Infection Control & Hospital Epidemiology (2022), **43**, 1625–1633
doi:10.1017/ice.2021.462

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Original Article

Staphylococcus aureus infections after elective pediatric surgeries

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Abstract

Objective: To determine the 180-day cumulative incidence of culture-confirmed *Staphylococcus aureus* infections after elective pediatric surgeries.

Design: Retrospective cohort study utilizing the Premier Healthcare database (PHD).

Setting: Inpatient and hospital-based outpatient elective surgical discharges.

Patients: Pediatric patients <18 years who underwent surgery during elective admissions between July 1, 2010, and June 30, 2015, at any of 181 PHD hospitals reporting microbiology results.

Methods: In total, 74 surgical categories were defined using ICD-9-CM and CPT procedure codes. Microbiology results and ICD-9-CM diagnosis codes defined *S. aureus* infection types: bloodstream infection (BSI), surgical site infection (SSI), and other types (urinary tract, respiratory, and all other). Cumulative postsurgical infection incidence was calculated as the number of infections divided by the number of discharges with qualifying elective surgeries.

Results: Among 11,874 inpatient surgical discharges, 180-day *S. aureus* infection incidence was 1.79% overall (1.00% SSI, 0.35% BSI, 0.45% other). Incidence was highest among children <2 years of age (2.76%) and lowest for those 10–17 years (1.49%). Among 50,698 outpatient surgical discharges, incidence was 0.36% overall (0.23% SSI, 0.05% BSI, 0.08% others); it was highest among children <2 years of age (0.57%) and lowest for those aged 10–17 years (0.30%). MRSA incidence was significantly higher after inpatient surgeries (0.68%) than after outpatient surgeries (0.14%; $P < .0001$). Overall, the median days to *S. aureus* infection was longer after outpatient surgery than after inpatient surgery (39 vs. 31 days; $P = .0116$).

Conclusions: These findings illustrate the burden of postoperative *S. aureus* infections in the pediatric population, particularly among young children. These results underscore the need for continued infection prevention efforts and longer-term surveillance after surgery.

Keywords: *Staphylococcus aureus*; blood stream infection; surgical site infection; epidemiology; elective surgery; pediatric

(Received 24 June 2021; accepted 5 October 2021; electronically published 11 March 2022)

Postsurgical infections in children may result in serious morbidity and substantial healthcare utilization.[1–3] Despite efforts to adhere to guidelines and other prevention efforts,[4] infections still occur with varying frequency depending upon the type of surgery and patient population.[5–8] Surgical site infections (SSIs) are currently the third most commonly reported type of healthcare-associated infection (HAI),[9,10] and they occur after 2%–5% of surgeries in the United States.[8,10,11] For pediatric patients, postsurgical infections may be particularly serious, given young age, immature immune systems, as well as comorbidities and congenital conditions that are more prevalent among young children undergoing surgery.[11,12]

Information on postsurgical infections across a broad range of surgeries in both inpatient and outpatient settings is limited, particularly for children. SSI surveillance through the National Healthcare Safety Network (NHSN) is available for selected inpatient surgeries,[13] but comparable data for a broad range of pediatric surgeries, particularly in the ambulatory settings, are more limited despite increasing performance of surgery in the outpatient setting.[14]

Staphylococcus aureus is the second most common cause of HAIs among all patients (children and adults).[10] It is the leading pathogen among healthcare-associated SSIs, ventilator-associated pneumonia, and the second leading pathogen among central-line–associated bloodstream infection (CLABSI) in children.[9] In a study involving SSIs reported to NHSN, of the 3,053 pathogens reported, *S. aureus* was the most common pathogen after pediatric orthopedic surgeries (39%) and cardiac surgeries (55%), and it was the second most common isolate after neurological surgery (28%).[9]

Most studies of pediatric postsurgical *S. aureus* infections have focused on limited surgery types and/or were conducted in single

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PREVIOUS PRESENTATION: Portions of this work were previously presented at the Pediatric Academic Societies Meeting on May 5–8, 2018, in Toronto, Canada.

Cite this article: Munjal IM, *et al.* (2022). *Staphylococcus aureus* infections after elective pediatric surgeries. *Infection Control & Hospital Epidemiology*, 43: 1625–1633, https://doi.org/10.1017/ice.2021.462

centers with large institutional variability.[2,14–30] National-level estimates of pediatric postoperative *S. aureus* infections based on real-world microbiological data are lacking. Surgeries planned during an elective admission may provide an opportunity to maximize perioperative preventative measures to decrease postoperative infections (eg, through a potential vaccine). In this study, we sought to determine the incidence and types of culture-confirmed *S. aureus* infections among a wide variety of pediatric elective surgeries in a large sample of US hospitals.

