Intraoperative Cardiac Arrests in Adults Undergoing Noncardiac Surgery

Incidence, Risk Factors, and Survival Outcome

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CME This article has been selected for the Anesthesiology CME Program. Learning objectives and disclosure and ordering information can be found in the CME section at the front of this issue.

ABSTRACT

Background: Intraoperative cardiac arrest (ICA) is a rare but potentially catastrophic event. There is a paucity of recent epidemiological data on the incidence and risk factors for ICA. The objective of this study was to assess the incidence, risk factors, and survival outcome of ICAs in adults undergoing noncardiac surgery.

Methods: The authors analyzed prospectively collected data for all noncardiac cases in the American College of Surgeons National Surgical Quality Improvement Program database from the years 2005 to 2007 (n = 362,767).

Results: The incidence of ICA was 7.22 per 10,000 surgeries. After adjustment for American Society of Anesthesiologists physical status and other covariates, the odds of ICA increased progressively with the amount of transfusion (adjusted odds ratios = 2.51, 7.59, 11.40, and 29.68 for those receiving 1–3, 4–6, 7–9, and ≥ 10 units of erythrocytes, respectively). Other significant risk factors for ICA were emergency surgery (adjusted odds ratio = 2.04, 95% CI = 1.45–2.86) and being functionally dependent presurgery (adjusted odds ratio = 2.33, 95% CI = 1.69–3.22). Of the 262 patients with ICA, 116 (44.3%) died within 24 h, and 164 (62.6%) died within 30 days.

Conclusions: Intraoperative blood loss as indicated by the amount of transfusion was the most important predictor of ICA. The urgency of surgery and the preoperative composite indicators of health such as American Society of Anesthesiologists status and functional status were other important risk factors. The high case fatality suggests that primary prevention might be the key to reducing mortality from ICA.

What We Already Know about This Topic

- The reported incidence of intraoperative cardiac arrest varies widely, in large part due to paucity of epidemiological data that allows quantitative assessment of associated risk factors
- This study determined the incidence, risk factors, and survival outcome of intraoperative cardiac arrests in adults undergoing noncardiac surgery

What This Article Tells Us That Is New

- Intraoperative cardiac arrest occurs at a rate of approximately 7 per 10,000 noncardiac surgeries, with a 30-day mortality rate of 63%
- The most important risk factor is the amount of intraoperative erythrocyte transfusion

INTRAOPERATIVE cardiac arrest (ICA) is a rare but potentially catastrophic event that is associated with high mortality. The reported incidence of ICA varies considerably across studies.[1–7] One principal reason for the lack of consistency could be that the incidence of ICA has decreased with

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improved technology and clinical practices.[8,9] Study periods vary from 5 to 18 yr,[4,10–12] and thus the impact of changing technology and clinical practices may result in variation in the incidence of ICA across individual studies. Another reason is that most studies are based on data from single institutions and consequently suffer from limited external validity.[1,3,6,12–14] Furthermore, the incidence of ICA also varies in different countries during similar periods, based on the quality and the availability of health care.[7,14] To increase the study sample size, many previous studies report the combined incidence of ICA in adult and pediatric patients or cardiac and noncardiac procedures.[1,3,7] Finally, some studies have reported the combined incidence of cardiac risk in patients suffering from perioperative cardiac arrest and myocardial infarction,[15] outcomes with potentially different risk factors and incidence. Thus the reported incidence of ICA ranges from 1.1 to 34.6 cardiac arrests per 10,000 anesthetics.[7,12] Although there is a wide variation in the reported incidence, the case fatality of ICA has remained consistently high at approximately 60–80% since the 1950s.[1,5–7,10,14] The paucity of epidemiological data prevents us from accurately estimating the incidence of ICA and quantitatively assessing the associated risk factors. The risk profile of our patients continues to change as we operate on patients who are older and sicker.[16–18] With the changing risk profile of our patients, it is important to identify modifiable risk factors and intervene by changing our clinical practices to further decrease the morbidity and the mortality in the operating room. The goal of this study was to assess the incidence of and risk factors for ICA in adults undergoing noncardiac surgery. The results of this study may help cardiologists, primary care physicians, anesthesiologists, and surgeons to improve the risk stratification of patients and develop interventions to lower the incidence of ICA in high-risk patients.

