






## Original Article

# Postoperative wound care protocol prevents surgical site infection after craniotomy

Mariya Kovryga Kornick MD, MPH<sup>1</sup> , Eunjung Lee MD, PhD<sup>2,3</sup> , Lisa Wilhelm MSN, RN<sup>4</sup>, Janice White DNP, RN<sup>5</sup>, Oh-Hyun Cho MD, PhD<sup>2,6</sup>, Michelle Paff MD<sup>7</sup>, Frank P.K. Hsu MD, PhD<sup>7</sup> , Jefferson Chen MD, PhD<sup>7</sup>, Linda Dickey RN, MPH<sup>1</sup>  and Susan S. Huang MD, MPH<sup>1,2</sup> 

<sup>1</sup>Department of Epidemiology and Infection Prevention, University of California, Irvine Health, Orange, USA, <sup>2</sup>Division of Infectious Diseases, University of California, Irvine School of Medicine, Irvine, USA, <sup>3</sup>Division of Infectious Diseases, Department of Internal Medicine, Soonchunhyang University Seoul Hospital, Soonchunhyang University College of Medicine, Seoul, Republic of Korea, <sup>4</sup>Department of Nursing Education, University of California, Irvine Health, Orange, USA, <sup>5</sup>Nursing Administration, University of California, Irvine Health, Orange, USA, <sup>6</sup>Division of Infectious Diseases, Soonchunhyang University Cheonan Hospital, Cheonan, Republic of Korea and <sup>7</sup>Department of Neurological Surgery, University of California, Irvine School of Medicine, Orange, USA

## Abstract

**Background:** Postoperative wound care after craniotomy is not standardized.

**Objective:** Evaluate the impact of a standardized post-craniotomy wound care protocol on surgical site infection (SSI).

**Design and Setting:** Prospective quasi-experimental single-center intervention cohort study involving adult patients undergoing craniotomy at a 461-bed academic medical center in Orange County, California from January 2019–March 2023 (intervention) compared to January 2017–December 2018 (baseline).

**Methods:** A postoperative neurosurgical wound care protocol was developed involving chlorhexidine cloths to remove incisional clots and to clean the surgical incision and adjacent hair after craniotomy surgery. Protocol adherence was monitored by routine inpatient surveillance of wounds and photo-documentation for real-time feedback to surgeons and nursing staff. Impact of the intervention was assessed using multivariable regression models.

**Results:** There were 3560 craniotomy surgeries and 62 (1.7%) SSIs; 1251 surgeries and 30 (2.4%) SSIs during baseline, and 2309 surgeries and 32 (1.4%) SSIs during intervention. Process evaluation after implementation found significant decreases in incisional clots, erythema, drainage, and unclean hair. In multivariable analysis, the intervention was associated with fewer SSI (odds ratio (OR): 0.5 (0.3, 0.9),  $P = 0.02$ ).

**Conclusions:** A standardized post-craniotomy wound care protocol involving cleaning of the incision and adjacent hair, including removal of incisional clots with chlorhexidine cloths was effective in reducing the risk of SSI.

(Received 16 May 2024; accepted 26 June 2024; electronically published 14 October 2024)

## Introduction

Nearly 50,000 craniotomy procedures are performed annually in the United States.<sup>1</sup> Surgical site infections (SSIs) after craniotomy cause substantial morbidity and mortality, often requiring extended hospital stays and additional operations.<sup>2–4</sup>

Approximately 70% to 95% of SSIs are caused by endogenous flora colonizing the head, neck, and shoulder area.<sup>5</sup> Most SSI prevention strategies involve preoperative chlorhexidine (CHG) bathing, incisional skin antiseptics, appropriate hair removal, antibiotic prophylaxis, intraoperative vancomycin powder and irrigation solution, various closure methods and/or materials, and

managing postoperative hyperglycemia.<sup>6–15</sup> Some also include screening for and decolonizing *Staphylococcus aureus* carriers.<sup>16</sup>

