MAJOR ARTICLE

Relationship between Skin Microbial Counts and Surgical Site Infection after Neurosurgery

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A prospective study was performed to describe the density of bacterial counts on the skin of neurosurgical patients and examine the association between total colony-forming unit (cfu) counts of skin flora at the operative site and surgical site infection (SSI). Two skin cultures were obtained, immediately before and after skin preparation, from the operative sites of 609 neurosurgical patients. SSI surveillance that used Centers for Disease Control/National Nosocomial Infection Surveillance definitions was performed. Predictors for high bacterial counts and SSI among craniotomies were analyzed by means of logistic regression. Neither pre- nor postpreparation counts were associated with SSI. Other SSI risk factors were obesity (relative risk [RR], 2.5), duration of surgery (RR, 1.3 for every additional 30 minutes) and age (RR, 0.7 for each additional 10 years). Duration of skin preparation was not correlated with postpreparation cfu counts. We were unable to detect an association between preoperative bacterial skin counts and SSI.

Surgical site infection (SSI) continues to be a significant problem, particularly after neurosurgery, where infection can result in rehospitalization, multiple operative procedures, and aggressive antibiotic therapy. Most of these infections are caused by organisms that are part of normal skin flora, such as *Staphylococcus* species, *Propionibacterium acnes,* and gram-negative bacilli [1–4]. Further, an increasing number of infections are caused by organisms that are resistant to multiple antibiotics. A few studies have examined the role of the density of the patient's endogenous flora in SSI and have suggested that there may be a correlation between bacterial counts on the skin at the operative site and SSI [5, 6].

Received 7 December 2000; revised 27 March 2001; electronically published 14 September 2001.

This study was approved by the Institutional Review Board of the Columbia University Health Sciences Center.

Fiancial support: 3M, St. Paul, Minnesota.

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Clinical Infectious Diseases 2001; 33:1302–8

1058-4838/2001/3308-0005$03.00

We designed a prospective study in order to describe the density of bacterial counts on the skin of patients who undergo surgery, to determine the prevalence of antibiotic resistance in their skin flora, and to examine whether there is an association between total colony-forming unit (cfu) counts of skin flora at the operative site and subsequent SSI.

METHODS

Over a period of 17 months (January 1999–May 2000), a longitudinal study was conducted in which samples from neurosurgical patients were cultured while the patient was in the operating room and then observed for development of SSI. The study was approved by the institutional review board of the Columbia Presbyterian Medical Center.

Setting and sample. The study took place in an academic health center in New York City in the neurosurgical service. Approximately 1300 eligible procedures were conducted in the year before the inception of the study, with a SSI rate of ~3.4%. On the basis of these figures, and with 609 patients in the study group, we had 80% power to detect a 3-fold increase in risk for SSI in patients with high bacterial counts compared

with patients with lower bacterial counts ($\alpha = 0.05$) [7]. Potential subjects were identified from daily operating room schedules. Study inclusion criteria were met if a patient was at least 18 years old and was undergoing a craniotomy, spinal surgery, or ventriculoperitoneal (VP) shunt insertion, classified as class 1/clean (uninfected operative wound, primarily closed, and, if necessary, drained with closed drainage) by the neurosurgical team.

Sampling and microbiologic techniques. Two skin cultures were obtained in the operating room ~1 cm from the surgical site by the research nurse. The first sample (the prepreparation culture) was taken after hair removal, if any, and before the application of any antiseptic agent. The second sample (postpreparation culture) was collected after the application of antiseptic agents and immediately before the surgeon draped the area for the incision. A sterile cotton swab was moistened with sterile buffered transport medium (composed of 0.075 *M* phosphate buffer, pH 7.9, 0.1% polysorbate 80, 0.1% sodium thiosulfate, and 0.3% lecithin), and a quarter-sized area was swabbed in a circular motion, with approximately the pressure applied when a pencil eraser is used. Each swab was placed in a vial containing 2.0 mL of the transport medium and was plated within 2 h.