Materials and Methods

Data

Data from this study came from the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP).‖ The ACS NSQIP is a nationally validated, risk-adjusted, outcomes-based program to measure and improve the quality of surgical care among all participating hospitals. A surgical clinical reviewer captures the data on 136 variables, including preoperative patient characteristics, intraoperative variables, and 30-day postoperative mortality and morbidity outcomes for patients undergoing major surgical procedures using standardized protocols. Participating hospitals submit data to ACS NSQIP through either the general and vascular surgery module or the multispecialty module. Each of the two modules includes a high- and a low-volume category. The hospitals participating in the high-volume module must submit a minimum of 1,680 cases, whereas the hospitals participating in the low-volume module must include a minimum of 900 cases.

There is a systematic sampling system called the 8-day cycle for the hospitals not able to capture all their surgical cases. To obtain a representative sample of operations, the first 40 consecutive eligible operations are entered into the NSQIP in each 8-day cycle, with each cycle starting on the different day of the week. There are 46, 8-day cycles in 1 yr, and the program requires that data be submitted for 42 of those cycles.# The hospitals participating in the high-volume, general, and vascular surgery model capture the first 40 consecutive cases meeting the inclusion/exclusion criteria in the 8-day cycle for a total of 1,680 cases annually. The hospitals participating in the low-volume, general, and vascular surgery model are required to submit all general and vascular cases that meet the inclusion/exclusion criteria in the 8-day cycle. A minimum of 900 cases must be submitted annually. The hospitals participating in the high-volume, multispecialty model must submit approximately 20% of each of the following subspecialties: general, gynecologic, neurologic, orthopedic, otolaryngology, plastic, cardiac, thoracic, urologic, and vascular. If 20% of the hospital volume is less than 1,680 cases annually, the hospital must submit a higher percentage to reach a minimum of 1,680 cases. The hospitals participating in the low-volume, multispecialty model must submit the maximum number of cases that meet the inclusion/exclusion criteria, with a minimum of 900 cases annually. The ACS NSQIP includes all cases receiving general, spinal, or epidural anesthesia. Carotid endarterectomy, inguinal herniorrhaphy, parathyroidectomy, thyroidectomy, breast lumpectomy, and endovascular abdominal aortic aneurysm repair cases are included regardless of the anesthesia modality. The following patients are not included in ACS NSQIP: those receiving monitored anesthesia care; those receiving peripheral nerve block or local anesthesia; trauma cases, transplant cases, concurrent cases; patients less than 16 yr of age; and brain-dead patients categorized as American Society of Anesthesiology (ASA) physical classification 6. Hospitals with a 30-day follow-up rate of less than 80% and whose surgical volume does not meet eligibility criteria are also excluded.

To support the acquisition of high-quality data, ACS NSQIP from its start has relied on robust clinical data with rigorous definitions, collected by trained and audited personnel. The mechanisms for collection of high-quality data include: presence of a dedicated surgical clinical reviewer for data collection at each institution; initial and ongoing reviewer training, examination and support; creation and continual review of rigorous data definitions; audits for data integrity and interrater reliability.[19] The high quality of ACS NSQIP data has been recognized by the Institute of

‖ American College of Surgeons National Surgical Quality Improvement Program - Program Overview. Available at: http://site.acsnsqip.org/about/. Accessed April 13, 2012.

ACS-NSQIP: User Guide for the 2008 Participant Use Data File. Available at: http://site.acsnsqip.org/wp-content/uploads/2012/03/Final-user-guide-08-PUF.pdf. Accessed April 13, 2012.

Medicine and the Joint Commission. The interrater reliability audit is a tool to assess the quality of data collected at the participating site; it evaluates the disagreement rates between the surgical clinical reviewer and the site reviewer. Interrater reliability is calculated as a percentage using the number of disagreements divided by the total number of variables reviewed. The overall disagreement on variables has been extremely low from the beginning (3.15% in 2005) and has steadily fallen (1.56% in 2008).[19]