In contrast to preoperative and perioperative SSI prevention guidance,<sup>17</sup> postoperative craniotomy SSI prevention efforts have not been standardized. Evidence-based guidelines do not recommend a specific postoperative wound care protocol.<sup>18</sup> Although various publications for postoperative wound management after craniotomy have included options for advanced dressings<sup>13</sup> and prophylactic topical antibiotic application to the incision,<sup>19</sup> studies focusing on care for postoperative incisional wounds and adjacent hair are lacking.<sup>6</sup>

Post-craniotomy incisional care is complicated by local wound factors, including the high vascularity of the face and scalp (which contributes to clot formation),<sup>20</sup> the high microbial colonization of the sebaceous scalp and head,<sup>5</sup> and the presence of hair, as some neurosurgeons prefer to minimize hair clipping along the incision

**Corresponding author:** Mariya Kovryga Kornick; Email: [mkovryga@hs.uci.edu](mailto:mkovryga@hs.uci.edu)

**Cite this article:** Kovryga Kornick M, Lee E, Wilhelm L, et al. Postoperative wound care protocol prevents surgical site infection after craniotomy. *Infect Control Hosp Epidemiol* 2024. 45: 1399–1404, doi: [10.1017/ice.2024.134](https://doi.org/10.1017/ice.2024.134)

© The Author(s), 2024. Published by Cambridge University Press on behalf of The Society for Healthcare Epidemiology of America. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.



line.<sup>21</sup> Hair not only causes physical contamination of the incision, but it raises questions about how to keep the area clean and keep adhesive dressings in place.

The objectives of this study were to design an effective postoperative wound care protocol for cleaning craniotomy incisions as well as the surrounding hair, and to evaluate the impact on SSI.

## Methods

We conducted a prospective quasi-experimental intervention cohort study of patients undergoing craniotomy at the University of California Irvine Medical Center, a 461-bed academic medical center. We included a 24-month baseline period (January 2017–December 2018) and a 48-month intervention period (January 2019–March 2023), which excluded a 3-month period from October to December 2020 when the intervention program was halted due to the first COVID-19 pandemic surge in California. The program restarted in January 2021, following the December 2020 rollout of the first COVID-19 vaccine to healthcare providers. This quality improvement project was conducted for hospital operations and was exempt from review by an institutional review board.

Descriptive data on craniotomy surgeries were collected from the electronic health record and included common characteristics required for national reporting. This included patient demographics, body mass index, diabetes status, surgical urgency (elective versus emergent), and surgical wound class.

### *Development of a post-craniotomy wound care protocol*

A multidisciplinary performance improvement team was convened at the end of 2018 to create a standardized post-craniotomy wound care protocol to address dressing integrity, incisional clots, postoperative hair cleanliness, and wound care. The team included wound care nurses, neurosurgical nurse specialists, neurosurgeons, and infection prevention leaders. At the time, monthly SSI rates were commonly 2%–4% with most pathogens representing skin flora.

Multiple products were trialed for removing incisional clots: hydrogen peroxide (0.3%, 1.5%, 3%), 2% CHG sponge and swab stick applicators, and 2% CHG cloths. We applied products two-at-a-time on opposite ends of a convenience sample of incisional clots to test their effect on clot removal. We began with lower hydrogen peroxide percentages to find the minimum effective concentration since higher concentrations may cause skin cell damage and adversely affect wound healing.<sup>22</sup> Nevertheless, none of the tested dilutions were effective for clot removal. In trialing CHG, 2% CHG sponge and swab applicators were impractical because their surface material became trapped by metal staples. Warmed 2% CHG cloths were consistently able to soften, loosen, and remove dried blood clots. The developed protocol involved squeezing 2% CHG solution from a warmed impregnated cloth onto the incision and laying the cloth flat for 15 minutes to breakdown dried blood/clots before cleaning the incision with a new CHG cloth.

To address unkempt and/or greasy hair over the incision, the two inches of peri-incisional skin and hair were included in the existing hospital-wide daily CHG bed bathing protocol. This protocol already included cleaning the proximal 6 inches of any surgical drain.<sup>23</sup> To keep hair away from the incision, soft baby hair ties were used, avoiding hard clips or braiding to prevent abrasion or pressure injury. If a dressing was present, cleaning occurred over and around the dressing. This protocol was adopted once the

surgical dressing was removed or on postoperative day 1, whichever came first. Dressings, if used, were typically removed on postoperative day 2, with variation from 1–3 days among neurosurgeons. In addition, shampooing began on postoperative day 3 and occurred every 3 days using 4% rinse-off CHG soap for long hair and 2% CHG cloths for short hair or bald heads. No-rinse shampoo caps were eliminated. The final developed inpatient protocol is found in Supplemental Appendix 1.

