Variation in the Type and Frequency of Postoperative Invasive Staphylococcus aureus Infections According to Type of Surgical Procedure •

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ORIGINAL ARTICLE

Variation in the Type and Frequency of Postoperative Invasive *Staphylococcus aureus* Infections According to Type of Surgical Procedure

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OBJECTIVE. To determine the epidemiological characteristics of postoperative invasive *Staphylococcus aureus* infection following 4 types of major surgical procedures.

DESIGN. Retrospective cohort study.

SETTING. Eleven hospitals (9 community hospitals and 2 tertiary care hospitals) in North Carolina and Virginia.

PATIENTS. Adults undergoing orthopedic, neurosurgical, cardiothoracic, and plastic surgical procedures.

METHODS. We used previously validated, prospectively collected surgical surveillance data for surgical site infection and microbiological data for bloodstream infection. The study period was 2003 through 2006. We defined invasive *S. aureus* infection as either nonsuperficial incisional surgical site infection or bloodstream infection. Nonparametric bootstrapping was used to generate 95% confidence intervals (CIs). P values were generated using the Pearson χ^2 test, Student t test, or Wilcoxon rank-sum test, as appropriate.

RESULTS. In total, 81,267 patients underwent 96,455 procedures during the study period. The overall incidence of invasive *S. aureus* infection was 0.47 infections per 100 procedures (95% CI, 0.43–0.52); 227 (51%) of 446 infections were due to methicillin-resistant *S. aureus.* Invasive *S. aureus* infection was more common after cardiothoracic procedures (incidence, 0.79 infections per 100 procedures [95% CI, 0.62–0.97]) than after orthopedic procedures (0.37 infections per 100 procedures [95% CI, 0.32–0.42]), neurosurgical procedures (0.62 infections per 100 procedures [95% CI, 0.53–0.72]), or plastic surgical procedures (0.32 infections per 100 procedures [95% CI, 0.17–0.47]) ($P < .001$). Similarly, *S. aureus* bloodstream infection was most common after cardiothoracic procedures (incidence, 0.57 infections per 100 procedures [95% CI, 0.43–0.72]; $P < .001$, compared with other procedure types), comprising almost three-quarters of the invasive *S. aureus* infections after these procedures. The highest rate of surgical site infection was observed after neurosurgical procedures (incidence, 0.50 infections per 100 procedures [95% CI, 0.42–0.59]; $P < .001$, compared with other procedure types), comprising 80% of invasive *S. aureus* infections after these procedures.

CONCLUSION. The frequency and type of postoperative invasive *S. aureus* infection varied significantly across procedure types. The highest risk procedures, such as cardiothoracic procedures, should be targeted for ongoing preventative interventions.

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The number of infections caused by *Staphylococcus aureus* has increased dramatically during the past 20 years. Patients undergoing major surgery are at high risk for surgical site infection (SSI) and bloodstream infection (BSI) due to *S. aureus.*[1-7] These *S. aureus* postsurgical infections are associated with increased mortality, length of hospitalization, and cost of care.[8-13]

Surprisingly, the epidemiological characteristics of *S. aureus* postsurgical infections remain incompletely understood. Previous studies on the burden of postoperative *S. aureus* infections have been limited to single procedure types, single healthcare centers, tertiary care institutions, and/or only 1 type of postoperative infection (typically SSI). Thus, the overall objective of this multicenter study was to compare the

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frequency and epidemiological characteristics of *S. aureus* SSI and BSI following 4 types of major surgical procedures in both tertiary and community hospitals.