Study Sample

The study cohort included all the noncardiac cases in the ACS NSQIP database for the years 2005–2007 (n = 362,767). This consists of data from 121 institutions in 2005 and 2006 and from 183 institutions in 2007. ICA is defined as the absence of cardiac rhythm or presence of chaotic cardiac rhythm that requires the initiation of any component of basic and/or advanced cardiac life support. Patients who have automatic implantable cardioverter defibrillator that fire but have no loss of consciousness are not included as ICA cases. Excluded from this study were 1,130 patients who underwent cardiac surgery, as indicated by the Current Procedural Terminology codes.[20] Surgical procedures were divided into two categories of low/moderate risk and high risk, based on the incidence of cardiac death and nonfatal myocardial infarction as discussed in the guidelines published by American College of Cardiology/American Hospital Association, the European Society of Cardiology, and the European Society of Anaesthesiology.[21,22] Patients having vascular surgery were included in the high-risk group and patients undergoing other procedures, such as endovascular repair of abdominal aortic aneurysm and carotid endarterectomy, were included in the low/moderate-risk group.

Statistical Analysis

The study protocol was reviewed and judged to be exempt by the Columbia University Institutional Review Board. The incidence, odds ratios, and 95% CI of ICA were calculated according to demographic and preoperative clinical characteristics, such as age, sex, race, body mass index (BMI), and emergency case status and patient comorbidities, including but not limited to dyspnea, chronic obstructive pulmonary disease, heart disease, hypertension, impaired sensorium, coma, cortical disease, spinal disease, renal failure or on dialysis, diabetes, sepsis, and bleeding disorders. Preoperative and intraoperative transfusion histories were also examined. A subset analysis was also performed by excluding the patients who received more than 4 units of blood 72 h before surgery. Interactions between surgical procedure risk and preoperative clinical characteristics on ICA were assessed. Multivariable logistic regression was used to choose predictors of ICA. Age, sex, race, procedure risk, renal disease, heart disease, cerebrovascular disease, and dyspnea were forced into the model, and the remaining variables were chosen using stepwise selection. The significance level of the score chi-square for entering an effect into the model was 0.05 and the significance level of the Wald chi-square for an effect to stay in the model was 0.05. The model goodness of fit was assessed with the Hosmer and Lemeshow test.[23] Using the same process, a stratified analysis of high- and moderate-risk procedures was performed to assess risk factors for each surgical procedure group. Statistical analysis was performed using SAS version 9.2 (SAS Institute, Cary, NC).

Results

Of the 362,767 patients studied, 262 had an ICA, yielding an incidence of 7.22 per 10,000 surgeries. Of the 262 patients with ICA, 116 (44.3%) died within 24 h, and 164 (62.6%) died within 30 days. The incidence of ICA varied significantly with preoperative patient and clinical variables (table 1). Specifically, the risk of ICA increased with age, ASA physical status classification, impaired functional status, presence of comorbidities, and surgical-risk level (table 1). Emergency surgery and participation by resident surgeon were also associated with a substantially increased risk of ICA (table 1). The highest incidence of ICA, 814.25 per 10,000 surgeries, was found among patients receiving intraoperative transfusion of 10 or more erythrocyte units (table 1).

Complications associated with tracheal intubation such as airway (lip, tongue, pharyngeal, or laryngeal laceration) injury or failure to intubate were not observed in any of the patients suffering from ICA. Of the 262 patients, one patient suffered from a tooth injury. None of the patients who could not be intubated progressed to an ICA.

Multivariable logistic regression modeling revealed that the risk of ICA increased progressively with the amount of intraoperative transfusion; compared with patients with no transfusion, the adjusted odds ratios were 2.51, 7.59, 11.40, and 29.68 for those receiving 1–3, 4–6, 7–9, and 10 or more erythrocyte units of transfusion, respectively (fig. 1; table 2). Excluding the patients receiving more than 4 units of blood 72 h before surgery (n = 1,573) did not change the results in any meaningful way.

The odds of ICA also increased in a dose–response fashion with ASA physical status classification. Other risk factors for ICA were emergency surgery (adjusted rate ratio = 2.04, 95% CI = 1.45– 2.86), and being functionally dependent presurgery (adjusted rate ratio = 2.33, 95% CI = 1.69–3.22) (table 2). The Hosmer-Lemeshow test indicated that the multivariable logistic regression model (table 2) fitted the data adequately (chi-square = 9.484, df = 8, P = 0.302). In patients undergoing low- or moderate-risk procedures, the odds of ICA was lower in patients with higher BMI. Compared with patients with BMI less than 25, the adjusted odds ratios were 0.84 and 0.31 for patients with BMI between 30–39 and 40 and higher, respectively. Stratification analysis indicated that the amount of intraoperative transfusion was the most important predictor of ICA regardless of the risk level of surgical procedures. The odds of ICA associated with emergency surgery and preoperative functional status, however, appeared to be more pronounced

