Case Report

Healing Exposed Calvarial Hardware Using Negative-Pressure Wound Therapy and Vashe Wound Solution: Case Report

Kyle M. Ockerman, BS; Elizabeth A. Cox, MD; Gayle Wiesemann, BS; D. Spencer Nichols, MD; Gregory J. A. Murad, MD; Jessica Ching, MD; and Sarah Sorice-Virk, MD

ABSTRACT

OBJECTIVE: The management of cranioplasty infections has historically been explantation followed by delayed reimplantation/reconstruction. This treatment algorithm necessitates surgery, tissue expansion, and prolonged disfigurement. In this report, the authors describe a treatment approach consisting of serial vacuum-assisted closure (VAC) with hypochlorous acid (HOCl) solution (Vashe Wound Solution; URGO Medical) as a salvage strategy.

METHODS: A 35-year-old man who sustained head trauma, neurosurgical complications, and severe syndrome of the trephined (SOT; devastating neurologic decline treated by cranioplasty) underwent titanium cranioplasty with free flap. Three weeks postoperation, he presented with pressure-related wound dehiscence/partial flap necrosis, exposed hardware, and bacterial infection. Given the severity of his precranioplasty SOT, hardware salvage was critical. He was treated with serial VAC with HOCl solution for 11 days followed by VAC for 18 days and definitive split-thickness skin graft placement over resulting granulation tissue. Authors also conducted a literature review of cranial reconstruction infection management.

RESULTS: The patient remained healed 7 months postoperatively without recurrent infection. Importantly, his original hardware was retained, and his SOT remained resolved. Findings from the literature review support the use of conservative modalities to salvage cranial reconstructions without hardware removal.

CONCLUSIONS: This study investigates a new strategy for managing cranioplasty infections. The VAC with HOCl solution regimen was effective in treating the infection and salvaging the cranioplasty, thus obviating the complications associated with explantation, new cranioplasty, and recurrence of SOT. There is limited literature on the management of cranioplasty infections using conservative treatments. A larger study to better determine the efficacy of VAC with HOCl solution is underway.

KEYWORDS: cranial reconstruction, cranioplasty, hypochlorous acid solution, infection, syndrome of the trephined, vacuum-assisted closure, Vashe Wound Solution

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INTRODUCTION

Cranioplasty with or without flap reconstruction offers patients with cranial defects the opportunity to restore the morphology and protect the contents of the cranial cavity.[1–4] Alloplastic materials, such as titanium mesh, have been widely used in cranioplasty to decrease postoperative complications.[5,6] Despite recent technological advances, cranioplasty is associated with a significant risk of infection, ranging between 5% and 33%.[1,7,8] These devastating infections and complications can lead to increases in morbidity, cost, number of surgical interventions, and neurologic deterioration within an already vulnerable population.[9]

Managing these infections can be challenging because the risk of recurrent infection is high.[10] Historically, explantation and surgical debridement followed by delayed reimplantation/reconstruction have been the standard approach.[11] However, this treatment algorithm necessitates additional surgery in an often tenuous patient population and wound environment, frequently requires tissue expansion, and results in prolonged disfigurement.[12] Discussions of alternative strategies to avoid implant removal are lacking in the plastic surgery literature.[8]

Here, the investigators present a case of infection following cranioplasty that was treated with serial vacuum-assisted closure (VAC) with a hypochlorous acid (HOCl) solution that was commercially available and in the authors' institution's formulary (Vashe Wound Solution; URGO Medical) as a salvage strategy to avoid hardware explantation and its risks. The investigators also reviewed the literature to further understand alternative infection control strategies to better treat this vulnerable patient population.