METHODS

Study Design and Participating Centers

This multicenter retrospective cohort study combined preexisting, prospectively collected surgical surveillance data for SSI and microbiological data for BSI from 11 hospitals located in North Carolina and Virginia. Two surgical surveillance databases were used: the Duke Infection Control Outreach Network (DICON) surgical database and the Duke University Medical Center (DUMC) surgical database. Both of these surgical surveillance databases have been previously described and validated.[14,15] These databases included operative variables, such as patient age, date of surgical procedure, type of procedure, and National Healthcare Safety Network (NHSN) risk index variables (ie, wound class, American Society of Anesthesiologists [ASA] score, and length of procedure).[16] For patients with SSI, the following data were obtained: type of SSI (ie, superficial incisional, deep incisional, or organ/space), causative pathogen, pathogen susceptibility to antibiotics, date of infection, and anatomic site of culture sampling. Patients who developed SSI after undergoing operations were prospectively identified and recorded in the DICON and DUMC surgical surveillance databases by using identical and standard surveillance definitions and methods from the Centers for Disease Control and Prevention (CDC).[17] BSI data were identified by querying study hospitals' microbiological databases for the following variables: patient medical record number, date of culture sampling, culture type ("blood"), pathogen(s), and pathogen susceptibilities to antibiotics. We identified patients who developed BSI after undergoing surgical procedures by electronically merging data from the surgical surveillance databases and the microbiological databases on the basis of the medical record number and dates of surgery and BSI. The study was approved by the institutional review boards at all participating hospitals.

Study Population

The study population consisted of all adult patients (aged at least 18 years) who underwent a major surgical procedure at a study hospital during the period from January 1, 2003, through December 31, 2006. Major surgical procedures were defined as one of the following: specific cardiothoracic procedure (coronary artery bypass graft or prosthetic implant: cardiac valve replacement), neurosurgical procedure (insertion of prosthetic implants [ie, spinal fusion and ventricular shunt replacement], laminectomy, spinal fusion without implant, craniotomy, and other neurosurgical procedure), orthopedic procedure (insertion of prosthetic implants [ie, insertion of knee, hip, or other prosthesis]), open reduction internal fixation of a fracture, other musculoskeletal procedure, or amputation), or plastic surgical procedure (mastectomy, skin graft, or other plastic surgical procedure).

Outcome Variables

The primary outcome for the study, invasive *S. aureus* infection, was defined as invasive SSI and/or BSI due to *S. aureus*. Other study outcomes of interest included the methicillin susceptibility of the invasive *S. aureus* isolate and whether the infection was monomicrobial or polymicrobial.

Collectively, deep incisional and organ/space SSIs were defined as invasive SSIs. According to CDC definitions,[17] SSIs could be diagnosed within 1 year after the procedure for all procedures involving implantation of a prosthetic device; if no prosthetic device was implanted during the procedure, SSIs could be diagnosed within 30 days after the procedure. BSIs were defined with the use of modified CDC criteria: at least 1 positive blood culture result within 90 days after the surgical procedure for all pathogens except coagulase-negative staphylococci, micrococci, propionibacteria, diphtheroids, enterococci, viridans group streptococci, and bacilli, for which at least 2 positive results for cultures of blood collected during a 48-hour period were required.[18] We modified the CDC definition by including enterococci as a type of potential skin contaminant (ie, including it in the list of pathogens for which at least 2 positive blood culture results during a 48-hour period were required) to reduce the effect of contaminants on our results.[19,20]

Statistical Analysis

Patients could undergo multiple major surgical procedures during the study period. Infections were attributed to the patients' most recently performed surgical procedure. Patients' procedures were excluded from the analyses for the following reasons: (1) their procedures were identified as belonging to a dirty or infected wound class; (2) their procedures were performed after documentation of their first *S. aureus* infection; however, patients were included if they had both an *S. aureus* BSI and an *S. aureus* SSI after the same procedure, as long as both infections met the study definitions described above; or (3) their procedures were associated with a superficial incisional *S. aureus* SSI or SSI of unknown type (ie, there was no information to distinguish between superficial SSI and invasive SSI).

A size cutoff of 500 beds was used to categorize each hospital as a community hospital (9 hospitals) or a tertiary care hospital (2 hospitals) (10 DICON hospitals: mean size, 245 beds [range, 102–537 beds]; DUMC: 750 beds). In addition, hospitals were stratified into tertiles on the basis of surgical volume as follows: high surgical volume (range, 9,567–34,458 procedures during the study period; 3 hospitals), medium surgical volume (range, 5,940–9,226 procedures; 4 hospitals), and low surgical volume (range, 1,925–4,891 procedures; 4 hospitals). Two hospitals did not perform cardiothoracic procedures, and 1 hospital did not conduct SSI surveillance on plastic surgical procedures.