Samples were diluted 10-fold in the transport medium, up to 10^{-3}, and were spread plated onto 5% sheep blood agar (BBL) and selective media for isolation of gram-positive cocci (colistin nalidixic acid agar [BBL]), gram-negative rods (MacConkey agar [BBL]), and *P. acnes* (phenylethyl alcohol agar [BBL]). Plates were incubated at 37°C for 48 h. Bacteria were identified by means of standard laboratory identification methods [8, 9]. Oxacillin resistance testing was performed for *Staphylococcus aureus* isolates by use of oxacillin screen agar (BBL). For each sample, total bacterial counts were enumerated, and the 3 most prevalent organisms were recorded, in order of density.

Procedure. The patient preoperative skin preparation was performed by the neurosurgical resident or the attending surgeon. The technique and duration of the surgical site preparation were directly observed and recorded in the operating room by the research nurse. Information on other variables was obtained via chart review. These included age, obesity (defined as a body mass index [BMI] >27), smoking, American Society of Anesthesiologists (ASA) score [12], duration of preoperative hospital stay, history of recent chemotherapy or radiation therapy, surgical procedure, surgeon, duration of surgery, antibiotic use preoperatively and postoperatively, length of hospital stay, use of steroids, and use of postoperative drains at the surgical site.

Surveillance for SSI was performed by the nurse epidemiologist at the study institution by use of standard Centers for Disease Control/National Nosocomial Infection Surveillance (CDC/NNIS) definitions for SSI [10]. Infections were classified as superficial incisional, deep incisional (soft tissue), or organ/space infections (intracranial, osteomyelitis, disc space, spinal abscess, meningitis, or ventriculitis). All patients were followed for at least 60 days postoperatively. Both inpatient and postdischarge surveillance methods were used.

Data analysis. For each sample, total cfu count was converted to a $\log_{10}$ count to normalize the data. Counts were divided into high and low categories. For prepreparation data, the top 30% of bacterial counts was considered to be high. As a result, a log count >5 was considered high, and counts of ⩽5 logs were considered low. For postpreparation data, low counts equaled zero culturable bacteria, and high counts were any values greater than zero. Prevalence of an organism was defined as the percentage of patients from whom that organism was isolated [11].

The main outcome of the study was whether a patient developed a SSI. The χ^2 and Student's *t* test were used as appropriate. Variables that were significant or close to significant were entered into a logistic regression model. Variables were eliminated manually by use of a $P = .05$ cutoff point. The model was checked for confounding and interaction. SPSS, version 9.0, and Epi Info, version 6.04 (CDC), were used for data analysis.

RESULTS

A total of 609 subjects were included in the study. Demographic data are presented in table 1. Most subjects came directly from home and were admitted for surgery at the day of admission. Perioperative and postoperative characteristics are described in table 2. The majority of procedures were craniotomies (469 [77%]), followed by spinal surgeries (102 [17%]) and VP shunt insertions (38 [6%]). Most surgeons used the same procedure for preparing the skin at the surgical site. This included the use of a clipper for hair removal, scrubbing the site with a povidone iodine scrub, rinsing with isopropyl alcohol, and painting the site with povidone iodine paint. Half of the time, the surgeons draped the surgical site before the paint had dried. Perioperative antibiotics were administered to all study patients, and cultures were obtained while prophylactic antibiotics were infusing or within 10–15 min after their completion. An antiseptic-impregnated plastic drape (Ioban; 3M Healthcare) was used for all neurosurgical procedures at the study institution. Neither inpatients nor outpatients were instructed in or given any special skin-cleaning regimen before surgery.

Microbiology. Prepreparation cfu counts varied significantly by the site of surgery: the mean log cfu count for prepreparation samples taken from the head (craniotomies and VP shunt insertions) was 4.13 log (range, 0–7 log), and from

Table 1. Characteristics of 609 patients in a study of skin flora and surgical site infection.

Characteristic	Value
Age, median years (range)	53 (17–88)
Sex, female	356 (58)
Race/ethnicity	
White	459 (75)
Black	53 (9)
Latino	73 (12)
Asian	24 (4)
Diabetic	52 (9)
Smoker	129 (21)
Obese (body mass index >27)	216 (35)
HIV positive	3 (0.5)
Antibiotics before surgery[a]	49 (8)
Chemotherapy before surgery[a]	13 (2)
Radiation therapy before surgery[a]	8 (1)
Steroid therapy before surgery[a]	135 (22)
Admitted from	
Home	548 (90)
Other hospital	3 (0.5)
Long-term-care facility	58 (10)
Previous hospital admission[a]	37 (6)
Hospitalization before surgery, median days	0 (0–77)
No. of patients in hospital	
0 days before surgery	443 (73)
1 day before surgery	62 (10)
⩾2 days before surgery	104 (17)

NOTE. Data are no. (%) of patients, unless otherwise indicated.