At the University of Florida College of Medicine, Gainesville, Florida, USA, Kyle M. Ockerman, BS, and Gayle Wiesemann, BS, are Medical Students; Gregory J. A. Murad, MD, is Full Clinical Professor, Department of Neurosurgery; Jessica Ching, MD, is Assistant Professor, Division of Plastic and Reconstructive Surgery; and Sarah Sorice-Virk, MD, is Assistant Professor, Division of Plastic and Reconstructive Surgery. At Stanford University School of Medicine, Palo Alto, California, Elizabeth A. Cox, MD, is Resident, Division of Plastic and Reconstructive Surgery. At Duke University School of Medicine, Durham, North Carolina, D. Spencer Nichols, MD, is Resident, Division of Plastic and Reconstructive Surgery. The authors have disclosed no financial relationships related to this article. Submitted April 30, 2022; accepted in revised form August 12, 2022. Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (www.ASWCjournal.com).

METHODS

One patient who was treated with VAC with HOCl solution postcranioplasty infection at a large academic center was identified about a prospectively maintained database. Demographic data extracted about the patient included age, race, body mass index, medical comorbidity, and prior trauma and neurosurgical history. Procedure-related data extracted included preoperative cranial defect details, hardware type, flap type, treatment duration of VAC with HOCl solution therapy, schedule for VAC change, and final patient and surgeon satisfaction. Infection-related data extracted included time of infection from surgery, signs of infection, and antibiotic regimen (Table 1).

Written informed consent was obtained from this patient for publication of the case report and images. The patient was assessed for capacity to consent; because his neurologic deficits had resolved, he could consent without the use of a caregiver or power of healthcare. University of Florida's Institution Review Board approval was obtained for the retrospective study (approval no. IRB202200259).

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A 35-year-old man presented with a history of intracranial hemorrhage after an assault necessitating emergent craniectomy and multiple prior attempted autologous cranioplasties by the neurosurgical service. Unfortunately, this was complicated by loss of the bone flap secondary to infection. The subsequent large defect then resulted in severe syndrome of the trephined (SOT): a rare and rapid neurologic deterioration resulting from a large craniectomy defect that may progress to "paradoxical" herniation as a result of atmospheric pressure exceeding intracranial pressure. The treatment of SOT is restoring normal intracranial versus extracranial pressure relationships with cranioplasty.[13]

Soft tissue recruitment was necessary because there was insufficient available scalp skin. However, because of the rapidly progressive nature of the SOT and the need for urgent cranioplasty, tissue expansion to gradually expand the existing scalp soft tissue envelope was not possible. Thus, to simultaneously address the soft tissue deficit and bone defect, the patient underwent titanium cranioplasty with a free latissimus dorsi flap and split-thickness skin graft in a joint case with neurosurgery and plastic surgery.

The patient recovered well, and his cognitive status improved dramatically. He was discharged after 29 days in the hospital to a skilled nursing facility. However, 3 weeks postoperation, he presented with pressure-related wound dehiscence, partial flap necrosis, and exposed hardware that measured approximately 4.0 × 2.5 cm. Although the patient showed no signs of infection, computed tomography of the head revealed a collection of intracranial subdural and epidural fluid with air beneath the flap. Wound culture grew extended-spectrum β-lactamase *Escherichia coli* and *Pseudomonas aeruginosa*. Traditionally with this finding, hardware removal would be performed, followed by a 4 to 6 months' interval before reattempting cranioplasty. However, given the severity of the patient's previous SOT and his history of multiple prior surgeries, hardware salvage was attempted to prevent further neurologic decompensation.

The patient was treated with VAC VERAFLO (3M) instilled with 30 mL of HOCl solution with a dwell time

Table 1. PATIENT CHARACTERISTICS AND OUTCOME POST CRANIAL RECONSTRUCTION INFECTION

Characteristic	Patient Data
Age, y	35
Sex	Male
Race/ethnicity	White
Body mass index, kg/m^2	22.24
Diabetes mellitus	No
Tobacco use	No
Cranial reconstruction procedure	Titanium mesh cranioplasty with latissimus dorsi flap and skin graft
SSI/wound type	Exposed titanium mesh, ESBL *E coli*, Pa
Time to SSI, wk	3
Antibiotic regimen	1.5 g IV meropenem
VAC and Vashe treatment length, d	11
VAC treatment length, d	18
Hardware and flap salvaged	Yes
Infection relapse[a]	No