All statistical analyses were performed using SAS software, version 9.1 (SAS Institute). All statistical tests were 2 tailed, and a *P* value of less than .05 was considered to indicate a significant difference. Incidences were calculated as the number of infections per 100 surgical procedures. Nonparametric bootstrapping was used to generate 95% confidence intervals (CIs) for the incidences.

Among patients with infection, Kaplan-Meier analyses were performed to compute the median time between the date of the surgical procedure and the date of onset of infection and to make comparisons across procedure types. We used χ^2 statistics to compare proportions of patients with infections due to methicillin-resistant *S. aureus* (MRSA) and patients with infections due to methicillin-susceptible *S. aureus* across types of surgical procedure. Patients whose *S. aureus* isolates lacked susceptibility data were excluded from analyses comparing MRSA and MSSA (8 patients with SSI and 11 patients with BSI). Bivariable comparisons were performed to evaluate which characteristics were associated with the development of invasive *S. aureus* infection by comparing patients who did with patients who did not develop an infection that met our endpoint definitions. Patients with a superficial *S. aureus* infection or an infection due to another pathogen were excluded from the uninfected patient comparison group. *P* values were calculated with the use of the Pearson χ^2 test for categorical variables and the Student *t* test or the Wilcoxon rank-sum test for continuous variables (as indicated).

RESULTS

Overall Study Population

In total, 81,267 patients underwent 96,455 surgical procedures at 11 study hospitals during the 48-month study period; 11,955 patients (14.7%) underwent more than 1 major surgical procedure. The mean age ($\pm$ standard deviation) of the overall cohort at the time of each patient's first surgical procedure was 55 $\pm$ 17 years (range, 18–105 years). In total, 572 *S. aureus* infections and 497 non–*S. aureus* infections were identified during the study period. Of the 572 *S. aureus* infections, 102 superficial incisional SSIs and 16 SSIs of unknown type were subsequently excluded from the analysis. Thus, the final study cohort included 454 invasive *S. aureus* infections in 454 unique patients, which occurred after 96,455 surgical procedures (overall rate, 0.47 infections per 100 procedures [95% CI, 0.43–0.52]).

Of the 454 patients with invasive *S. aureus* infection, 317 patients received a diagnosis of SSI (0.33 infections per 100 procedures [95% CI, 0.29–0.37]), 188 received a diagnosis of BSI (0.19 infections per 100 procedures [95% CI, 0.17–0.22]), and 51 received a diagnosis of both SSI and BSI (0.05 infections per 100 procedures [95% CI, 0.04–0.07]) (Figure 1). The overall incidence of invasive *S. aureus* infection did not change in a statistically significant manner during the 4-year

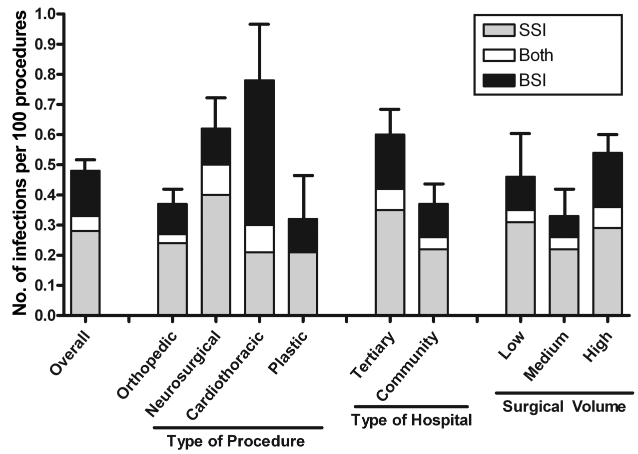

FIGURE 1. Incidence of invasive *Staphylococcus aureus* infection after major surgical procedures in 11 study hospitals, stratified by type of procedure, type of hospital, and surgical volume. Error bars represent 95% confidence intervals for overall rate of invasive *S. aureus* infection. BSI, bloodstream infection; SSI, surgical site infection.

study period (from 101 infections following 17,559 procedures [0.58 infections per 100 procedures] in 2003 to 109 infections following 23,324 procedures [0.47 infections per 100 procedures] in 2006; $P = .09$ for trend).

