of comorbidities and complications may be underestimated if not captured by the specific ICD-9-CM codes used (see appendix). However, both groups (CCS *vs.* non-CCS) should be equally exposed to any potential bias, so comparative analysis is less affected by this influence. However, it must be noted that despite potential bias associated with the analysis of complications compared with the outcome of mortality, the former are much more common and therefore clinically important endpoints. Thus, we sought to analyze complications as thoroughly as possible.

Although our approach to identify perioperative complications is modeled after previous reports,[31] it is important to consider that the identification of perioperative complications using the ICD-9 coding system may be limited and definitions may vary by institution, as noted previously.[32] However, although such limitations may be considered, in this comparative analysis of CCS *versus* non-CCS patients, the inclusion of such data may be justified by the data providing information about the comparative incidence of complications within the database construct, and thus may inform critical care physicians about the proportional nature of problems likely to be encountered.

Finally, the definition of CCS was derived from billing entries in the database, and concerns similar to those affecting the use of ICD-9 codes should be considered. Another consideration when interpreting our data is the issue of access to an intensive care unit. The possibility exists that some critically ill patients did not receive CCS because of factors such as patient refusal or medical futility. These patients would have been captured in the non-CCS group in our study.

In conclusion, approximately 1 of 30 (3%) patients undergoing total joint arthroplasty required CCS. Given the large number of arthroplasty procedures performed in the United States annually, critical care physicians need to be familiar with the demographics, risk factors, and outcomes of patients who require CCS. In addition, clinicians and hospital administrators need to be aware of the significant clinical and economic impact that this patient population represents and allocate resources accordingly. In this context, the reassessment of the appropriateness of arthroplasty procedures in patients at high risk for complications and the need for CSS seems appropriate. This is especially warranted for elective cases in patients with significant end organ disease.

References

1. 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

2. Memtsoudis SG, Rosenberger P, Walz JM: Critical care issues in the patient after major joint replacement. J Intensive Care Med 2007; 22:92–104

3. Liu SS, Della Valle AG, Besculides MC, Gaber LK, Memtsoudis SG: Trends in mortality, complications, and demographics for primary hip arthroplasty in the United States. Int Orthop 2009; 33:643–51

4. Memtsoudis SG, Della Valle AG, Besculides MC, Gaber L, Laskin R: Trends in demographics, comorbidity profiles, in-hospital complications and mortality associated with primary knee arthroplasty. J Arthroplasty 2009; 24:518–27

5. Memtsoudis SG, Ma Y, González Della Valle A, Mazumdar M, Gaber-Baylis LK, MacKenzie CR, Sculco TP: Perioperative outcomes after unilateral and bilateral total knee arthroplasty. ANESTHESIOLOGY 2009; 111:1206–16

6. Memtsoudis SG, González Della Valle A, Besculides MC, Gaber L, Sculco TP: In-hospital complications and mortality of unilateral, bilateral, and revision TKA: Based on an estimate of 4,159,661 discharges. Clin Orthop Relat Res 2008; 466:2617–27

7. US Department of Health and Human Services: OCR Privacy Brief: Summary of the HIPAA Privacy Rule. Washington, DC, Office for Civil Rights, HIPAA Compliance Assistance, 2003

8. Blanchette CM, Wang PF, Joshi AV, Kruse P, Asmussen M, Saunders W: Resource utilization and costs of blood management services associated with knee and hip surgeries in US hospitals. Adv Ther 2006; 23:54–67

9. Chandwani S, Wentworth C, Burke TA, Patterson TF: Utilization and dosage pattern of echinocandins for treatment of fungal infections in US hospital practice. Curr Med Res Opin 2009; 25:385–93

10. Stulberg JJ, Delaney CP, Neuhauser DV, Aron DC, Fu P, Koroukian SM: Adherence to surgical care improvement project measures and the association with postoperative infections. JAMA 2010; 303:2479–85

11. 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

12. Xue FS, Liao X, Wang Q, Yuan YJ, Liu JH: Is not high-inspired oxygen fraction really a risk for postoperative pulmonary complications in obese patients? ANESTHESIOLOGY 2012; 116: 229–30

13. Hosmer DW, Lemeshow S: Applied Logistic Regression, 2nd edition. New York, John Wiley & Son, 2000, pp 162

14. Sauerbrei W, Schumacher M: A bootstrap resampling procedure for model building: Application to the Cox regression model. Stat Med 1992; 11:2093–109

15. Steyerberg EW, Harrell FE Jr, Borsboom GJ, Eijkemans MJ, Vergouwe Y, Habbema JD: Internal validation of predictive models: Efficiency of some procedures for logistic regression analysis. J Clin Epidemiol 2001; 54:774–81