Methods

In this retrospective study, we utilized data from the Premier Healthcare Database (PHD) to identify *S. aureus* infections among children after inpatient surgeries and hospital-based outpatient surgeries during elective admissions. The PHD is a large, geographically diverse, hospital administrative database containing patient-, hospital-, and payer-level discharge information.[31] Visits from the same hospital were tracked through unique masked identifiers. The PHD represents 20% of US hospital discharges, and data were deidentified. During the study period, 665 hospitals contributed data; 181 hospitals also provided microbiology laboratory data. Culture results include specimen type and site (eg, wound, blood, urine), isolated pathogen(s), and susceptibility results(s).

Discharges for patients <18 years of age with surgeries performed on the day of or day after an elective admission during July 1, 2010, and June 30, 2015, were identified from hospitals continuously reporting microbiology data for ≥180 days following surgery. Admissions with emergency department charges or transfers from other facilities were excluded to restrict the population to surgeries performed during elective admissions. Admissions with *International Classification of Diseases, Ninth Revision Clinical Modification* (ICD-9-CM) diagnosis codes for *S. aureus* infections that were present on admission and those with positive *S. aureus* cultures 2 days prior through 1 day after the surgery were excluded (Fig. 1).

Patient characteristics at index surgical discharge included age, sex, and race. Patient comorbidities were defined according to the Feudtner pediatric complex chronic conditions classification system (CCC v2), including diagnostic and procedure codes indicating likely dependence on medical technology or organ transplantation.[32] Visit characteristics included admission type and source; discharge status and destination; and primary payer. Hospital characteristics included teaching status, urban or rural populations served, geographical region, and bed capacity.

Qualifying surgeries were identified with ICD-9 CM and current procedural terminology (CPT) codes using NHSN operative procedure categories,[33,34] as well as other relevant surgeries identified by one author (M.A.O.), as detailed elsewhere.[35] For discharges with multiple elective procedures in the same anatomic category, the infection was attributed to the surgery with the highest risk of infection according to the NHSN hierarchy.[33] Discharges with multiple surgeries involving >1 surgical category during the index visit were classified in a multiple surgery group. For patients with multiple surgical visits in the 180 days prior to infection, the surgical encounter closest in date to the infection was chosen as the attributable surgery.

Identification of postsurgical *S. aureus* infection was based on an algorithm combining positive nonsurveillance culture results, hospital chargemaster descriptions, and ICD-9-CM diagnosis codes (ICD-10 after October 1, 2015), as detailed elsewhere.[35] Infections were assigned into mutually exclusive categories, in the following order: BSI > SSI > all other. Because culture results did not always distinguish deep incisional and organ-space infections from superficial SSIs, they are reported as a single SSI category. The "all other" infection type category included urinary tract, respiratory, uncertain, and all other types. Uncertain types of *S. aureus* infections were those with a nonspecific culture descriptions from the hospital. All *S. aureus* infections were classified as methicillin sensitive (MSSA) or methicillin resistant (MRSA).

Incident *S. aureus* infections were reported dichotomously overall, by infection category for each of the surgical groups, and by inpatient and outpatient settings for the surgeries. The cumulative incidences of infection were assessed during the index hospitalization for inpatients, and within 30, 90, and 180 days after surgery for both operative settings, and these data are reported per 100 discharges. For patients with >1 type of *S. aureus* infection (eg, BSI and SSI), infection was included once in the numerator of the overall *S. aureus* incidence but individually for the surgical groups.

Projected US inpatient elective surgical volumes were estimated using 2014 surgery counts from the National Inpatient Sample (NIS)[36] for those aged 0–17 years multiplied by the proportion of each surgical category reported during elective admissions in the PHD for the same age group. To estimate the national inpatient *S. aureus* infection burden, surgery-specific infection rates calculated from the subset of PHD hospitals reporting microbiology data were multiplied by the number of nationally projected inpatient elective surgeries.

For descriptive statistics, we used means (standard deviation) or medians (interquartile range) for continuous variables and counts (percentages) for categorical variables. Continuous variables were compared using Student *t* tests or Wilcoxon rank-sum tests, and categorical variables were compared using χ^2 tests. All statistical analyses were performed using SAS version 9.4 software (SAS Institute, Cary, NC), and $P < .05$ was considered statistically significant.

Results

Patient, visit, and hospital characteristics

In total, 62,572 pediatric elective surgical discharges were identified with 11,874 (19.0%) and 50,698 (81.0%) occurring in the inpatient and outpatient settings, respectively. Among these discharges, 5,268 patients (8.42%) had >1 operation. Total postsurgical *S. aureus* infections through 180 days were identified from 393 (0.63%) surgical discharges. Inpatient postsurgical *S. aureus* infections were identified from 213 (1.79%) surgical discharges. Outpatient postsurgical *S. aureus* infections were identified from 180 (0.36%) surgical discharges.

Children with postsurgical *S. aureus* infections tended to be younger, had a greater frequency of Medicaid as the primary payer, and more often had their surgery at a teaching hospital (Table 1). Children with versus without *S. aureus* infection after inpatient surgery were less often discharged to home, were more frequently discharged to another facility, and were more often given codes for complex chronic conditions,[32] indicating a higher level of medical complexity. Children with versus without *S. aureus* infection after outpatient surgery were more often male and were more often treated in rural hospitals.