Approximately one-half of the invasive *S. aureus* infections were due to MRSA (227 [51%] of 446 with susceptibility data); 147 (48%) of the 309 SSIs with susceptibility data were due to MRSA, whereas 107 (60%) of the 178 BSIs with susceptibility data were due to MRSA. Twenty-eight (6.2%) of the 454 invasive *S. aureus* infections, 24 (7.6%) of the 317 *S. aureus* SSIs, and 4 (2.1%) of the 188 *S. aureus* BSIs were polymicrobial.

The median time to onset of invasive *S. aureus* infection after surgery was 30 days (IQR, 13–33). The median time to onset of *S. aureus* SSI after surgery was 19 days (IQR, 13–28), whereas the time to onset of *S. aureus* BSI was 18 days (IQR, 10–44).

Patients with invasive *S. aureus* infections generally had higher NHSN risk index scores than did uninfected patients (Table 1). The higher NHSN risk index scores were reflective of higher ASA scores and significantly longer durations of surgical procedures (typically more than 1 hour longer than for uninfected patients).

Invasive *S. aureus* Infection According to Type of Procedure

The majority of procedures included in the study cohort were orthopedic (57,748 [60%] of 96,455 procedures); there were fewer neurosurgical procedures (24,135 [25%]), cardiothoracic procedures (9,299 [10%]), and plastic surgical procedures (5,273 [5%]). The highest rates of invasive *S. aureus* infection and *S. aureus* BSI occurred after cardiothoracic pro-

TABLE 1. Comparison of Surgical Patients with Postoperative Invasive *Staphylococcus aureus* Infection and Uninfected Surgical Patients, Overall and after 4 Types of Major Surgical Procedures at 11 Hospitals

	Overall			Orthopedic procedure			Neurosurgical procedure			Cardiothoracic procedure[a]			Plastic surgical procedure[b]		
Risk factor	Infected (n = 454)	Uninfected (n = 95,171)	P	Infected (n = 214)	Uninfected (n = 57,197)	P	Infected (n = 150)	Uninfected (n = 23,734)	P	Infected (n = 73)	Uninfected (n = 9,022)	P	Infected (n = 17)	Uninfected (n = 5,218)	P
NHSN risk index			<.001			<.001			<.001			.27			.52
0	51 (11)	38,769 (41)		25 (12)	27,885 (49)		19 (13)	7,756 (33)		0	81 (1)		7 (41)	3,047 (58)	
1	204 (45)	39,715 (42)		102 (48)	22,403 (39)		66 (44)	10,993 (46)		28 (38)	4,404 (49)		8 (47)	1,915 (37)	
⩾2	149 (33)	13,340 (14)		79 (37)	5,750 (10)		35 (23)	3,761 (16)		33 (45)	3,577 (40)		2 (12)	252 (5)	
Missing	50 (11)	3,347 (4)		8 (4)	1,159 (2)		30 (20)	1,224 (5)		12 (16)	960 (11)		0	4 (0.1)	
ASA score			<.001			<.001			<.001			.85			.02
1	8 (2)	9,386 (10)		5 (2)	7,479 (13)		3 (2)	1,272 (5)		0	7 (0.1)		0	628 (12)	
2	106 (23)	43,155 (45)		48 (22)	27,628 (48)		50 (33)	12,462 (53)		1 (1)	116 (1)		7 (41)	2,949 (57)	
3	204 (45)	30,899 (32)		120 (56)	18,740 (33)		58 (39)	8,030 (34)		19 (26)	2,694 (30)		7 (41)	1,435 (28)	
⩾4	97 (21)	9,611 (10)		38 (18)	2,761 (5)		10 (7)	1,021 (4)		46 (63)	5,622 (62)		3 (18)	206 (4)	
Missing	39 (9)	2,120 (2)		3 (1)	588 (1)		29 (19)	949 (4)		7 (10)	583 (6)		0	0	
Wound class			.14			.007			.2			.58			.02
Clean	402 (89)	86,497 (91)		179 (84)	51,688 (90)		144 (96)	22,586 (95)		69 (95)	8,092 (90)		10 (59)	4,131 (79)	
Clean-contaminated	40 (9)	6,662 (7)		24 (11)	3,863 (7)		5 (3)	1,039 (4)		4 (5)	871 (10)		7 (41)	889 (17)	
Contaminated	10 (2)	1,881 (2)		10 (5)	1,571 (3)		0	81 (0.3)		0	31 (0.3)		0	198 (4)	
Missing	2 (0.4)	131 (0.1)		1 (0.5)	75 (0.1)		1 (1)	28 (0.1)		0	28 (0.3)		0	0	
Age, years, median (IQR)	60 (48–71)	55 (43–67)	<.001	61 (49–74)	54 (42–67)	<.001	57 (45–68)	52 (42–63)	.007	64 (55–71)	64 (55–72)	.97	51 (44–60)	55 (44–69)	.54
Length of procedure, minutes, mean ± SD	203.0 ± 150.8	131.5 ± 129.2	<.001	142.3 ± 107.4	99.5 ± 112.3	<.001	243.4 ± 149.1	162.9 ± 119.1	<.001	325.6 ± 171.4	283.8 ± 131.2	.007	82.6 ± 53.3	76.0 ± 114.3	.81