Abbreviations: ESBL, *E coli*, extended-spectrum β-lactamases *Escherichia coli*; Pa, *Pseudomonas aeruginosa*; SSI, surgical site infection; VAC, vacuum-assisted-closure.
[a]Recurrence of infection measured 7 months posttreatment with VAC and Vashe.

of 10 minutes, followed by 12 hours of continuous suction at 75 mm Hg for 11 days. Once the wound appeared clinically clean, the patient was switched to conventional VAC ULTA (3M) therapy with continuous suction at 75 mm Hg for 18 days. His wound VAC was changed Monday, Wednesday, and Friday. He was also treated for 3 weeks with 1.5 g IV meropenem. After the wound fully granulated 3 weeks later, the patient underwent placement of a 12.0 × 2.5-cm meshed split-thickness skin graft.

Literature Review

To further assess current treatment algorithms for infection after cranioplasty, the authors conducted a literature review. They searched PubMed and EMBASE without limits for studies discussing a variety of infection control strategies after cranioplasty (Supplemental Table, http://links.lww.com/NSW/A142). The search was restricted to original clinical studies published in English that discussed infection control strategies after cranioplasty. Review articles and non-English articles were excluded. Studies that involved animals or included noncalvarial or maxillofacial procedures were excluded.

RESULTS

Case Report

Although wound cultures showed scant growth after 4 days of VAC with HOCl solution, the patient had complete resolution of his scalp wound and concomitant infection, resulting in retention of his original cranioplasty and resolution of his SOT (Figure 1). Seven months postoperatively, he remained asymptomatic with a viable and durable soft tissue coverage and complete resolution of his SOT. Both the patient and the surgeon reported satisfaction with his results.

Literature Review

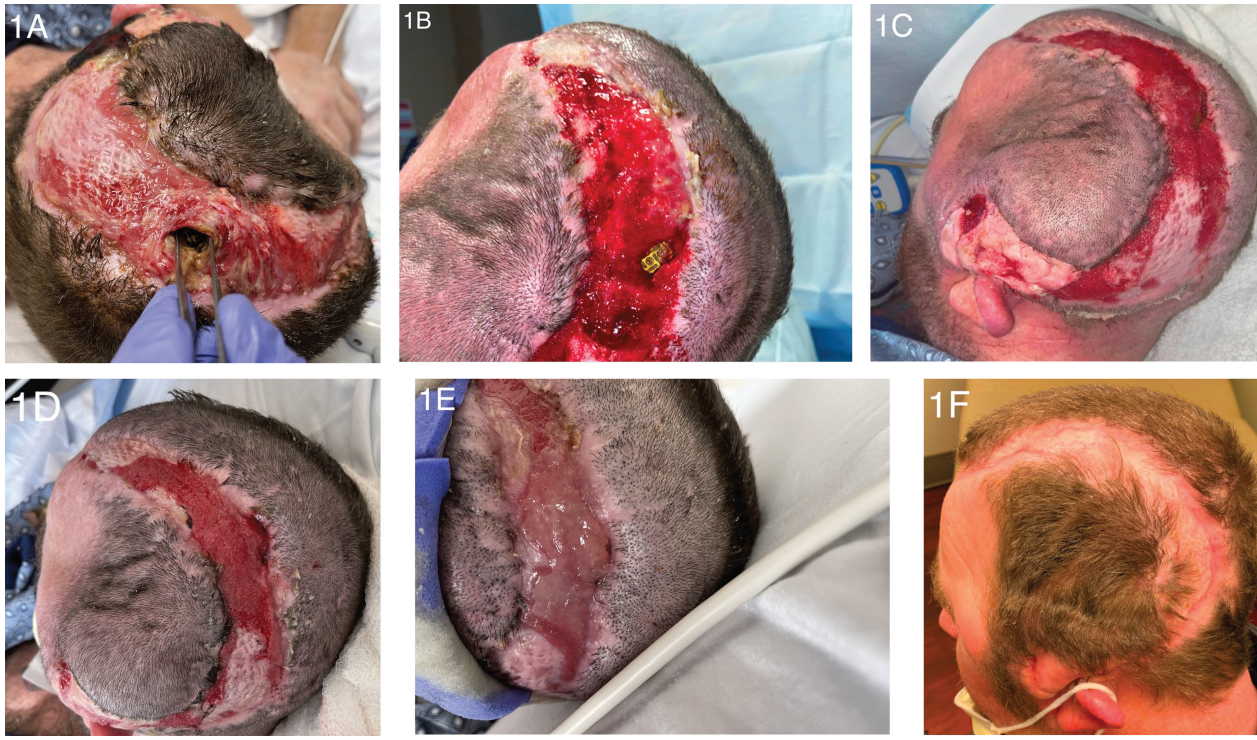
Through this search, the authors identified 12 studies discussing 75 patients who met the inclusion/exclusion criteria (Table 2). This population does not include the patient reviewed in the present investigation.