[a] Within 30 days before surgery.

backs (spinal surgery) was 2.39 log (range, 0–7 log; $P < .0001$). Eighteen percent of prepreparation samples from backs showed no bacterial growth, and 1.4% of head prepreparation samples had no growth ($P < .0001$). Mean postpreparation log counts from the head (0.62) and back (0.54) were not significantly different, and the proportion of samples with no growth did not differ by site. There was microbial growth in approximately one quarter of postpreparation samples. Not surprisingly, prepreparation cfu counts were correlated with postpreparation cfu counts ($r = .26$, $P < .0001$).

Among those prepreparation and postpreparation samples with microbial growth, coagulase-negative staphylococcus was the most prevalent type of organism (table 3). In prepreparation samples, *P. acnes* was recovered more often from the head than from the back ($P = .0004$), whereas micrococci were more often isolated from the back than from the head ($P < .0001$). In postpreparation samples, the prevalence of organisms did not vary by site. The highest cfu counts in preoperation and postpreparation sampling were found among coagulase-negative staphylococcus (figure 1). None of the *S. aureus* isolates was resistant to oxacillin. No enterococci were isolated.

Patients with high prepreparation counts (>5 logs) were more likely to have been transferred from either a long-term-

Table 2. Perioperative and postoperative characteristics of 609 patients in a study of skin flora and surgical site infection.

Characteristic	Value
Craniotomy	469 (77)
Reason for craniotomy ($n = 469$)	
Tumor	251 (54)
Vascular	139 (30)
Other (e.g., seizure disorder)	79 (17)
Spinal	102 (17)
VP shunt	38 (6)
Previous operation at same site	106 (17)
ASA score [12]	
1–2	423 (69)
3–4	184 (30)
Hair removal	
Clipper	479 (79)
Razor	59 (10)
None	49 (8)
Both clipper and razor	22 (4)
Antiseptics used for skin preparation	
PI scrub/alcohol/PI paint	539 (89)
PI scrub/PI paint	60 (10)
Chlorhexidine scrub/alcohol	10 (2)
Duration of skin preparation, mean s (range)	213 (60–515)
Skin cultured/draped before dry ($n = 420$)	210 (50)
Duration of surgery, mean min	234 (15–745)
Surgery, length >4 h	253 (42)
Postoperative drain used	109 (18)
Type of drain	
Hemovac	64 (10.5)
Spinal drain	26 (4.3)
External ventricular drain	16 (2.6)
Other	2 (0.3)
Type of dressing	
Dry sterile	543 (89)
Transparent	48 (8)
Xeroform gauze	15 (2)
Other	3 (0.5)
Antibiotics used after initial 48 h	114 (19)
Radiation therapy received	6 (1)
Systemic steroids received	522 (86)
Length of stay, median days (range)	4 (1–113)

NOTE. Data are no. (%) of patients, unless otherwise indicated. ASA, American Society of Anesthesiologists; PI, povidone iodine; VP, ventriculoperitoneal.

Table 3. Prevalence of each organism (or group) isolated, among samples with microbial growth, sorted by operative site.

Preparation time	Head, %[a]	Back, %[b]	P[c]
Prepreparation			
CNS	97.8	95.2	.25
Propionibacterium acnes	22.6	6.0	.0004
Micrococci	24.4	48.8	<.0001
Diphtheroids	4.8	3.6	.78
Gram-negative bacilli	2.2	3.6	.44
MSSA	1.4	—	.60
Other	1.6	3.6	.20
Postpreparation			
CNS	81.6	85.7	.77
P. acnes	13.6	—	.13
Micrococci	16.0	19.0	.75
Diphtheroids	4.0	4.8	1.00
Gram-negative bacilli	2.4	—	1.00
MSSA	0.8	—	1.00
Other	1.6	—	1.00

NOTE. CNS, coagulase-negative staphylococci; MSSA, methicillin-sensitive *Staphylococcus aureus*.