NOTE. Data are no. (%) of patients unless otherwise specified. ASA, American Society of Anesthesiologists; IQR, interquartile range; NHSN, National Healthcare Safety Network; SD, standard deviation.
[a] Two hospitals did not perform cardiothoracic procedures.
[b] One hospital did not conduct surveillance on plastic surgery procedures.

cedures, whereas the highest rate of *S. aureus* SSI occurred after neurosurgical procedures (Table 2).

MRSA was the predominant cause of invasive *S. aureus* infection after cardiothoracic procedures (45 [62%] of 73) and orthopedic procedures (112 [54%] of 207) but not neurosurgical procedures (64 [43%] of 150) or plastic surgical procedures (6 [35%] of 17) ($P = .03$). Of note, MRSA was the predominant cause of *S. aureus* BSI after orthopedic procedures (45 of 69 BSIs with available susceptibility data [65%]) and cardiothoracic procedures (34 of 52 BSIs with available susceptibility data [65%]) and caused 50% of *S. aureus* BSIs after both neurosurgical procedures (25 of 50 BSIs with available susceptibility data) and plastic surgical procedures (3 of 6 BSIs).

Patients who had an invasive *S. aureus* infection had different characteristics than did uninfected patients who underwent the same type of procedure (Table 1). However, specific risk factors, including NHSN risk index, ASA score, wound class, and age, varied across procedure types. The median time to onset of invasive *S. aureus* infection varied significantly according to type of surgical procedure (Table 2).

Invasive *S. aureus* Infection According to Hospital Characteristics

Invasive *S. aureus* infections were more common in tertiary care hospitals ($n = 239$; incidence, 0.61 infections per 100 procedures [95% CI, 0.53–0.68]) than in community hospitals ($n = 215$; incidence, 0.38 infections per 100 procedures [95% CI, 0.33–0.43]; Figure 1). Among infections with available susceptibility data, MRSA was responsible for 112 (54%) of 209 invasive infections due to *S. aureus* in the community hospitals and 115 (49%) of 237 invasive infections due to *S. aureus* in the tertiary care hospitals ($P = .29$); similarly, the proportions of *S. aureus* SSIs due to MRSA (75 of 150 SSIs [50%]) and *S. aureus* BSIs due to MRSA (52 of 82 BSIs [63%]) in community hospitals were not statistically different from the proportions seen in tertiary care hospitals (72 of 167 *S. aureus* SSIs [43%] [$P = .22$] and 55 of 96 *S. aureus* BSIs [57%] [$P = .41$]). Medium-volume hospitals had the lowest incidence of invasive *S. aureus* infections, compared with both high-volume hospitals and low-volume hospitals (Figure 1).

When infection rates for specific types of procedures were compared, tertiary care hospitals had higher rates of invasive *S. aureus* infection after orthopedic, neurosurgical, and cardiothoracic procedures, compared with community hospitals (Table 2). Medium-volume hospitals had lower rates of invasive *S. aureus* infection than did low- or high-volume hospitals for all 4 procedure types (Table 2).