Postcranioplasty aggressive infection management strategies were described in four studies.[10,11,18,20] Han et al[10] report on 19 patients with titanium mesh exposure and infection who underwent removal of cranioplasty implant and free myocutaneous flap followed by an average of 12 months of no hardware before implant reinsertion. All flaps survived with no complications, and there were no cranioplasty failures or reinfection.[10] Moneim et al[11] describe five patients with exposed titanium plate and infection who underwent cranioplasty implant removal followed by immediate intraoperative autoclave sterilization, skin debridement, and reimplantation followed by postoperative antibiotics. Plate exposure recurred in three of the five patients postoperatively, resulting in one patient repeating the single-stage revision cranioplasty and two patients removing the plate.[11] After the plate was removed, those patients remained complication-free.[11] Yoshioka[14] describes two patients with postcranioplasty infection who underwent implant removal followed by immediate intraoperative autoclave sterilization, obliteration of the epidural space using free latissimus dorsi muscle flap, and reimplantation followed by antibiotics postoperation. Neither patient had any complications or reinfections during the 6- to 22-month postoperation period.[18] Zhao et al[20] report on eight patients identified with skin and titanium mesh exposure who underwent implant followed by immediate sterilization, reimplantation, and reversed temporal island flap coverage.[20] These patients had no complications during the 10- to 24-month follow-up period; the authors reported survival of all flaps.

In contrast, eight studies reported on postcranioplasty conservative infection management strategies.[9,14–17,19,21,22] In the article by Chen et al,[9] 11 patients with infection under the skin flap after cranioplasty received 3 weeks of systemic IV antibiotics and 1 week of enclosed continuous irrigation and drainage. All 11 patients salvaged their implants and had no recurrence of infection for 2 to 6 years postoperation.[9] Hwang and Chang[15] describe a patient with scalp necrosis and implant exposure postcranioplasty who underwent debridement and a transposition flap followed by an indwelling antibiotic irrigation system for 5 days and IV vancomycin for 4 weeks.[15] The flap survived, and the patient had no reinfection at 4 months postoperatively.[15] In the article by Huang et al,[14] 21 patients with implant infection and titanium mesh exposure received U-shaped surgical debridement and either total removal (n = 4), partial removal (n = 3), or retention of titanium implant (n = 14) followed by immediate negative-pressure wound therapy (NPWT) with chymotrypsin irrigation for 5 days.[14] Notably, 1 of the 21 patients experienced treatment failure and underwent a second debridement to remove the implant.[14] The rest of the patients who retained their hardware did not have any other surgical or reconstructive procedures and remained free from infection 2 years postoperatively.[14] Dupuy et al[21] treated two patients with infected and exposed hardware with surgical debridement followed by less than 3 weeks of NPWT and reconstruction by locoregional or free flap. Two years after treatment, the two patients remained free of infection.[21] Hu et al[16] report on a patient presenting with epidural infection after cranioplasty who was treated with vancomycin and corticosteroids for 2 weeks. Five months after treatment, no evidence of reinfection was observed.[16] Iaccarino et al[17] describe four patients with septic complications and no exposed hardware postcranioplasty who were treated