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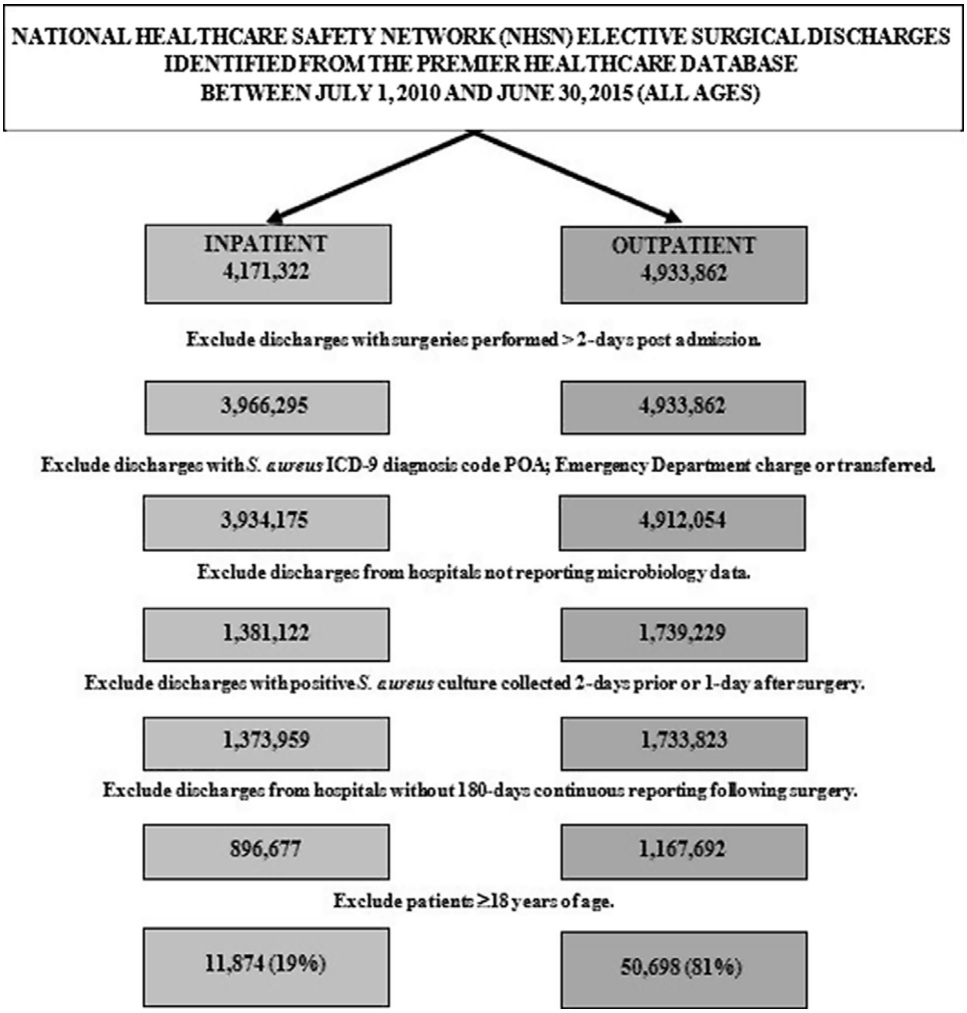

Fig. 1. Attrition. Attrition diagram shows the inclusion and exclusion criteria applied to the inpatient and hospital-based outpatient populations identified in the Premier Healthcare Database with elective surgical discharges between July 1, 2010, and June 30, 2015.

Incidence and time to infection

Staphylococcus aureus incidence was 5-fold higher after inpatient (1.79%) versus hospital-based outpatient (0.36%) surgeries (Fig. 2a and b, Table 2). The cumulative incidence of postsurgical *S. aureus* infections increased steadily from index surgical hospitalization through 180 days for all age groups after inpatient and outpatient surgeries. More than half of infections were identified between 30 and 180 days after surgery in both settings. The most common type of *S. aureus* infection was SSI, followed by BSI, and finally "other" (Table 2). MRSA represented 38% (81 of 213) and 39% (70 of 180) of postsurgical inpatient and outpatient *S. aureus* infections. The overall MRSA incidence was significantly higher after inpatient (0.68%) compared with outpatient (0.14%) surgeries ($P < .0001$). Among surgeries with at least 100 discharges, the highest incidences of MRSA were found after the following surgeries: colon (1.55%), skull (1.26%), and vascular (1.17%). Patients who developed MRSA had characteristics like those who developed an MSSA infection, except a higher proportion with MSSA had a neurologic or neuromuscular comorbidity or were technology dependent after outpatient surgery. We detected slight differences between these groups in the distribution of the bed size for treating hospitals (Supplementary Table 1).