Invasive *S. aureus* Infection after Major Procedures Involving Prosthetic Devices

Of the 22,442 procedures involving implantation of a prosthetic device, the majority were orthopedic (16,549 [74%]), followed by neurosurgical (3,634 [16%]) and cardiothoracic (2,259 [10%]). The overall incidence of invasive *S. aureus* infection after major surgical procedures involving prosthetic devices was 0.70 infections per 100 procedures (95% CI, 0.59–0.81).

Rates of invasive *S. aureus* infection were similar across the 3 procedure types with prosthetic devices (Table 2). Rates of infection after orthopedic and neurosurgical procedures were largely driven by higher rates of SSI; in contrast, the rate of invasive *S. aureus* infection after cardiothoracic procedures was almost entirely due to BSI.

More than half of the infections after placement of a prosthetic device (83 [54%] of 154) were caused by MRSA. MRSA caused 13 (87%) of 15 infections after cardiothoracic procedures involving implants but only 12 (40%) of 30 infections after neurosurgical procedures involving implants (Table 2). The median time from surgery to onset of invasive infection due to *S. aureus* was 27 days (IQR, 17–47). The time to infection varied across the 3 types of surgical procedures (Table 2).

DISCUSSION

This multicenter study is one of the largest studies on invasive *S. aureus* infection after major surgical procedures to date and provides novel information regarding the epidemiological characteristics of invasive *S. aureus* infections. In contrast to previously published reports on postoperative *S. aureus* infection, our epidemiologic analysis included data on 2 types of postoperative infections (SSI and BSI) from different types of hospitals with varying volume of surgical procedures performed. To our knowledge, our analysis is the first to specifically compare the epidemiological characteristics of postoperative *S. aureus* infections following 4 specific procedure types.

Previously published studies have reported overall incidences of postoperative *S. aureus* infection of 0.8–1.3 infections per 100 procedures.[1,21-24] Other studies have reported incidences of *S. aureus* SSI of 0.4–11.6 infections per 100 procedures for cardiothoracic procedures[1,7,25-27] and 0.12–0.73 infections per 100 procedures for orthopedic procedures.[28-31] The reported incidence of postoperative *S. aureus* BSI after cardiothoracic procedures is 0.60–1.09 infections per 100 procedures.[1,7] Our results are generally consistent with these procedure-specific rates, although our overall rate of invasive *S. aureus* infection was lower than that of previously published reports. To our knowledge, no previously published studies have evaluated the rate of *S. aureus* SSI specifically for neurosurgical or plastic surgical procedures and no previously published reports have evaluated the postoperative rate of *S. aureus* BSI following orthopedic, neurosurgical, or plastic surgical procedures. Interstudy comparisons of procedure-specific rates, however, are limited by differences in study methods among different studies (eg, infection definitions, prospective or retrospective classification, distribution of proce-

TABLE 2. Incidence of *Staphylococcus aureus* Infection after Major Surgical Procedures Stratified by Type of Infection, Type of Hospital, and Surgical Volume