Table 1. Incidence and 95% CI of Intraoperative Cardiac Arrest per 10,000 Surgeries by Pre- and Intraoperative Characteristics, American College of Surgeons National Surgical Quality Improvement Program, 2005–2007

Characteristic	No. of Surgeries* (n = 362,767)	Number of Intraoperative Cardiac Arrests (n = 262)	Incidence per 10,000 Surgeries (95% CI)
Age, yr			
16–49	138,804	34	2.45 (1.63–3.27)
50–69	143,127	98	6.85 (5.49–8.20)
≥70	80,834	130	16.08 (13.32–18.85)
Sex			
Female	208,918	110	5.27 (4.28–6.25)
Male	153,829	152	9.88 (8.31–11.45)
Race			
White	256,798	183	7.13 (6.09–8.16)
Black	35,339	27	7.64 (4.76–10.25)
Other/unknown	70,630	52	7.36 (5.36–9.36)
Body mass index, kg/m^2			
<25	108,584	76	7.00 (5.43–8.57)
25–<30	108,658	66	6.07 (4.61–7.54)
30–<40	95,177	53	5.57 (4.07–7.07)
≥40	39,295	9	2.29 (0.79–3.79)
Surgical-risk level†			
Low/ moderate risk	346,048	180	5.20 (4.44–5.96)
High risk (vascular)	16,719	82	49.05 (38.46–59.64)
Emergency surgery‡			
No	315,352	97	3.08 (2.46–3.69)
Yes	47,415	165	34.80 (29.50–40.10)
Resident surgeon participation			
No	131,083	64	4.88 (3.69–6.08)
Yes	220,053	190	8.63 (7.41–9.86)
ASA physical status classification			
1–2	206,879	18	0.87 (0.46–1.27)
3	131,007	67	5.11 (3.89–6.34)
4	22,794	98	42.99 (34.50–51.49)
5	1,145	78	681.22 (535.07–827.38)
Functional health status before surgery§			
Independent	337,775	108	3.20 (2.59–3.80)
Partially or totally Dependent	24,992	154	61.62 (51.92–71.32)
Dyspnea			
No	321,006	175	5.45 (4.64–10.96)
Moderate exertion	36,254	40	11.03 (7.62–14.45)
At rest	5,507	47	85.35 (61.04–109.65)
Severe chronic obstructive pulmonary disease			
No	346,337	226	6.53 (5.67–7.38)
Yes	16,430	36	21.91 (14.76–29.06)
Current smoker within 1 yr			
No	286,386	198	6.91 (5.95–7.88)
Yes	76,381	64	8.38 (6.33–10.43)
Heart disease‖			
No	322,312	163	5.06 (4.28–5.83)
Yes	40,455	99	24.47 (19.66–29.29)
Hypertension requiring medications			
No	202,194	94	4.65 (3.71–5.59)
Yes	160,573	168	10.46 (8.88–12.04)

(continued)

Table 1. (Continued)

Characteristic	No. of Surgeries* (n = 362,767)	Number of Intraoperative Cardiac Arrests (n = 262)	Incidence per 10,000 Surgeries (95% CI)
Impaired sensorium#			
No	359,312	220	6.12 (5.31–6.93)
Yes	3,455	42	121.56 (85.01–158.12)
Coma**			
No	362,452	244	6.73 (5.89–7.58)
Yes	315	18	571.43 (313.70–829.16)
Cerebrovascular disease††			
No	338,849	219	6.46 (5.61–7.32)
Yes	23,918	43	17.98 (12.61–23.35)
Spinal disorder‡‡			
No	360,838	258	7.15 (6.28–8.02)
Yes	1,929	4	20.74 (0.41–41.05)
Renal disease§§			
No	353,129	221	6.26 (5.43–7.08)
Yes	9,638	41	42.54 (29.54–55.54)
Diabetes mellitus with oral agents or insulin			
No	311,481	203	6.52 (5.62–7.41)
Yes	51,286	59	11.50 (8.57–14.44)
Preoperative sepsis			
No	328,804	139	4.23 (3.52–4.93)
SIRS‖‖/sepsis	30,212	58	19.20 (14.26–24.13)
Septic shock	3,751	65	173.29 (131.51–215.07)
Bleeding disorders			
No	341,136	202	5.92 (5.11–6.74)
Yes	21,631	60	27.74 (20.73–34.75)
Transfusion of > 4 units of packed erythrocytes in 72 h before surgery			
No	361,194	242	6.70 (5.86–7.54)
Yes	1,573	20	127.15 (71.72–182.57)
No. of erythrocyte units transfused intraoperatively			
0	343,054	98	2.86 (2.29–3.42)
1–3	14,937	42	28.12 (19.63–36.61)
4–6	3,103	38	122.46 (83.74–161.18)
7–9	694	16	230.55 (118.62–342.48)
≥10	786	64	814.25 (622.64–1005.86)