### *Intervention implementation*

The intervention period included education and protocol monitoring of all postoperative craniotomy wounds twice-weekly with photo-monitoring by a rounding team consisting of a neurosurgery clinical specialist and an infection preventionist. Adoption of the protocol was facilitated by dissemination of practices via clinical updates, presentations, and demonstrations at the nursing practice councils and department meetings. Protocol ambassadors among doctors and nurses were engaged to promote the protocol among their peers.

Protocol lapses were addressed with just-in-time educational feedback to bedside nurses, and photos of protocol lapses were shared by email with the attending surgeon and unit nurse manager to ensure appropriate response consistent with the protocol. Preoperative processes were unchanged and included preoperative CHG bathing and hair washing for inpatients awaiting surgery.

### *Evaluation of the impact of the post-craniotomy wound care protocol on surgical incision appearance*

Immediately before and after the protocol was implemented, we conducted a series of point prevalence assessments of post-craniotomy incisions, evaluating hair cleanliness, and presence of incisional clots, drainage, edema, erythema, and dehiscence of postoperative wounds. Assessments involved visual assessments and twice-weekly photo-surveys of all inpatients undergoing craniotomy during the end of the baseline period (October–December 2018) and shortly after intervention launch (March–August 2019). Data on incisional appearance were assessed by calculating and comparing the percent of problematic elements among all assessments in the baseline and intervention periods using chi-square tests.

### *Evaluation of the impact of the post-craniotomy wound care protocol on craniotomy SSI*

SSIs were identified according to the Centers for Disease Control and Prevention's National Healthcare Safety Network criteria, and described by depth (superficial, deep incisional, and organ space). The proportion of SSI among craniotomy surgeries was calculated for baseline and intervention periods. Bivariate analyses were conducted by entering patient and surgical characteristics, including period, as independent variables one-by-one into generalized-linear mixed models for the outcome of SSI. Models accounted for clustering by surgeon. Multivariable models were conducted with independent variables entered based upon clinical importance. Significance was assessed using a two-tailed alpha of 0.05 and conducted using SAS version 9.4 (SAS Institute, Cary, NC).

## Results

A total of 3560 craniotomies were performed across the study period, including 1251 during the baseline period and 2309 during

**Table 1.** Characteristics and surgical descriptors of patients undergoing craniotomy

Characteristics	Overall N (%)	Baseline (24-mo) N (%)	Intervention (48-mo) N (%)
N	3560	1251	2309
Age in years (median (IQR))	55 (40, 67)	54 (39, 66)	56 (40, 67)
Male	2022 (56.8)	692 (55.3)	1330 (57.6)
Diabetes	708 (19.9)	214 (17.1)	494 (21.4)
Body mass index $\geq 30$	934 (26.2)	293 (23.4)	641 (27.8)
Prior craniotomy in past year	567 (15.9)	208 (16.6)	359 (15.5)
Wound Class			
I	2945 (82.7)	1022 (81.7)	1922 (83.2)
II	422 (11.9)	157 (12.5)	265 (11.5)
III	72 (2.0)	23 (1.8)	49 (2.1)
IV	121 (3.4)	49 (3.9)	73 (3.2)
Trauma	244 (6.9)	54 (4.3)	190 (8.2)
Emergent operation	663 (18.6)	177 (14.1)	486 (21.0)
Endoscopic	317 (8.9)	113 (9.0)	204 (8.8)
Posterior fossa surgery	193 (5.4)	49 (3.9)	144 (6.2)
Procedure duration in hours (median (IQR))	2.6 (1.7, 3.8)	2.4 (1.5, 3.6)	2.7 (1.8, 4.0)

Note. IQR, interquartile range.

the intervention period. Patient characteristics were similar across the baseline and intervention periods, although patients in the intervention period were slightly more likely to have a body mass index of 30 or greater, diabetes, and an emergent operation or surgery due to trauma (Table 1).