[a] Prepreparation, $n = 499$; postpreparation, $n = 125$.

[b] Prepreparation, $n = 84$; postpreparation, $n = 21$.

[c] By χ^2 analysis.

care facility or another hospital than to have been admitted from home ($P = .002$). Patients who had received antineoplastic therapy were slightly less likely to have high counts ($P = .12$). No other variables, including sex, age, diabetes, obesity, steroid use, previous antibiotic use, or previous hospital admissions within 30 days were associated with high prepreparation counts.

Skin preparation. The mean duration of skin preparation was 213 s. Although there was no written hospital policy that detailed the duration of preoperative skin preparation, operating room staff (doctors and nurses) reported that patient skin preparation was supposed to be performed for 5 min. Duration of skin preparation was not correlated with postpreparation cfu count ($P = .31$). We used linear regression to control for the effects of prepreparation counts on a possible association between the duration of skin preparation and postpreparation counts and found that preparation time did not predict subsequent bacterial counts ($P = .75$). There was, however, a weak correlation between prepreparation counts and the duration of the skin preparation ($r = .11$; $P = .006$). To examine the possible effect on preparation duration of having an observer in the operating room, monthly mean preparation duration was plotted. Over the 17 months of the study, mean preparation duration fluctuated, but there was no trend toward increased or decreased time spent on skin preparation. There was no association between having positive postpreparation cultures and draping the area before the povidone iodine had dried ($P = .56$). The use of, or the lack of use of, an isopropyl alcohol rinse during skin preparation was not associated with an increased likelihood of positive postpreparation cultures ($P = .71$).

SSI. Twenty SSI were identified, 19 in craniotomy patients (19 of 469 [4.1%]). There were 6 cases of meningitis, 9 intracranial infections, and 4 superficial infections. There was one infection after spinal surgery, a spinal abscess (1 of 102 [1.0%]) and no infections after VP shunt insertion. The infecting organisms were as follows: coagulase-negative staphylococci (25%), *S. aureus* (20%), *P. acnes* (15%), and polymicrobial (5%). In 6 patients, no culture was obtained, and in 1 patient, the culture showed no growth, despite the fact that it fulfilled the CDC/NNIS criteria for a SSI.

Because there was only one spinal infection and no shunt infections, we examined predictors for SSI among craniotomies alone. Unadjusted associations are presented in table 4. Elevated cfu counts were not associated with SSI. For prepreparation samples, the RR of infection for patients with high counts compared with low counts was 1.19 (95% CI, 0.50–2.96); for postpreparation samples, the RR was 1.79 (95% CI, 0.72–4.44). Variables used for surgical risk stratification in the NNIS system [12], an ASA score ≥ 3, and surgery lasting >4 h were not independently associated with SSI in these data. However, the total NNIS risk index score did predict SSI risk. SSI incidence among patients in risk group 0 was 2.5%, in risk group 1, 5.4%, and for risk group 2, 6.8%. Because all procedures were clean surgeries, no patients were in risk group 3.

Multivariate analysis with logistic regression resulted in the model shown in table 5. Those whose BMI was >27 were 2.9 time more likely to develop a SSI compared with people with a lower BMI. Age and duration of surgery were also significant predictors of SSI. For age, younger people were at a higher risk

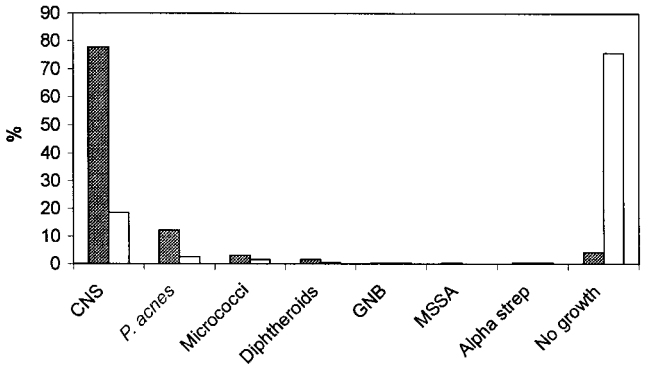

Figure 1. Frequency with which each organism had the highest density in that sample ($n = 609$). *Shaded bars,* before preparation; *open bars,* after preparation. Alpha strep, α-*Streptococcus;* CNS, coagulase-negative staphylococci; GNB, gram-negative bacteria; MSSA, methicillin-susceptible *Staphylococcus aureus;* P. acnes, *Propionibacterium acnes.*

Table 4. Unadjusted factors in surgical site infection after craniotomy.