The median number of days to *S. aureus* infection was longer after outpatient compared with inpatient surgery (39 vs. 31 days; $P = .0116$), although these differences for each of the specific types of *S. aureus* infections were not significant (Table 2). Infections in the "other" type category of *S. aureus* infections had the longest median times to positive culture after surgery in both inpatient and outpatient settings. The number of days to infection varied substantially across both surgical settings and all infection types.

Incidence by surgery types and by age groups

Among inpatient surgeries, those involving multiple surgical categories during the same visit were most frequent and had the highest burden of infections by number (Fig. 3a). Among surgeries with at least 100 discharges, the surgeries with the highest 180-day cumulative infection incidences after inpatient surgery were minor neck surgeries (8 of 145, 5.52%), vascular surgeries (7 of 168, 4.17%), and colon surgeries (10 of 288, 3.47%) (Supplementary Table 2). The surgeries with the highest 180-day infection incidences after outpatient surgery were gastric surgeries (4 of 160, 2.50%), vascular surgeries (4 of 173, 2.31%), and exploratory laparotomies (5 of 267, 1.87%) (Supplementary Table 3).

The overall 180-day incidence after inpatient surgery was highest in children aged <2 years (2.76%) followed by those aged 2–9 years (1.74%) and those aged 10–17 years (1.49%) (Fig. 2a). For inpatient surgeries with at least 100 discharges, the surgeries with the highest *S. aureus* incidences in children aged <2 years were minor neck surgeries (7.04%), multiple body systems surgeries (6.29%), and colon surgeries (3.97%) (Supplementary Table 4).

Table 1. Pediatric Patient, Visit, and Hospital Characteristics at the Index Surgical Visit

Variable	Inpatient Surgical Discharges (N=11,874)			Outpatient Surgical Discharges (N=50,698)		
	No Infection (N=11,661)	*S. aureus* Infection Within 180 Days (N=213)	*P* Value	No Infection (N=50,518)	*S. aureus* Infections Within 180 Days (N=180)	*P* Value
Patient characteristics						
Age, mean y ±SD	9.6 ± 6.2	8.1 ± 6.4	.0003	10.0 ± 6.0	8.5 ± 6.3	.0008
Sex, female, no. (%)	6,242 (54)	105 (49)		19,614 (39)	51 (28)	
Race/Ethnicity, no. (%)			.2410			.1651
White	6,930 (59)	130 (61)		31,758 (63)	115 (64)	
African-American	2,256 (19)	32 (15)		9,327 (18)	40 (22)	
Hispanic	129 (1)	4 (2)		556 (1)	2 (1)	
Other	2,346 (20)	47 (22)		8,877 (18)	23 (13)	
Feudtner comorbidities, no. (%)						
Neurologic and neuromuscular	2,023 (17)	64 (30)	<.0001	842 (2)	15 (8)	<.0001
Premature and neonatal	219 (2)	14 (7)	<.0001	150 (0.3)	5 (3)	<.0001
Malignancy	607 (5)	20 (9)	.0068	836 (2)	6 (3)	.0786
Other congenital or genetic defect	2,058 (18)	62 (29)	<.0001	1,014 (2)	15 (8)	<.0001
Metabolic	517 (4)	21 (10)	.0002	465 (0.9)	10 (6)	<.0001
Hematologic or immunologic	435 (4)	14 (7)	.0311	676 (1)	5 (3)	.0940
Gastrointestinal	1,360 (12)	65 (31)	<.0001	646 (1)	19 (11)	<.0001
Renal and urologic	1,416 (12)	40 (19)	.0034	876 (2)	16 (9)	<.0001
Respiratory	1,904 (16)	67 (31)	<.0001	5,723 (11)	30 (17)	.0242
Cardiovascular	924 (8)	41 (19)	<.0001	733 (1)	21 (12)	<.0001
Solid-organ or bone-marrow transplantation	60 (0.5)	3 (1)	.0751	59 (0.1)	0 (0)	.6464
Technology dependence	3,096 (27)	112 (53)	<.0001	1,471 (3.0)	31 (17)	<.0001
Visit characteristics						
Admission source, no. (%)			.4252			.6210
Home	11,554 (99)	210 (99)		50,252 (99)	180 (100)	
Other	85 (0.7)	3 (1)		215 (0.4)	0 (0)	
Born inside hospital	22 (0.2)	0 (0)		51 (0.1)	0 (0)	
Discharge status, no. (%)			<.0001			.9970
Home	10,315 (88)	158 (74)		50,126 (99)	179 (99)	
Expired	8 (0.1)	0 (0)		2 (<0.01)	0 (0)	
Skilled nursing facility, rehabilitation, intensive care facility or long-term care	20 (0.2)	0 (0)		5 (0.01)	0 (0)	
Transferred to acute care	73 (0.6)	3 (1)		16 (0.03)	0 (0)	
Other	1,245 (11)	52 (24)		369 (0.7)	1 (0.6)	
Primary Payer, no. (%)			<.0001			<.0001
Commercial	5,278 (45)	77 (36)		26,576 (53)	67 (37)	
Medicaid	5,649 (48)	124 (58)		20,486 (41)	102 (57)	
Medicare	16 (0.1)	3 (1)		93 (0.2)	3 (2)	
Other Payer	718 (6)	9 (4)		3,363 (7)	8 (4)	
Hospital characteristics						
Teaching status, no. (%)			.0043			.0016
Teaching Hospital	9,642 (83)	192 (90)		30,663 (61)	130 (72)	
Non-Teaching Hospital	2,019 (17)	21 (10)		19,855 (39)	50 (28)	