Variable	All types of procedures	Orthopedic procedures	Neurosurgical procedures	Cardiothoracic procedures[a]	Plastic surgery procedures[b]	P[c]
Type of infection						
Invasive infection						<.001
Proportion of infections	454/96,455	214/57,748	150/24,135	73/9,299	17/5,273	
Infections per 100 procedures	0.47 (0.43–0.52)	0.37 (0.32–0.42)	0.62 (0.53–0.72)	0.79 (0.61–0.97)	0.32 (0.17–0.47)	
SSI						<.001
Proportion of infections	317/96,455	157/57,748	121/24,135	28/9,299	11/5,273	
Infections per 100 procedures	0.33 (0.29–0.37)	0.27 (0.23–0.32)	0.50 (0.42–0.59)	0.30 (0.18–0.42)	0.21 (0.10–0.34)	
BSI						<.001
Proportion of infections	188/96,455	76/57,748	53/24,135	53/9,299	6/5,273	
Infections per 100 procedures	0.19 (0.17–0.22)	0.13 (0.10–0.16)	0.22 (0.16–0.28)	0.57 (0.43–0.72)	0.11 (0.03–0.21)	
BSI and SSI						<.001
Proportion of infections	51/96,455	19/57,748	24/24,135	8/9,299	0	
Infections per 100 procedures	0.05 (0.04–0.07)	0.03 (0.02–0.05)	0.10 (0.06–0.14)	0.09 (0.03–0.15)	0	
MRSA infection, proportion (% of *S. aureus* infections)[d]	227/446 (51)	112/207 (54)	64/150 (43)	45/73 (62)	6/17 (35)	.03
Polymicrobial infection, no. (% of *S. aureus* infections)	28 (6)	13 (6)	11 (7)	3 (4)	1 (6)	.84
Time to onset of *S. aureus* infection, days, median (IQR)	20 (13–33)	24 (14–41)	17 (13–23)	20 (12–35)	14 (9–28)	<.001
Type of hospital						
Tertiary care						<.001
Proportion of infections	239/39,349	96/22,035	92/11,107	51/6,205	0	
Infections per 100 procedures	0.61 (0.53–0.68)	0.44 (0.35–0.52)	0.83 (0.68–1.00)	0.82 (0.61–1.05)	0	
Community						.004
Proportion of infections	215/57,106	118/35,713	58/13,028	22/3,094	17/5,271	
Infections per 100 procedures	0.38 (0.33–0.43)	0.33 (0.27–0.39)	0.45 (0.34–0.57)	0.71 (0.42–1.03)	0.32 (0.17–0.47)	

Surgical volume of hospital						
Low						.01
Proportion of infections	52/11,045	22/7,092	15/1,861	11/1,529	4/563	
Infections per 100 procedures	0.47 (0.35–0.61)	0.31 (0.20–0.44)	0.81 (0.43–1.24)	0.72 (0.33–1.18)	0.71 (0.18–1.42)	
Medium						.05
Proportion of infections	100/30,310	53/19,515	35/7,220	8/1,989	4/1,586	
Infections per 100 procedures	0.33 (0.26–0.40)	0.27 (0.20–0.34)	0.49 (0.33–0.64)	0.40 (0.15–0.70)	0.25 (0.06–0.57)	
High						<.001
Proportion of infections	302/55,100	139/31,141	100/15,054	54/5,781	9/3,124	
Infections per 100 procedures	0.55 (0.49–0.62)	0.45 (0.37–0.52)	0.66 (0.54–0.78)	0.93 (0.70–1.17)	0.29 (0.13–0.48)	
Procedures involving implantation of prosthetic material[e]						
Invasive infection						.61
Proportion of infections	157/22,442	112/16,549	30/3,634	15/2,259	…	
Infections per 100 procedures	0.70 (0.59–0.81)	0.68 (0.56–0.81)	0.83 (0.52–1.11)	0.64 (0.35–1.00)	…	
SSI						.002
Proportion of infections	132/22,442	101/16,549	29/3,634	2/2,259	…	
Infections per 100 procedures	0.59 (0.49–0.69)	0.61 (0.50–0.73)	0.80 (0.52–1.10)	0.09 (0–0.22)	…	
BSI						<.001
Proportion of infections	42/22,442	21/16,549	8/3,634	13/2,259	…	
Infections per 100 procedures	0.19 (0.13–0.25)	0.13 (0.07–0.18)	0.22 (0.08–0.39)	0.58 (0.27–0.89)	…	
BSI and SSI						.02
Proportion of infections	17/22,442	10/16,549	7/3,634	0	…	
Infections per 100 procedures	0.08 (0.05–0.11)	0.06 (0.02–0.10)	0.19 (0.06–0.33)	0	…	
MRSA infection, proportion (% of *S. aureus* infections)[d]	83/154 (54)	58/109 (53)	12/30 (40)	13/15 (87)	…	.01
Time to onset of invasive *S. aureus* infection, days, median (IQR)	28 (17–47)	29 (17–55)	22 (15–41)	24 (2–33)	…	.04

NOTE. Data are no. of postsurgical invasive *S. aureus* infections; no. of infections per 100 surgical procedures (95% CI), unless otherwise indicated. BSI, bloodstream infection; CI, confidence interval; IQR, interquartile range; MRSA, methicillin-resistant *S. aureus;* SSI, surgical site infection (excluding superficial incisional SSI).