Variable	RR[a]	95% CI
High prepreparation cfu count	1.19	0.50–2.96
High postpreparation cfu count	1.79	0.72–4.44
Obese (body mass index >27)	2.51	1.03–6.12
Diabetes	1.96	0.60–6.44
Reoperation at same site	2.04	0.76–5.47
ASA score [12] ⩾3	1.33	0.53–3.31
CSF drain used postoperatively	1.91	0.58–6.29

[a] The mean age of patients with surgical site infection (SSI) was 42.4 years; the mean age of patients without SSI was 51.3 years ($P = .01$; *t* test). The mean duration of surgery for patients with SSI was 360 min; the mean duration of surgery for patients without SSI was 265 min ($P = .001$; *t* test). ASA, American Society of Anesthesiologists.

of SSI. For example, a 10-year increase in age would result in a RR of 0.71 for SSI compared with a person 10 years younger. Increased length of surgery resulted in increased risk for SSI. With each additional 30 min of surgery, the RR of infection increased by a factor of 1.3. There was no confounding from other variables, such as the type of craniotomy or diabetes, so these factors were not included in the final model.

DISCUSSION

Microbiology. These microbiologic findings are generally consistent with those of other investigators. The composition of skin flora on the body varies from site to site depending on many factors, including the amount of sebum, the location of sweat glands, and moisture content [13–15]. Prepreparation samples from the back had considerably lower cfu counts than those taken from the head. *P. acnes* was more prevalent on the head, an area with relatively high sebum production [15], whereas micrococci were more prevalent on the back, a drier area [13]. Coagulase-negative staphylococcus was by far the most prevalent and abundant group of organisms in most samples.

The only significant predictor of high prepreparation bacterial counts in these data was admission from another institution. This is likely a reflection of the fact that people who are in the hospital or in a nursing home cannot bathe as often or as completely as when they are at home. Davies et al. [5] also found that long-stay patients had higher cfu counts. Other studies have reported that demographic information is not helpful in predicting skin flora counts [16]. The correlation between prepreparation cfu counts and the length of skin preparation was unexpected. We postulate that surgeons may have spent more time preparing the skin of those they deemed unable to maintain good hygiene. Anecdotal evidence observed by the data collector in the operating room supports this hypothesis.

After the preoperative skin preparation, there was no difference between samples taken from the head or the back in terms of cfu counts and the type of flora isolated. Although the surgeons were aware that their skin preparation procedures were being timed, the mean preparation time was shorter than the 5-min period that they believed skin preparation should last. If anything, preparation times were likely to be slightly longer than usual when the research nurse was present in the operating room. None of the skin preparation variables we observed in the operating room was associated with postpreparation cfu counts, including the duration of the skin preparation. In light of this, perhaps it is time to rethink the value of the lengthy skin preparation, particularly because the preparation occurs while the patient is under anesthesia, increasing his or her risks of complications, and the preparation is performed in the operating suite, where every minute is costly.

SSI. In this study of neurosurgical patients, we found no association between high bacterial counts on the skin of operative sites, either before or after the skin preparation, and subsequent SSI. Although skin flora varies greatly between people, for an individual, its composition and quantity are stable over time [17]. Preoperative skin preparation can remove surface bacteria, but not flora at deeper layers of the skin. Brown et al. [18] have found that people with higher counts on the skin surface also have higher counts in the stratum corneum. They postulated that these bacteria can serve as a reservoir for infection, so higher surface counts would pose a higher risk for infection. Investigators have reported a significant association between bacterial counts on the skin near intravenous catheters and catheter tip colonization, but a link with sepsis has not been conclusively demonstrated [19–21]. In a study of cholecystectomy patients, high preoperative skin counts were associated with increased wound contamination and increased risk of SSI [6]. Among pediatric neurosurgical patients, Leclair et al. [22] compared the efficacy of several preoperative shampoos on operative site bacterial counts and demonstrated a correlation between presurgical cfu counts and levels of intra- and postoperative wound contamination, but the study did not have sufficient statistical power to examine an association with SSI. It is interesting to note, however, that 48% of scalp cultures were positive immediately before wound closure and 30% were positive immediately after closure, and no patients developed SSI.