### Intervention impact on craniotomy incision appearance

The pre- and post-evaluation of craniotomy incision appearance involved 308 assessments of 124 patients, including 101 assessments of 45 patients (2.2 photos per incision) during the pre-intervention assessment period, and 207 assessments of 79 patients (2.6 photos per incision) during the assessment period shortly after the intervention began. Characteristics of patients involved in these visual assessments of incisions and results from the visual assessments are shown in Table 2. The intervention was associated with a reduction in problematic wound issues, including a 46.3% reduction in incisional clots ( $P < 0.001$ ), 65.0% reduction in erythema ( $P < 0.001$ ), 68.2% reduction in greasy hair ( $P < 0.001$ ), and 90.0% reduction in drainage ( $P = 0.02$ ). Pictures of wounds before and after completing the wound care protocol are shown in Figure 1.

### Intervention impact on craniotomy surgical site infections

Across the entire study period, among the 3560 craniotomy surgeries, there were 62 SSIs. During the 24-month baseline period, there were 30 (2.4%) SSIs out of 1251 surgeries. This included 2 (6.7%) superficial, 3 (10.0%) deep incisional, and 25 (83.3%) organ-space infections. During the 48-month intervention period,

**Table 2.** Visual assessments of craniotomy incisions pre- and post-intervention, patient characteristics and findings

	Pre-Intervention (3-mo) N (%)	Post-Intervention (6-mo) N (%)	
<b>Characteristics of Assessed Patients</b>			
N	45	79	
Age in years (median (IQR))	60 (53-69)	57 (43-66)	
Male	23 (51.1)	51 (64.6)	
Diabetes	11 (24.4)	21 (26.6)	
Body mass index $\geq 30$	8 (17.8)	17 (21.5)	
Prior craniotomy in past year	6 (13.3)	5 (6.3)	
<b>Reason for surgery</b>			
Brain tumor	16 (35.6)	29 (36.7)	
Hemorrhage (trauma)	15 (33.3)	19 (24.0)	
Hemorrhage (non-trauma)	12 (26.7)	21 (26.6)	
Other	2 (4.4)	10 (12.7)	
Emergent operation	26 (57.8)	38 (48.1)	
Wound Class I	42 (93.3)	77 (97.5)	
Appropriate antibiotic prophylaxis	43 (95.6)	78 (98.7)	
Preoperative CHG bathing <sup>a</sup>	18 (94.7)	35 (85.4)	
<b>Visual Assessment Findings</b>			
	Pre-Intervention (3-months) N (%)	Post-Intervention (6-months) N (%)	P-Value
Number of assessments	101	207	
<b>Blood clots</b>			
Any	70 (69.3)	77 (37.2)	<b>&lt; 0.001</b>
< 50%	36 (35.6)	66 (31.9)	0.52
$\geq 50\%$	34 (33.7)	11 (5.3)	<b>&lt; 0.001</b>
Redness	28 (27.7)	20 (9.7)	<b>&lt; 0.001</b>
Edema	14 (13.9)	21 (10.1)	0.34
Drainage	5 (5.0)	1 (0.5)	<b>0.02</b>
Dehiscence	2 (2.0)	0 (0.0)	0.11
Greasy hair <sup>b</sup>	46 (76.7)	30 (24.4)	<b>&lt; 0.001</b>
Suture (vs staple)	33 (32.7)	68 (32.9)	1.00

Note. IQR, interquartile range; CHG, chlorhexidine.