*Data were missing for 2 patients on age, 20 patients on sex, 11,053 patients on body mass index, 11,631 patients on resident surgeon participation, 942 patients on ASA physical status classification, and 193 patients on number of erythrocytes transfused. †Patients undergoing vascular surgery were included in the high-risk group, and all the other patients were included in the low/moderate-risk group. This was based on the guidelines published by American College of Cardiology.[23] ‡Performed within 12 h of admission or onset of symptomatology. Trauma cases were excluded from the data set. §This variable focuses on the patient's abilities to perform activities of daily living. Activities of daily living are defined as "the activities usually performed in the course of a normal day in a person's life." Activities of daily living include: bathing, feeding, dressing, using the toilet, and being mobile. ‖Congestive heart failure in 30 days before the current surgery and/or myocardial infarction in 6 months before the current surgery and/or angina in 1 month before the current surgery and/or previous percutaneous coronary intervention, and/or any previous cardiac surgery. #Mental status changes and/or delirium in the context of the current illness. Patients with chronic or long-standing mental status changes were not included. **Patient is unconscious or postures to painful stimuli or is unresponsive to all stimuli entering surgery. ††Hemiplegia and/or history of transient ischemic attack and/or history of cerebrovascular accident. ‡‡Paraplegia and/or quadriplegia. §§Acute renal failure and/or on dialysis. Acute renal failure was defined as rapid, steadily increasing azotemia and a rising creatinine of > 3 mg/ dl (265 μmol/l) within 24 h before surgery. ‖‖Systemic inflammatory response syndrome. The syndrome is recognized by the presence of ≥ 2 of the following within the same time frame: temperature > 38°C or < 36°C, heart rate > 90 beats/min, respiratory rate > 20 breaths/min or partial pressure of carbon dioxide in arterial blood ($PaCO_2$) < 32 mmHg, leukocyte count > 12,000 cell/mm^3 (12×10^9 cell/l), < 4,000 cell/mm^3 (4×10^9 cell/l) or > 10% immature (band) forms.

ASA = American Society of Anesthesiologists; SIRS = systemic inflammatory response syndrome.

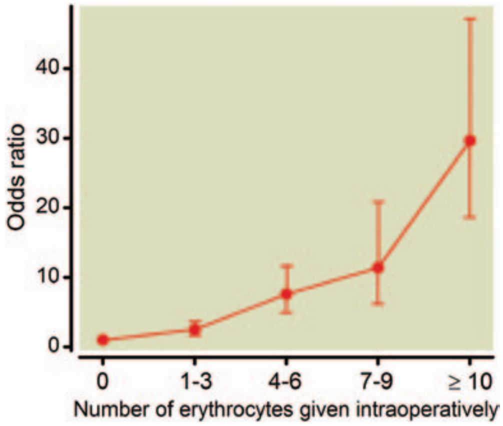

Fig. 1. The adjusted odds ratios and 95% CI of intraoperative cardiac arrest according to the amount of intraoperative erythrocyte transfusion in patients undergoing noncardiac surgery, American College of Surgeons National Surgical Quality Improvement Program, 2005–2007.