(*Continued*)

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Table 1. (*Continued*)

Variable	Inpatient Surgical Discharges (N=11,874)			Outpatient Surgical Discharges (N=50,698)		
	No Infection (N=11,661)	*S. aureus* Infection Within 180 Days (N=213)	*P* Value	No Infection (N=50,518)	*S. aureus* Infections Within 180 Days (N=180)	*P* Value
Population served, no. (%)			.1248			.0442
Rural	384 (3)	3 (1)		3,647 (7)	20 (11)	
Urban	11,277 (97)	210 (99)		46,871 (93)	160 (89)	
Geographic region, no. (%)			.0047			.0003
Midwest	1,221 (7)	15 (7)		9,161 (18)	17 (9)	
Northeast	2,719 (23)	63 (30)		4,954 (10)	20 (11)	
South	6,961 (60)	131 (62)		29,272 (58)	129 (72)	
West	760 (7)	4 (2)		7,131 (14)	14 (8)	
Hospital beds, no. (%)			0.1376			0.0602
<100	108 (0.9)	0 (0)		1,428 (3)	6 (3)	
100–199	375 (3)	4 (2)		4,590 (9)	12 (7)	
200–299	2,226 (19)	36 (17)		9,359 (19)	28 (16)	
300–499	4,436 (38)	75 (35)		12,710 (25)	35 (19)	
≥500	4,516 (39)	98 (46)		22,431 (44)	99 (55)	

Note. SD, standard deviation.

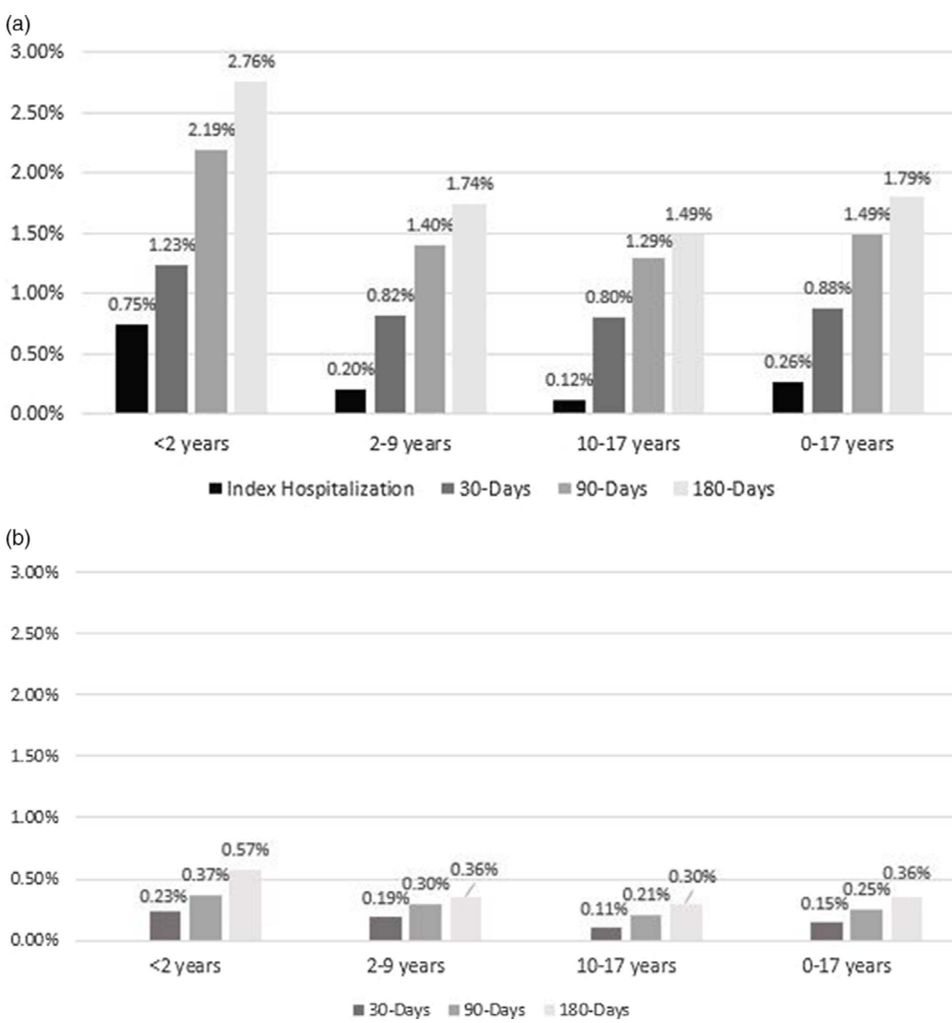

Fig. 2. Cumulative *S. aureus* incidence by timing of infections and pediatric age group after inpatient (a) or outpatient (b) elective surgeries. Bar graphs of *S. aureus* infection incidence at index hospitalization, 30 days, 90 days, and 180 days by age group after inpatient (a) and hospital-based outpatient (b) elective surgical discharges.