[a] Two hospitals did not perform cardiothoracic procedures.

[b] One hospital did not conduct surveillance for plastic surgery procedures. Only 2 plastic surgical procedures involved the implantation of prosthetic material; thus, these procedures were excluded from the subgroup analysis.

[c] *P* value for comparison of different surgical procedure categories determined with use of Pearson χ^2 test.

[d] *S. aureus* isolates without susceptibility data were excluded from analyses comparing MRSA and methicillin-resistant *S. aureus.*

[e] Includes cardiac valve replacement, spinal fusion with insertion of implants, ventricular shunt replacement, and insertion of knee, hip, or other prosthesis.

dure types, single-center or multicenter study, location, hospital type, and time period). Of note, no specific interventions (eg, screening using nasal samples or bathing with chlorhexidine gluconate) were routinely used at all study hospitals during the study period.

The results of this report make a key point: the frequency and type of postoperative invasive *S. aureus* infection varied significantly across procedure types. Overall, invasive *S. aureus* infections were more common after cardiothoracic procedures than after orthopedic, neurosurgical, or plastic surgical procedures. Similarly, *S. aureus* BSI was most common after cardiothoracic procedures, comprising almost three-quarters of the invasive *S. aureus* infections following this procedure type. By contrast, more than 80% of invasive *S. aureus* infections after neurosurgical procedures were SSIs.

Our results are consistent with previously published data that suggest that MRSA has emerged as the leading cause of invasive postoperative infections.[6,29,32] Overall, MRSA accounted for 51% of postoperative invasive *S. aureus* infections. Wide variability, however, was noted among the 4 procedure types. For example, MRSA accounted for 62% of *S. aureus* infections after cardiothoracic surgery but just 35% of *S. aureus* infections after plastic surgical procedures.

Our analysis also provides unique data regarding the time to onset of invasive *S. aureus* infection following the 4 specific surgical types. Previously published data suggest that most SSIs are detected within 3 weeks after surgery.[33,34] Our overall data were consistent with this finding (median time to invasive *S. aureus* infection was 20 days), but we found wide variability for the 4 surgical types (eg, median time to invasive *S. aureus* infection was 14 days after plastic surgery, 24 days after orthopedic surgery, and 28 days after the insertion of orthopedic prosthetic devices).

Finally, differences were also noted in the rates of invasive *S. aureus* infection after stratifying according to hospital characteristics. Consistent with previously published data, the rate of invasive *S. aureus* infection was higher at tertiary care hospitals than at community hospitals.[35] Also consistent with previously published data, hospitals with high surgical volume or low surgical volume had higher rates of postoperative invasive *S. aureus* infection than hospitals with medium surgical volume.[36] We were unable to determine, however, whether specific differences in case mix among hospitals (eg, predominance of 1 type of procedure) led to the observed associations between surgical volume and rates of invasive *S. aureus* infection.

This study has limitations that likely lead to underestimates of the true incidence of invasive *S. aureus* infection after major surgical procedures. First, we excluded superficial incisional SSIs and other invasive infections (eg, pneumonia). Second, this study did not include data from patients who died before diagnosis of invasive infection or who sought care for postoperative infections at an institution other than the one where the surgical procedure took place. In addition, we were unable to identify the type of SSI (invasive or superficial incisional) for 16 patients with *S. aureus* SSI. However, even if all of these individuals had invasive *S. aureus* infection, the overall incidence would have increased by only 0.016 infections per 100 procedures. Next, we were not able to gather information specifically on the type of antimicrobial prophylaxis used prior to each surgical procedure. In addition, we were unable to determine the source of BSIs (eg, primary vs secondary). Finally, all of the 11 sites included in this study are situated in the southeastern United States.

Despite these limitations, we believe that this study provides novel information for clinicians regarding the epidemiological characteristics of *S. aureus* infections. Our study emphasizes that, with regard to the epidemiologial characteristics of *S. aureus* infections after different types of surgical procedures, one size does not fit all. Although 100% prevention of postoperative infection is likely impossible, we must continue to strive for better preventative interventions for our most deadly and costly infections.

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