Table 2. Estimated Odds Ratios and 95% CI for Intraoperative Cardiac Arrest by Pre- and Intraoperative Characteristics, American College of Surgeons National Surgical Quality Improvement Program, 2005–2007

Characteristic	OR (95% CI)
Age, yr	
16–49	1.00
50–69	1.09 (0.71–1.65)
≥70	1.17 (0.77–1.80)
Sex	
Female	1.00
Male	1.00 (0.77–1.31)
Race	
White	1.00
Black	0.99 (0.64–1.53)
Other/unknown	1.45 (1.05–2.00)
Surgical risk*	
Low/ moderate risk	1.00
High risk (vascular)	1.11 (0.79–1.55)
Emergency surgery†	
No	1.00
Yes	2.04 (1.45–2.86)
ASA physical status classification	
1–2	1.00
3	3.71 (2.13–6.47)
4	8.75 (4.71–16.25)
5	30.27 (15.11–60.62)
Functional health status before surgery‡	
Independent	1.00
Partially or totally dependent	2.33 (1.69–3.22)
Heart disease§	
No	1.00
Yes	1.48 (1.11–1.96)
Coma‖	
No	1.00
Yes	1.91 (1.06–3.42)
Impaired sensorium#	
No	1.00
Yes	1.12 (0.76–1.64)
Cerebrovascular disease**	
No	1.00
Yes	1.09 (0.76–1.57)
Renal disease††	
No	1.00
Yes	1.37 (0.94–2.01)
Diabetes mellitus with oral agents or insulin	
No	1.00
Yes	0.89 (0.65–1.22)
No. of erythrocyte units given intraoperatively	
0	1.00
1–3	2.51 (1.69–3.71)
4–6	7.59 (4.94–11.67)
7–9	11.40 (6.22–20.88)
≥10	29.68 (18.66–47.18)

*Patients undergoing vascular surgery were included in the high-risk group, all the other patients were included in the low/-moderate risk group. This was based on the guidelines published by American College of Cardiology.[23] †Performed within 12 h of admission or onset of symptomatology. Trauma cases were excluded from the data set. ‡This variable focuses on the patient's abilities to perform activities of daily living. Activities of daily living are defined as "the activities usually performed in the course of a normal day in a person's life." Activities of daily living include: bathing, feeding, dressing, using the toilet, and being mobile. §Congestive heart failure in 30 days before the current surgery and/or myocardial infarction in 6 months before the current surgery and/or angina in 1 month before the current surgery and/or previous percutaneous coronary intervention and/or any previous cardiac surgery. ‖Patient is unconscious or postures to painful stimuli or is unresponsive to all stimuli entering surgery. #Mental status changes and/or delirium in the context of the current illness. Patients with chronic or long-standing mental status changes were not included. **Hemiplegia and/or history of transient ischemic attack and/or history of cerebrovascular accident. ††Acute renal failure and/or on dialysis. Acute renal failure was defined as rapid, steadily increasing azotemia and a rising creatinine of > 3 mg/ dl (265 μmol/l) within 24 h before surgery.

ASA = American Society of Anesthesiologists.

in high-risk surgical procedures than in low/moderate surgical procedures.

Discussion

The amount of intraoperative erythrocyte transfusion, a surrogate measure of intraoperative blood loss, appears to be the most important predictor of ICA. The complications associated with intraoperative blood loss and blood transfusions are well-known risk factors for cardiac arrests. A review article by Zuercher *et al.*[9] indicates that the cardiovascular complications from hypovolemia from blood loss and hyperkalemia from transfusion of stored erythrocytes are the most common causes of ICA. A study by Smith *et al.*[24] indicates that acidosis, hypothermia, and hypocalcemia in association with hyperkalemia are contributory factors in patients suffering from transfusion-associated ICA. The temporal relationship between ICA and blood transfusion is not recorded in the ACS NSQIP database, thus it is unclear if ICA was a complication of rapid blood loss or a complication associated with rapid blood transfusion. Previous preparation by the surgical team to rapidly transfuse blood as needed, good communication between the surgeons and the anesthesiologists, and point-of-care electrolyte testing may decrease the incidence of ICA associated with blood transfusion.