https://doi.org/10.1017/ice.2021.462 Published online by Cambridge University Press

Table 2. *Staphylococcus aureus* Infection Incidence and Timing of Infection Within 180 Days After Inpatient and Outpatient Surgeries

	S. aureus Incidence					Days to Infection		
	Inpatient (N=11, 874)		Outpatient (N=50,698)			Inpatient (N=11, 874)	Outpatient (N=50,698)	
Type of *S. aureus* infection	No.	%	No.	%	*P* Value	Median (IQR)	Median (IQR)	*P* Value
All								
Total	213	1.79	180	0.36	<.0001	31 (14–69)	39 (17–101)	.0116
SSI	119	1.00	115	0.23	<.0001	27 (13–62)	36 (17–91)	.0752
BSI	41	0.35	23	0.05	<.0001	28 (11–71)	52 (10–131)	.2568
Other types	53	0.45	42	0.08	<.0001	45 (15–87)	70 (24–108)	.1761
MRSA								
Total	81	0.68	70	0.14	<.0001	27 (12–67)	36.5 (16–88)	.1269
SSI	48	0.40	45	0.09	<.0001	28 (17–59)	37 (13–80)	.4769
BSI	14	0.12	7	0.01	<.0001	17 (11–88)	62 (11–92)	.4553
Other types	19	0.16	18	0.04	<.0001	28 (4–80)	34 (18–119)	.1666

Note. IQR, interquartile range; MRSA, methicillin-resistant *S. aureus*; SSI, surgical site infection; BSI, bloodstream infection.

For those aged 2–9 years, the highest *S. aureus* incidences were observed for plastic surgery or surgeries at other (non-hand) sites (4.95%), multiple body systems surgeries (1.48%), and osteotomy procedures (1.42%). The surgeries with the highest *S. aureus* incidences for those aged 10–17 years were spinal fusion (2.41%), thoracic surgeries (1.90%), and multiple body systems surgeries (1.75%).

The 180-day incidence of *S. aureus* infection after outpatient surgery was also highest for children <2 years of age (0.57%), followed by those aged 2–9 years (0.36%) and those aged 10–17 years (0.30%) (Fig. 2b). For outpatient surgeries with at least 100 discharges, the surgeries with the highest *S. aureus* incidences in children aged <2 years were gastric surgeries (7.14%), vascular surgeries (5.00%), and exploratory laparotomies (3.13%) (Supplementary Table 5). For those aged 2–9 years, the surgeries with the highest *S. aureus* incidences were peripheral or cranial nerve surgeries (6.67%), vascular surgeries (3.03%), and other or unclassified surgeries (2.54%). For those aged 10–17 years, the surgeries with the highest *S. aureus* incidences were lymph node surgeries (1.99%), exploratory laparotomies (1.69%), and vascular surgeries (1.15%).

National inpatient estimates

In 2014, there were an estimated 3,946 pediatric *S. aureus* infections identified within 180 days after 208,960 inpatient surgeries performed during elective admissions in the United States when applying the PHD *S. aureus* incidence rates to the NIS surgical volume estimates (Supplementary Table 2).

Discussion

In this real-world database study, we estimated the 180-day incidence of culture-confirmed *S. aureus* infection in children after elective surgeries performed in inpatient and hospital-based outpatient settings in a large US hospital network. These results add to the published literature by comprehensively summarizing the burden of culture-confirmed *S. aureus* infection following pediatric hospital-based surgeries overall and across all identified surgery types. We have estimated that nearly 4,000 postsurgical *S. aureus* infections occur in the US annually, following ∼200,000 inpatient pediatric surgeries. The infection risk was high, with nearly 2 in 100 inpatient surgeries and 1 in 250 outpatient procedures complicated by a culture-confirmed postoperative *S. aureus* infection.

Staphylococcus aureus infection incidence varied substantially by type of surgery and by surgical setting. Children aged <2 years had the highest incidence of *S. aureus* infections, which was ∼2-fold higher than for those aged 10–17 years. Some of the difference in incidence by age might be explained by greater frequency of higher-risk surgeries in younger versus older children (Supplementary Tables 4 and 5). For example, surgeries with a higher infection risk (eg, colon, stomach or intestine, skull other than craniotomy, and neck) were among the most commonly performed inpatient surgeries in children <2 years. Surgeries with a lower risk of infection such as cesarean section and osteotomy were more common among those aged 10–17 years. These findings highlight the heterogeneity of surgeries performed in the pediatric population, many of which are not part of routine surveillance.