Figure. WOUND PROGRESSION

A, Initial presentation of flap necrosis. B, Five days of successive vacuum-assisted closure (VAC) with hypochlorous acid (HOCl) solution. C, Seven days of successive VAC with HOCl solution. D, Eleven days of successive VAC with HOCl solution followed by 10 days of successive traditional VAC. E, Prior to skin graft. F, Two months after treatment.



with surgical debridement followed by antibiotics for an average of 2 months. Two to 7 years after treatment, all four patients remained healed with no instances of recurrence.[17] As reported by Zanotti et al,[19] one patient with infection and no exposed hardware postcranioplasty underwent levofloxacin and rifampicin every 24 hours for 8 weeks followed by debridement. At 2-year follow-up, the patient remained infection-free.[19] Johnson et al[22] treated a patient with skin necrosis and exposure of hardware with IV antibiotics for 3 weeks followed by debridement, drainage of infected tissue, scalp rotation flap, and 3 more weeks of antibiotics. The patient salvaged their hardware and was without infection 18 months after treatment.[22]

DISCUSSION

Cranioplasty carries a high risk of complications. A main concern is wound dehiscence, which can lead to exposed hardware and hardware infection.[23] Most studies have confirmed that the best treatment for cranioplasty infection is explantation and implantation of the hardware.[10,11,20] However, this algorithm carries significant additional morbidity in a challenging patient population, including increased risks of poor healing in a tenuous wound environment, delayed cognitive and motor recovery, devastating psychosocial consequences, and increased cost.[14] Because of these adverse complications, many patients may even refuse to undergo cranioplasty after explantation.[24] In addition to poor cosmesis, lack of skull protection can lead to sunken syndrome, otherwise known as SOT, a rare and rapid deterioration of cognitive function as a result of aberrant intracranial and extracranial pressure relationships.[14,16]

To address these issues, a variety of conservative treatment management strategies have been reported in the literature. Johnson et al[22] reported the first case of an infected hydroxyapatite (HA) cranioplasty prosthesis that was conservatively treated without removing the implant using antibiotics, surgical debridement, drainage, and rotation flap. Iaccarino et al[17] similarly found that antibiotics and surgical debridement were successful in treating four cases of severe septic complications following HA cranioplasty while salvaging the cranioplasty. The authors indicated that they could avoid prosthesis removal due to targeted antibiotic therapy, wound surgical revision, and the biomimetism of HA prosthesis. Zanotti et al[19] successfully salvaged an infected HA cranioplasty prosthesis without explantation through the use of targeted antibiotics followed by debridement. Six years after treatment, the patient revealed no problems or reinfections with the implant.[19]