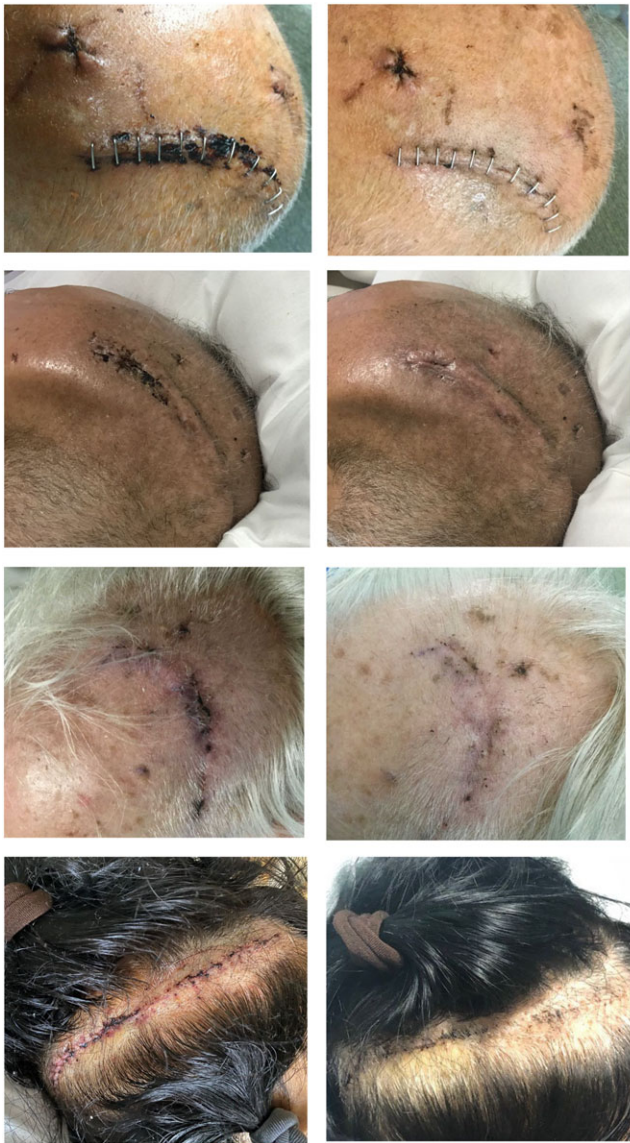
<sup>a</sup>Evaluated among elective surgeries: N = 19 pre-intervention, N = 41 post-intervention.

<sup>b</sup>Patients with hair evaluated.

there were 32 (1.4%) SSIs out of 2309 surgeries, including 2 (6.3%) superficial, 3 (9.4%) deep incisional, and 27 (84.4%) organ-space infections. Figure 2 displays the percent of SSI among craniotomies performed each month before and after the introduction of the post-craniotomy wound care protocol.

Types of pathogens associated with SSI are found in Supplemental Appendix 2.

In bivariate analyses, the intervention period (odds ratio (OR) = 0.6 (0.3, 1.0),  $P = 0.03$ ) and diabetes (OR = 0.4 (0.2, 1.0),  $P = 0.05$ ) were associated with a decreased odds of SSI at alpha  $< 0.1$  while procedure duration (per hour) (OR = 1.2 (1.1, 1.3),  $P < 0.001$ ), previous craniotomy within the past year (OR = 1.8 (1.0, 3.2),  $P = 0.06$ ), and emergent or trauma-related surgery (OR = 1.7



**Figure 1.** Examples of pre-intervention and post-intervention craniotomy wounds during photo-documentation monitoring.

(0.9, 3.0),  $p = 0.08$ ) were associated with increased odds of SSI. In multivariable analysis, the wound care intervention remained significantly associated with reduced SSI while procedure duration, and emergent or trauma-related surgery remained positively associated with SSI (Table 3).