Smaller, single-center studies have reported SSI incidence after a broad range of surgeries for pediatric patients with results similar to the current study. A 2005–2007 study from an Illinois children's hospital reported a *S. aureus* SSI incidence of 2% after pediatric elective surgeries, but no data on infection after individual procedures were reported.[37] Similarly, SSI incidence was 0.99% in a study from the St. Louis Children's Hospital that included only clean and clean-contaminated surgeries (75% ambulatory) from 1996–2008.[15]

Other studies focused on specific pediatric procedures and reported SSI rates ranging from 0.25% to 6% for cardiothoracic surgery[39–41] and 0.5% to 14% for spinal fusion surgery.[22–24,42,43] A 2011 collaborative of 30 children's hospitals reported an SSI incidence of 2.5% after spinal fusion, neurosurgical ventricular shunt, or cardiothoracic surgery, with reduction to 1.8% after implementation of a quality improvement initiative.[38] Among 50 hospitals reporting to the National Surgical Quality Improvement Program-Pediatric (NSQIP-P) 2013 database, the SSI rate was 5.9% after pediatric colorectal surgeries.[21] Another study using

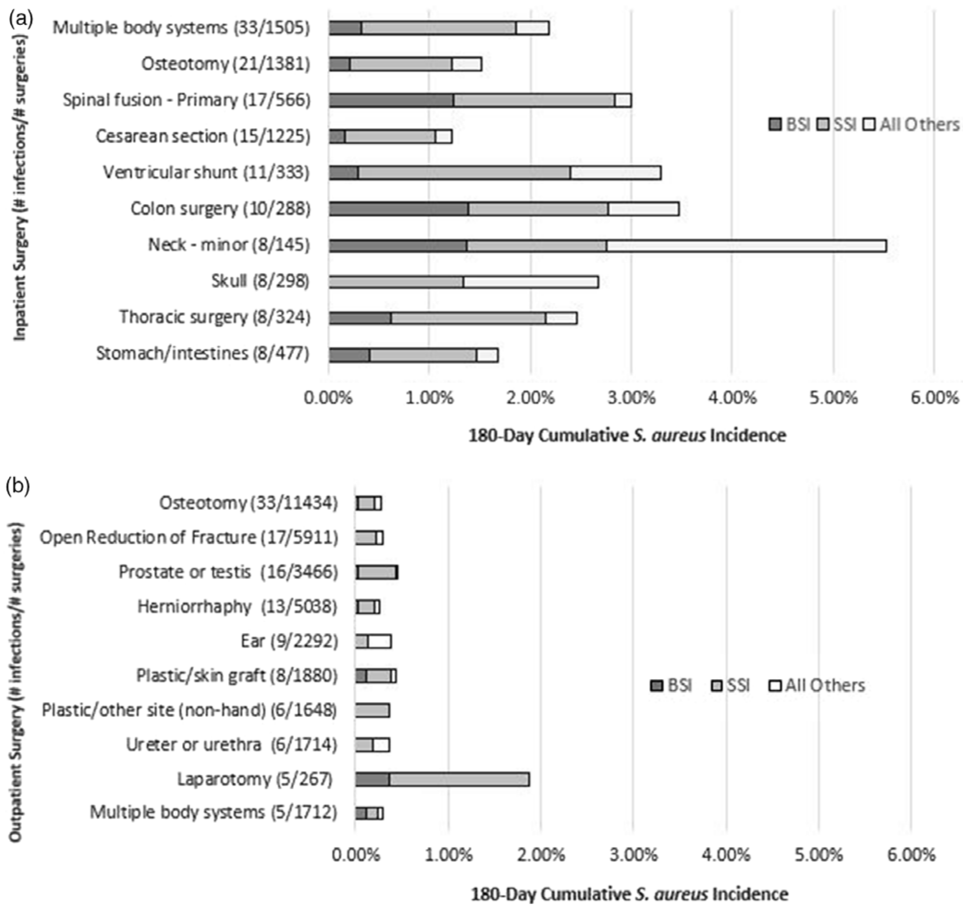

Fig. 3. Pediatric *S. aureus* infection 180-day incidence after (a) inpatient elective surgeries or (b) hospital-based outpatient elective surgeries—top 10 by highest volume by infections. Stacked bar graphs of *S. aureus* surgical site, bloodstream, and other infection types (respiratory, urinary tract infection (UTI), uncertain invasive, and/or all other uncertain sites) at 180 days after inpatient (a) and hospital-based outpatient (b) elective surgical discharges with the highest infection incidence identified from the Premier Healthcare Database microbiology reporting hospitals between July 1, 2010, and June 30, 2015.

the NSQIP-P 2012–2014 database of pediatric neurosurgical surgeries (other than shunt) reported 30-day SSI rates of 2.7%.[3]