Table 2. STUDY AND PATIENT DEMOGRAPHICS

Reference, Year, Country	Type	N	Sex, n (%)		Age, y, Mean (SD)	Cranial Reconstruction Procedure	SSI Type	Time to Infection Post-CP, d, Mean (SD)	SSI Treatment(s)	Cure Rate n (%)
			Male	Female						
Han et al,[10] 2021, China	CS	19	15 (78.9)	4 (21)	41.89 (16.2)	Titanium mesh CP	Klebsiella (n = 1), Pa (n = 3), *S aureus* (n = 7), *S epidermidis* (n = 3)	217.7 (7.8)	Explantation, free myocutaneous flap, and reimplantation	19 (100)
Chen et al,[9] 2020, China	CS	11	8 (72.7)	3 (27.3)	41.8 (11.2)	Titanium mesh CP	Ab (n = 1), *E cloacae* (n = 1), *S aureus* (n = 5), *S epidermidis* (n = 4)	7.5 (2.2)	IV antibiotics and irrigation and drainage system	11 (100)
Huang et al,[14] 2020, China	CS	21	8 (38)	13 (62)	47.2	Titanium mesh CP	Ab (n = 1), Kp (n = 1), Pa (n = 3), *S aureus* (n = 9), *S capitis* (n = 1), *S epidermidis* (n = 2), *S intermedius* (n = 1)	40.48	Surgical debridement; total, partial, or no implant removal; and NPWTi with chymotrypsin	20 (95.2)
Hwang and Chang,[15] 2020, Korea	CR	1	1 (100)	0 (0)	73	Polyethylene implant CP	MRSA (N = 1)	90	Surgical debridement, transposition flap, antibiotic irrigation system, and IV antibiotic	1 (100)
Moneim et al,[11] 2020, UK	CS	5	4 (80)	1 (20)	36.88 (0.36)	Titanium CP	Pa (n = 1), P spp (n = 1), *S aureus* (n = 2)	—	Explantation, intraoperative autoclave sterilization, reimplantation, debridement, and antibiotics	2 (40)
Hu et al,[16] 2018, China	CR	1	1 (100)	0 (0)	41	Titanium alloy CP	Epidural infection (n = 1)	90	Antibiotic and corticosteroids	1 (100)
Iaccarino et al,[17] 2018, Italy	CR	4	3 (75)	1 (25)	46 (19.65)	HA CP	*S aureus* (n = 2), *G adiacens* (n = 1)	—	Surgical debridement and antibiotics	4 (100)
Yoshioka,[18] 2018, Japan	CR	2	2 (100)	0 (0)	62 (3)	Titanium CP	Pa (n = 1), MRSA (n = 1)	182.5	Explantation, intraoperative autoclave sterilization, free flap epidural space obliteration, reimplantation, and antibiotics	2 (100)
Zanotti et al,[19] 2018, Italy	CR	1	0 (0)	1 (100)	68	HA CP	*S aureus* (N = 1)	90	Surgical debridement and antibiotics	1 (100)
Zhao et al,[20] 2018, China	CS	8	5 (62.5)	3 (37.5)	37.6 (8.5)	Titanium mesh CP	Skin ulcer	—	Explantation, sterilization, reimplantation, and reversed temporal island flap coverage	8 (100)
Dupuy et al,[21] 2017, France	CR	2	2 (100)	0 (0)	61 (6)	Methylmethacrylate CP (n = 1), dural plasty (n = 2), craniectomy (n = 1)	—	—	Surgical debridement, NPWT, and free flap	2 (100)
Johnson et al,[22] 2000, USA	CR	1	0 (0)	1 (100)	43	HA CP	*C albicans* (n = 1), *S aureus* (n = 1)	42	Surgical debridement, drainage, scalp rotation flap, and antibiotics	1 (100)

Abbreviations: Ab, *Acinetobacter baumanii*; *C albicans*; *Candida albicans*; CP, cranioplasty; CR, case report; CS, case series; *E coli*; *Escherichia coli*; *E cloacae*, *Enterobacter cloacae*; *G adiacens*, *Granulicatella adiacens*; HA, hydroxyapatite; Kp, *Klebsiella pneumoniae*; MRSA, methicillin-resistant *Staphylococcus aureus*; NPWT, negative-pressure wound therapy; NPWTi, negative-pressure wound therapy with irrigation/instillation; Pa, *Pseudomonas aeruginosa*; P spp, *Propionibacterium* species; *S aureus*, *Staphylococcus aureus*; *S capitis*, *Staphylococcus capitis*; *S epidermidis*, *Staphylococcus epidermidis*; *S intermedius*, *Staphylococcus intermedius*; SSI, surgical site infection; VP, ventriculoperitoneal.
Note: Empty cells denote not reported or not extractable data.