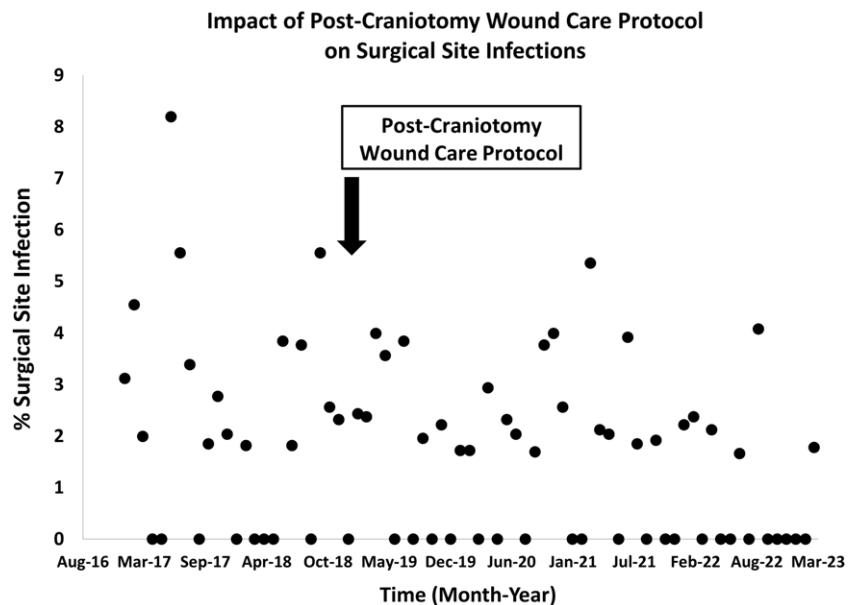
**Discussion**

We found that a post-craniotomy wound care protocol involving warmed CHG-impregnated cloths to remove incisional clots as well as to clean the incision and adjacent hair, in conjunction with soft ties to keep hair away from the incision, was associated with a 50% lower odds of SSI. This highlights the potential value of scalp wound care protocols for postoperative craniotomy care.

Primarily closed surgical wounds begin to seal within 24-48 hours postoperatively. For this reason, we encouraged cleansing of the incision and surrounding hair starting on postoperative day 1. The American College of Surgeons and Surgical Infection Society’s SSI guidelines state that early showering does not increase SSI and can be encouraged at the surgeon’s discretion.<sup>18</sup> These data suggest that early postoperative wound care prevents SSI by reducing bacteria, sweat, and dirt accumulation near the incision.<sup>24</sup> This may be particularly important for the scalp, given commensal bacteria associated with hair follicles and sebaceous glands. Furthermore, postoperative hair washing may be more important when the hair is minimally clipped, as is the preference of several surgeons at our institution.

Before the intervention, we identified several challenges to effective cranial wound cleaning, including inconsistent wound care, and variation in cleansing products, dressings, timing of dressing removal, and instructions about hair washing. There were unclear roles and responsibilities between neurosurgery and nursing for incisional care. This inconsistency likely led to the pre-intervention findings of unkempt and greasy hair and variable dressing practices.

In addition, the scalp’s vascularity often leads to incisional clots, a nutrient source for scalp and facial bacteria. There was reluctance to clean the incision until it was demonstrated that CHG cloths could remove clots without disrupting the wound or impeding healing.



**Figure 2.** Scatterplot of monthly craniotomy surgical site infection rates before and after introduction of the post-craniotomy wound care protocol demonstrating reduction in monthly rates after implementing soft hair ties to keep hair away from the incision, warmed 2% chlorhexidine (CHG) cloths for cleansing and removal of incisional clots on a daily basis, and CHG shampoo for hair every 3 days.

**Table 3.** Multivariable analysis of factors associated with post-craniotomy surgical site infections

Variable	Odds Ratio (95% CI)	P-Value
Wound Care Protocol Intervention (vs Baseline)	0.5 (0.3, 0.9)	0.02
Age (referent <40 years)		0.61
40–49	1.0 (0.4, 2.2)	
50–59	1.2 (0.6, 2.4)	
60–69	0.8 (0.4, 1.9)	
70–79	0.4 (0.1, 1.5)	
80+	1.5 (0.5, 4.6)	
Male sex	1.2 (0.7, 2.1)	0.48
Diabetes	0.4 (0.2, 1.0)	0.06
Body mass index $\geq 30$	1.3 (0.7, 2.3)	0.42
ASA score (referent $\leq 2$ )		0.59
3	1.7 (0.6, 4.3)	
4+	1.6 (0.5, 4.9)	
Prior craniotomy in past year	1.8 (1.0, 3.3)	0.07
Trauma or emergency surgery	2.1 (1.0, 4.3)	0.05
Dirty or contaminated wound class	1.0 (0.4, 2.9)	0.99
Procedure duration in hours	1.2 (1.1, 1.3)	<0.001
Endoscope used	0.6 (0.2, 2.1)	0.47
Posterior fossa surgery	0.5 (0.1, 2.3)	0.40

Note. ASA, American Society of Anesthesiologists.