16. Hosmer DW, Lemeshow SA: Goodness-of-fit test for the multiple logistic regression model. Commun Stat 1980; A10: 1043–69

17. Pepe MS: The Statistical Evaluation of Medical Tests for Classification and Precision. Oxford, United Kingdom, Oxford University Press, 2003, pp 66–94

18. Kramer AA, Zimmerman JE: Assessing the calibration of mortality benchmarks in critical care: The Hosmer-Lemeshow test revisited. Crit Care Med 2007; 35:2052–6

19. Memtsoudis SG, Salvati EA, Go G, Ma Y, Sharrock NE: Perioperative pulmonary circulatory changes during bilateral total hip arthroplasty under regional anesthesia. Reg Anesth Pain Med 2010; 35:417–21

20. Memtsoudis SG, Starcher B, González Della Valle A, Ma Y, Jules-Elysee K, Sculco TP: Urine desmosine as a marker of lung injury following total knee arthroplasty. A pilot study. HSS J 2009; 5:154–8

21. White JJ, Khan WS, Smitham PJ: Perioperative implications of surgery in elderly patients with hip fractures: An evidence-based review. J Perioper Pract 2011; 21:192–7

22. Hawkins K, Escoto KH, Ozminkowski RJ, Bhattarai GR, Migliori RJ, Yeh CS: Disparities in major joint replacement surgery among adults with Medicare supplement insurance. Popul Health Manag 2011; 14:231–8

23. Danis M, Linde-Zwirble WT, Astor A, Lidicker JR, Angus DC: How does lack of insurance affect use of intensive care? A population-based study. Crit Care Med 2006; 34:2043–8

24. Macfarlane AJ, Prasad GA, Chan VW, Brull R: Does regional anaesthesia improve outcome after total hip arthroplasty? A systematic review. Br J Anaesth 2009; 103:335–45

25. Rodgers A, Walker N, Schug S, McKee A, Kehlet H, van Zundert A, Sage D, Futter M, Saville G, Clark T, MacMahon S: Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: Results from overview of randomised trials. BMJ 2000; 321:1493

26. van Lier F, van der Geest PJ, Hoeks SE, van Gestel YR, Hol JW, Sin DD, Stolker RJ, Poldermans D: Epidural analgesia is associated with improved health outcomes of surgical patients with chronic obstructive pulmonary disease. ANESTHESIOLOGY 2011; 115:315–21

27. Memtsoudis SG, Ma Y, Chiu YL, Walz JM, Voswinckel R, Mazumdar M: Perioperative mortality in patients with pulmonary hypertension undergoing major joint replacement. Anesth Analg 2010; 111:1110–6

28. Mashour GA, Shanks AM, Kheterpal S: Perioperative stroke and associated mortality after noncardiac, nonneurologic surgery. ANESTHESIOLOGY 2011; 114:1289–96

29. Glance LG, Dick AW, Mukamel DB, Fleming FJ, Zollo RA, Wissler R, Salloum R, Meredith UW, Osler TM: Association between intraoperative blood transfusion and mortality and morbidity in patients undergoing noncardiac surgery. ANESTHESIOLOGY 2011; 114:283–92

30. D'Agostino RB Jr: Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group. Stat Med 1998; 17:2265–81

31. Iezzoni LI, Daley J, Heeren T, Foley SM, Fisher ES, Duncan C, Hughes JS, Coffman GA: Identifying complications of care using administrative data. Med Care 1994; 32:700–15

32. Le Manach Y, Ibanez Esteves C, Bertrand M, Goarin JP, Fléron MH, Coriat P, Koskas F, Riou B, Landais P: Impact of preoperative statin therapy on adverse postoperative outcomes in patients undergoing vascular surgery. ANESTHESIOLOGY 2011; 114:98–104

Appendix. ICD-9-CM Diagnosis Codes for Major Complications

Complications	ICD-9-CM Diagnosis Codes
Cerebrovascular accident	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, 790.7
Shock	427.5, 785.50, 785.59, 995.4
Cardiac (nonmyocardial infarction)	426.0, 427.41, 427.42, 429.4, 997.1, 427.4, 427.3, 427.31, 427.32
Pneumonia	481, 482.00–482.99, 483, 485, 486, 507.0, 997.31, 997.39
Myocardial infarction	410.00–410.99
Acute renal failure	584, 584.5, 584.9
Pulmonary embolism	415.1
Gastrointestinal complication	997.4, 560.1, 560.81, 560.9, 536.2, 537.3
Hemorrhage	998.1, 998.11, 459.0
Wound complication	998.3, 998.30, 998.31, 998.32, 997.4, 997.5, 998.33, 998.83, 998.12, 998.13, 998.6, 998.51, 729.92

ICD-9-CM = International Classification of Diseases-ninth revision-Clinical Modification.