Hu et al[16] used antibiotics and a glucocorticoid to conservatively treat a titanium implant cranioplasty without removal of the implant. This patient did not have any scalp necrosis or exposed hardware, allowing for a conservative treatment without surgical intervention.[16]

Other authors have proposed antibiotic irrigation systems as conservative treatments. Chen et al[9] used an antibiotic irrigation system to successfully treat 11 patients with infection under the skin flap and no exposed hardware after titanium mesh cranioplasty without removal of bone flaps and hardware. Similarly, Hwang and Chang[15] salvaged a cranioplasty implant in a patient with scalp necrosis, exposed implant, and infection after undergoing cranioplasty by installing an indwelling antibiotic irrigation system after debriding devitalized skin and covering the defect with a transposition flap.

Negative-pressure wound therapy has also become popular in treating large cranial infected defects. Dupuy et al[21] showed that NPWT after debridement surgery can salvage infected methylmethacrylate cranioplasty and duraplasty in two patients with exposed and infected hardware without removal of implant. Huang et al[14] further demonstrated the clinical effect of NPWT with chymotrypsin in implant-related infection and titanium mesh exposure. The major concern in leaving exposed hardware in place is the presence of biofilm–a syntrophic consortium of microorganisms in which adherent cells are fixed within a slimy extracellular matrix that is impenetrable by antibiotics. Adjunct use of instillation agents such as chymotrypsin theoretically helps disrupt the biofilm on the implant to enable implant salvage.[14]

In the current study, wound cultures showed scant growth after 4 days of NWPT with HOCl irrigation solution. Although biofilms are not detectable by culture, HOCl solution, which is modeled after the leukocyte-intracellular-killing pathway, is effective against them.[25] Similar sodium hypochlorite bactericidal antiseptic products can cause allergic reactions and cytotoxicity and are inherently unstable, minimizing sustained effectiveness.[26] Further, sodium hypochlorite solutions have a pH range of 10 to 11, frequently causing discomfort on application.[27] In contrast, HOCl solution is noncytotoxic, nonsensitizing, and nonirritating and has long-term stability.[27,28] Further, with a pH of 5.5, applications are gentle and well tolerated.[27] It can be delivered as a soak, wound packing, and in combination with NPWT as an instill-dwell solution to treat a variety of wounds and burns.[29,30] In addition, HOCl solution is effective in treating various species of *Candida* and bacteria, including *Bacillus anthracis*, *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus*, *P aeruginosa*, and *E coli* biofilms.[25,31,32] Consequently, in the present case, because *P aeruginosa* (a powerful biofilm former) and *E coli* were detected in the wound cultures, VAC with HOCl solution was used strategically to attempt to salvage the patient's cranioplasty. For this particular patient, salvaging his hardware was especially critical given the profound degree of his SOT in the absence of cranioplasty and his degree of neurologic recovery after cranioplasty. The traditional pathway of explantation with a lag time of multiple months between reattempting another cranioplasty risked irrecuperable neurologic decline in a very young patient. The patient treated with this strategy had complete resolution of the infection and completely granulated over the exposed hardware necessitating only a small skin graft. Most importantly, he retained his cranial hardware, leading to a complete and sustained resolution to his SOT 7 months after surgery.

To the authors' knowledge, this is the first study that describes the use of VAC with Vashe in the treatment of postcranioplasty infections. The patient included in this case report did not exhibit residual deformity or recurrence of infection. The patient and the surgeons were ultimately satisfied with the results. It is encouraging that the evidence from this case report suggests that the conservative treatment of VAC with HOCl solution offers a salvage reconstruction technique to treat patients who would otherwise be left with the consequences, risks, and costs associated with explantation and redo cranioplasty. Although further studies are necessary, these findings suggest that providers should consider alternative strategies to explantation and delayed reimplantation as part of the cranioplasty infection armamentarium, particularly when neurologic function is at stake.

This report provides the investigator's preliminary findings in the management of cranioplasty infection when surgical explantation is not a viable option. A larger study to better determine the efficacy of VAC with HOCl solution is currently underway.

CONCLUSIONS

The treatment strategy of VAC and HOCl solution can effectively treat cranioplasty infection without hardware explantation, thus obviating the associated complications, risks, and costs associated with explantation and repeat cranioplasty in a multiply operated wound bed and patient with neurologic decline. ●

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