The 180-day cumulative incidence of *S. aureus* SSI infection in this study was 5-fold higher after inpatient surgeries (1.0%) compared with hospital-based outpatient surgeries (0.2%). Consistent with our finding, in a single pediatric tertiary-care center, the overall SSI incidence was 0.29% after pediatric ambulatory surgeries during 2009–2014.[44]

SSIs were the most common type of postsurgical *S. aureus* infections in our study, followed by all other types of infection and BSIs. Comparable pediatric studies reporting the incidence of postsurgical BSI and other non-SSI *S. aureus* infections are limited. A study of the Danish Civil Registration System that included children aged 5–18 years during 2000–2015 reported an incidence of postsurgical bacteremia of 0.33%, which is close to the BSI estimate of 0.35% for inpatients in our study.[46]

In this study, MRSA represented 38% and 39% of all *S. aureus* infections after inpatient and outpatient surgeries, respectively. MRSA was commonly isolated in children with *S. aureus* SSI (40% and 39% MRSA after inpatient and outpatient surgeries, respectively) but was slightly less common from children with *S. aureus* BSI (34% after inpatient and 30% after outpatient surgeries). These proportions were slightly higher than those reported by Lake et al[9] of pathogens isolated from SSIs to the NHSN after pediatric surgeries from 2011–2014; 26%–31% of the *S. aureus* isolates were resistant to methicillin, depending on the type of surgery.[9] The difference may be due to inclusion of procedures in this study beyond those under standard NHSN SSI surveillance.

Time to infection onset was significantly longer after outpatient versus inpatient surgeries. In a systematic review of SSI among adults and children of all ages, median time to SSI onset was 17 days and was longer for orthopedic (33.5 days) and transplant (41 days) surgeries.[47] These times are comparable to the median time to SSI in our current study of 31 days after inpatient and 39 days after outpatient surgeries. Recommended surveillance for SSI is for 30 days for superficial incisional and 90 days for deep incisional and organ-space infections associated with a foreign body.[48] The findings in our study point to the need for longer-term monitoring and prevention of infections beyond just the typical 30-day surveillance window. Future studies to determine the incidence and timing of postoperative *S. aureus* infections after emergent surgeries would provide a more comprehensive profile of postoperative *S. aureus* infections in the pediatric population to support surveillance and prevention programs.

This study had several limitations. Neonates are underrepresented in the analysis because of the restriction to elective admission type, and infants or children transferred to a PHD hospital were also excluded. Infections may have been missed if patients presented to hospitals other than the one where the surgery was performed. Data from the subset of hospitals reporting the microbiology laboratory data were assumed to represent the burden of *S. aureus* infections among the selected operative surgeries nationwide. There is no way to verify this assumption, but we included a large sample of 181 hospitals from diverse geographic areas of the United States. Misclassification was possible because the definition for each surgery used administrative codes and not clinical review of medical records. Finally, this study included only culture-positive *S. aureus* cases and missed infections that were not cultured or were culture negative. The study was not designed to evaluate the underlying reasons for variation in infection incidence.

Strengths of the study include the large sample size, which allowed capture of infrequent postsurgical infections among the pediatric population and use of microbiology data to confirm *S. aureus* infections. The PHD includes diverse geographic areas and races or ethnic groups across the United States, including all payers, varying sizes, teaching status, geographic locations, and surgeries from both inpatient and outpatient settings. Additionally, we report the prevalence of specific pediatric comorbidities among patients highlighting areas for future research into underlying conditions that could be targeted for enhanced infection prevention measures and surveillance. Finally, our study included procedure codes defined by the NHSN plus additional categories and focused on surgeries during elective admissions, which may provide a greater opportunity for infection prevention.

In this study, we made a comprehensive assessment of *S. aureus* incidence using microbiology data from a large number of US hospitals. *S. aureus* infection incidence after surgeries performed during an elective admission was highest for the youngest children and for certain surgical groups in the inpatient and outpatient settings that are not currently part of routine SSI surveillance. The surgeries and patient characteristics with higher incidence of infections represent priority areas for existing and novel methods for prevention, such as vaccination. These results may help guide targeted postsurgery infection prevention efforts among children after surgeries performed at US hospitals.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2021.462

Acknowledgments. The authors thank Alvaro Quintana, Pfizer, Inc, for his contributions to the study design and guidance on interpretation of the results; Carol Cohen for her medical writing and editing contributions; and Ning Rosenthal for providing consultation on identification of infections in the Premier Healthcare Database. Jessica Chung, Jake Gundrum, John House, and Roberta James from Premier provided programing and statistical support for this project.

Financial support. The study was performed by Premier Applied Sciences (Premier, Charlotte, NC) with funding from Pfizer.

Conflicts of interest. J.D. was an employee and shareholder of Premier at the time of this work and is now employed by Pfizer. J.G. is an employee of Premier. H.Y., A.G., I.M., and E.B. are employees and shareholders of Pfizer. M.A.O. is a paid consultant by Pfizer, working for Washington University in St. Louis.

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