The post-craniotomy wound care protocol appeared to reduce all depths of SSI. The odds of SSI were reduced by 50% while the distribution of superficial, deep, and organ-space SSIs was unchanged. This suggests that a substantial proportion of post-craniotomy SSI derives from scalp bacteria that enter the incision and cause SSI of all depths, particularly given the proximity of skin to cranial bone.

We highlight the value of a multidisciplinary approach to reduce craniotomy-associated SSI. Engagement of neurosurgeons, wound care nurses, nursing leadership, and infection prevention enabled the formation of a consensus protocol, provided support for training and education, and allowed twice-weekly protocol adherence monitoring of all postoperative craniotomy wounds with rapid feedback to clinical partners and frontline staff for lapses, which were quickly rectified. Photos of the wounds were particularly impactful as an effective visual tool for providing feedback on practice improvement opportunities and increasing adherence to the protocol.

While previous research has focused on multiple preoperative and perioperative practices to reduce SSIs, these results showed that a postoperative antiseptic wound care protocol could reduce nearly half of the SSIs at an academic medical center. Limitations include the single-center nature of study, and the fact that the intervention was interrupted by the COVID-19 pandemic. Nevertheless, the fact that the intervention was only halted for 3 months reflected the adoptability of the protocol and the value conferred by patient care staff.

In conclusion, the implementation of a standardized post-craniotomy wound care protocol using soft hair ties to keep hair

away from the incision, warmed 2% CHG cloths for cleansing and removal of incisional clots on a daily basis, and CHG shampoo for hair every 3 days led to visible improvements in incisional and peri-incisional hygiene, as well as marked reduction in SSIs when paired with ongoing photo-documentation and feedback for protocol adherence.

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1017/ice.2024.134>

#### Acknowledgments.

**Financial support.** This study was supported by usual operational infrastructure and staff at UCI Health. No financial support was provided relevant to this article.

**Competing interest.** All authors report no conflicts of interest relevant to this article.

**Disclosures.** S. Huang conducts other studies in which participating nursing homes and hospitalized patients have received contributed antiseptic product from Xtium laboratories. Companies contributing product have no role in design, conduct, analysis, or publications of studies.

The remaining authors have no further disclosures to declare.

#### References

- National and state healthcare-associated infections progress report, 2022. Centers for Disease Control and Prevention website. <https://www.cdc.gov/hai/data/portal/progress-report.html#Tables>
- Buchanan IA, Donoho DA, Patel A, *et al.* Predictors of surgical site infection after nonemergent craniotomy: a nationwide readmission database analysis. *World Neurosurg* 2018;120:e440–e452.
- Chiang HY, Kamath AS, Pottinger JM, *et al.* Risk factors and outcomes associated with surgical site infections after craniotomy or craniectomy. *J Neurosurg* 2014;120(2):509–521.
- McCutcheon BA, Ubl DS, Babu M, *et al.* Predictors of surgical site infection following craniotomy for intracranial neoplasms: an analysis of prospectively collected data in the American college of surgeons national surgical quality improvement program database. *World Neurosurg* 2016;88:350–358.
- Wenzel RP. Surgical site infections and the microbiome: an updated perspective. *Infect Control Hosp Epidemiol* 2019;40(5):590–596.
- Mann M, Wright CH, Jella T, *et al.* Cranial surgical site infection interventions and prevention bundles: a systematic review of the literature. *World Neurosurg* 2021;148:206–219.e4.
- Davies BM, Patel HC. Does chlorhexidine and povidone-iodine preoperative antiseptics reduce surgical site infection in cranial neurosurgery? *Ann R Coll Surg Engl* 2016;98(6):405–408.
- Corsini Campioli C, Challener D, Comba IY, *et al.* Overview and risk factors for postcraniotomy surgical site infection: a four-year experience. *Antimicrob Steward Healthc Epidemiol* 2022;2(1):e14.
- Ho AL, Cannon JGD, Mohole J, *et al.* Topical vancomycin surgical prophylaxis in pediatric open craniotomies: an institutional experience. *J Neurosurg Pediatr*. 2018;22(6):710–715.
- Mallela AN, Abdullah KG, Brandon C, Richardson AG, Lucas TH. Topical vancomycin reduces surgical-site infections after craniotomy: a prospective, controlled study. *Neurosurgery* 2018;83(4):761–767.
- Ravikumar V, Ho AL, Pendhakar AV, Sussman ES, Kwong-Hon Chow K, Li G. The use of vancomycin powder for surgical prophylaxis following craniotomy. *Neurosurgery* 2017;80(5):754–758.
- Fiani B, Cathel A, Sarhadi KJ, Cohen J, Siddiqi J. Neurosurgical post-operative wound infections: a retrospective study on surgical site infections for quality improvement. *Int Wound J* 2020;17(4):1039–1046.
- Wu N, Li L. A review on wound management strategies in enhanced recovery after craniotomy: an in-depth analysis of their influence on patient recovery and surgical outcomes. *Int Wound J* 2024;21(1):e14595.