The present study directly examined the relationship between

Table 5. Final logistic regression model for predictors of surgical site infection.

Variable	Parameter estimate	OR	95% CI
Age, years	−0.0348	0.96	0.93–1.00
Obese	1.0782	2.94	1.09–7.90
Duration of surgery, min	0.0041	1.004	1.001–1.008

SSI and preoperative bacterial cfu counts. Our data on preprep-aration counts and SSI show no association. Looking at post-preparation cfu counts and SSI, there is a slight but nonsignificant association with SSI. If prepreparation bacterial counts are associated with risk for SSI, it is reasonable to expect that predictors of bacterial counts might also be risk factors for SSI. The only significant predictor of high bacterial counts in these data was admission from another institution, which was not associated with SSI in these data. It is possible that the antiseptic-impregnated drape minimized the potential role of skin flora in SSI by continuing to decrease microbial counts after the skin preparation and after the time when sampling could be performed or that the adhesive nature of the drape inhibited bacteria from entering the wound [23, 24]. This could not be examined here because the drape was used on all study patients. In looking at SSI, it is important to note that we did not have sufficient statistical power to detect a RR smaller than 3.

Reported rates of infection after neurosurgery vary from 0% to 15% [3, 22, 25–27]. Use of the NNIS system for risk stratification has recently been validated by Korinek [27], and the present study provides further support for use of risk stratification with neurosurgical patients, even though neither of the components of the risk index—ASA score or surgery duration >4 h—was an independent predictor of SSI. Although the rates of SSI in this study were higher than those most recently published by NNIS [12], increasing risk was associated with increased risk indexes. SSI rates were made known to the infection control and neurosurgical departments, increased infection control measures were undertaken, and SSI rates continue to be monitored. Because the study was not conducted in the setting of an outbreak (there were no common organisms or other commonalties between infected patients), we feel our inferences about risk factors are valid.

Many studies have shown that prolonged duration of surgery increases risk of postoperative infection [1, 27, 28]. The longer duration can be a marker for the complexity of the procedure, the surgeon's skill, or the amount of trauma to the tissues [28]. Our data are in agreement with these findings; however, the 4-h cutoff for surgical duration was not helpful in predicting SSI. Obesity has been described as a risk factor for SSI among other procedures [1, 29–31]. It appears to be a risk factor among craniotomies as well.

The finding that younger age was an independent predictor of SSI is puzzling. This association remained after controlling for the reason for craniotomy (tumor, vascular, etc.), ASA score, length of surgery and length of stay. Other studies have found that older age predicts increased SSI risk [1, 32] or has no effect on SSI [30, 33]. It is possible that another variable describing the severity of illness was not captured in the data collection.

In conclusion, this study of the role of skin flora in SSI has not found an association between bacterial cfu counts and subsequent SSI. Whereas some preoperative measures aimed at resident skin flora, such as eliminating nasal carriage of *S. aureus,* have been shown to be effective in reducing rates of SSI [34], our results call into question the practice of prolonged skin preparation protocols and preoperative showers with antimicrobial agents. Longer skin preparation time was not correlated with subsequent postpreparation bacterial counts. Several studies have documented the efficacy of preoperative showers at reducing skin microbial counts [35–37], but the evidence on their effect on infection rates is less compelling [38–41]. Our study provides more proximal evidence of the role of prepreparation skin flora in SSI, and we therefore suggest that preoperative antimicrobial showers and prolonged skin preparation in the operating room as currently practiced may need reexamination.

Acknowledgments

The help of Dr. Robert Solomon, C. Jusi Thomas, RN, and the staff and physicians of the neurosurgical core of the Columbia-Presbyterian Medical Center (New York) is gratefully acknowledged.

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