We also found that the composite indicators of preoperative patient health were important predictors of ICA. High ASA physical status was found to be a significant predictor of ICA even after adjusting for various comorbid conditions such as heart disease, cerebrovascular disease, renal disease, diabetes, and preoperative sepsis. Previous studies have demonstrated similar association between ICA and higher ASA physical status.[7,13] Braz *et al.*[7] analyzed data from 53,718 consecutive anesthetics over a 9-yr period, 92% of the patients experiencing cardiac arrests had an ASA classification of 3 or higher. Newland *et al.*[13] analyzed data from 72,959 consecutive anesthetics over a 10-yr period; 96% of the patients experiencing cardiac arrests had an ASA classification of 3 or higher. Although controversy exists regarding the reliability of ASA physical status classification,[25,26] this study demonstrates its robustness in predicting ICA even after adjusting for other comorbid conditions.

Functional capacity is another composite indicator of patient health. Decreased functional capacity can be caused by several factors such as advanced age, poor pulmonary reserve, deconditioning, and cardiac disease.[21] Poor functional capacity has been associated with increased incidence of postoperative cardiac events.[22] Preoperative functional status is also an important part of preoperative cardiac risk assessment as per guidelines published by both American college of Cardiology and European Society of Cardiology.[21,22] We found that preoperative functional status is another global indicator of patient health, which is a significant predictor of ICA.

The urgency of surgery is a well-established preoperative risk factor for ICA.[3,7] Newland *et al.*[13] reported that 60% of all cardiac arrests occurred in patients of having emergency surgery. Our study indicates that the risk of ICA associated with urgency of surgery was more pronounced in high-risk surgical procedures. The heightened risk of ICA in emergency surgeries is likely due to multiple factors. It is difficult to evaluate and optimize a patient before surgical emergencies such as ruptured aortic aneurysms, perforated or ischemic viscus, ischemic limb, or trauma. Furthermore, patients that require emergency high-risk (vascular) procedures will have an even higher risk of cardiac complications as either the patients are likely to have additional cardiac risk factors or the patients might experience substantial intraoperative fluctuation in volume status, heart rate, and blood pressure.

Historically, respiratory events have played a major role in anesthesia-related cardiac arrests.[3,4,6,27] Although the ACS NSQIP database did not record any direct information related to the ease of ventilation or tracheal intubation, it did record some surrogate indicators of difficult tracheal intubation such as tooth, tongue, pharyngeal or laryngeal injury. The lack of association in the current study between ICA and the inability to perform tracheal intubation, or presence of surrogate measures of difficult tracheal intubation, most likely reflects the improvement in monitoring and clinical practices. Some of the changes in monitoring include widespread adoption of pulse oximetry, capnography, disconnection alarms, and low-pressure alarms.[9] Improvement in clinical practices such as adoption of a standardized algorithm for management of difficult airway might also have decreased the incidence of airway-related cardiac events.[28]

An intriguing finding of this study was that patients with higher BMI had lower incidence of ICA. Previous studies have reported that higher BMI is an independent predictor of short-term survival after in-hospital cardiopulmonary arrest[29] and of long-term survival after ventricular fibrillation in out-of-hospital cardiac arrests.[30] Whether morbid obesity confers any protection against the occurrence of ICAs warrants further investigation.

This study has several notable limitations. First, due to data limitations, it is not clear whether blood transfusion was in response to ICA or whether complications associated with blood transfusion resulted in ICA. Second, due to data limitations, it is unclear whether the patients were medically optimized before the surgery. Thus, it is not clear whether some of these risk factors are modifiable. Data limitations also make it difficult to analyze the role of known factors such as anaphylactic shock in causing ICA. Another limitation of this study is that the ACS NSQIP participating hospitals are not a nationally representative sample, making it impossible to generalize the findings from this study to other hospitals. Participation by hospitals is voluntary, and it is possible that the hospitals with poor outcomes may not participate in the ACS NSQIP program. Furthermore, smaller community hospitals may not be able to afford participation in the ACS NSQIP program. Finally, the data from the current study cannot be extrapolated to patients receiving monitored anesthesia care, patients receiving peripheral nerve block or local anesthesia, trauma cases, transplant cases, cardiac cases, and patients less than 16 yr of age.

In conclusion, this large observational study indicates that ICA occurs at a rate of approximately 7 per 10,000 noncardiac surgeries, with a 30-day mortality rate of 63%. The most important risk factor is the amount of intraoperative erythrocyte transfusion. Other significant predictors of ICA include the urgency of surgery and the composite indicators of patient health such as ASA physical status and the functional status before surgery. The high case fatality suggests that primary prevention might be the key to reducing mortality from ICA.

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