14. Bilotta F, Caramia R, Paoloni FP, Delfini R, Rosa G. Safety and efficacy of intensive insulin therapy in critical neurosurgical patients. *Anesthesiology* 2009 Mar;110(3):611–619. doi: [10.1097/ALN.0b013e318198004b](https://doi.org/10.1097/ALN.0b013e318198004b). PMID: 19237874.
15. Jiménez-Martínez E, Cuervo G, Carratalà J, *et al.* A care bundle intervention to prevent surgical site infections after a craniotomy. *Clin Infect Dis* 2021;73(11):e3921–e3928. doi: [10.1093/cid/ciaa884](https://doi.org/10.1093/cid/ciaa884). Erratum in: *Clin Infect Dis*. 2021 May 4;72(9):1686. PMID: 32594119.
16. Nannapaneni S, Satkovich M, Aukerman W, *et al.* Choose your patients wisely: a preoperative protocol to reduce surgical site infection rates in elective neurosurgical procedures. *World Neurosurg* 2022;164:341–346.
17. Berríos-Torres SI, Umscheid CA, Bratzler DW, *et al.* Healthcare infection control practices advisory committee. Centers for disease control and prevention guideline for the prevention of surgical site infection, 2017. *JAMA Surg*. 2017;152(8):784–791. doi: [10.1001/jamasurg.2017.0904](https://doi.org/10.1001/jamasurg.2017.0904). Erratum in: *JAMA Surg*. 2017 Aug 1;152(8):803. PMID: 28467526.
18. Ban KA, Minei JP, Laronga C, *et al.* American college of surgeons and surgical infection society: surgical site infection guidelines, 2016 update. *J Am Coll Surg* 2017;224(1):59–74.
19. Winston KR, McBride LA, Dudekula A. Bandages, dressings, and cranial neurosurgery. *J Neurosurg* 2007;106(6 Suppl):450–454.
20. Cardona S, Hernández C, Bohórquez-Tarazona MP, Rubiano AM, Parra DMS. Scalp wound management: a narrative review from a neurosurgical perspective. *J Wound Care* 2024;33(2):127–135.
21. Sebastian S. Does preoperative scalp shaving result in fewer postoperative wound infections when compared with no scalp shaving? A systematic review. *J Neurosci Nurs* 2012;44(3):149–156.
22. Zhu G, Wang Q, Lu S, Niu Y. Hydrogen peroxide: a potential wound therapeutic target? *Med Princ Pract* 2017;26(4):301–308.
23. Huang SS, Septimus E, Kleinman K, *et al.* ABATE infection trial team. Chlorhexidine versus routine bathing to prevent multidrug-resistant organisms and all-cause bloodstream infections in general medical and surgical units (ABATE Infection trial): a cluster-randomised trial. *Lancet* 2019;393(10177):1205–1215.
24. Toon CD, Sinha S, Davidson BR, Gurusamy KS. Early versus delayed postoperative bathing or showering to prevent wound complications. *Cochrane Database Syst Rev* 2015;2015(7):CD010075.