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ORIGINAL ARTICLE - NEUROSURGERY GENERAL

Experiences with a temporary synthetic skin substitute after decompressive craniectomy: a retrospective two-center analysis

Lukas Grassner[1,2,3,4] · Franz Marhold[5] · Miron Yousif[1] · Andreas Grillhösl[6] · Karl Ungersboeck[5] · Joachim Schulz[1] · Martin Strowitzki[1]

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Abstract

Background Decompressive craniectomy is a commonly performed procedure. It reduces intracranial pressure, improves survival, and thus might have a positive impact on several neurosurgical diseases and emergencies. Sometimes primary skin closure is not possible due to cerebral herniation or extensive skin defects. In order to prevent further restriction of the underlying tissue, a temporary skin expansion might be necessary.

Methods and material We retrospectively reviewed patients in need for a temporary skin substitute because skin closure was not possible after craniectomy without violating brain tissue underneath in a time period of 6 years (2011–2016). With this study, we present initial experiences of Epigard (Biovision, Germany) as an artificial temporary skin replacement. We performed this analysis at two level-1 trauma centers (Trauma Center Murnau, Germany; University Hospital of St. Poelten, Austria). Demographic data, injury and surgical characteristics, and complication rates were analyzed via chart review. We identified nine patients within our study period. Six patients suffered from severe traumatic brain injury and developed pronounced cerebral herniation in the acute or subacute phase. Three patients presented with non-traumatic conditions (one atypical intracerebral hemorrhage and two patients with extensive destructive tumors invading the skull and scalp).

Results A total of 20 Epigard exchanges (range 1–4) were necessary before skin closure was possible. A CSF fistula due to a leaky Epigard at the interface to the skin was observed in two patients (22%). Additional complications were four wound infections, three CNS infections, and three patients developed a shunt dependency. Three patients died within the first month after injury.

Conclusions Temporary skin closure with Epigard as a substitute is feasible for a variety of neurosurgical conditions. The high complication and mortality rate reflect the complexity of the encountered pathologies and need to be considered when counseling the patient and their families.

Keywords Outcome · Edema · Decompressive craniectomy · Brain herniation · Skin replacement

Lukas Grassner and Franz Marhold contributed equally to this work.

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✉ Lukas Grassner
lukas.grassner@googlemail.com

[1] Department of Neurosurgery, Trauma Center Murnau, Professor-Küntscher Straße 8, 82418 Murnau, Germany

[2] Center for Spinal Cord Injuries, Trauma Center Murnau, Murnau, Germany

[3] Institute of Molecular Regenerative Medicine, Paracelsus Medical University, Salzburg, Austria

[4] Spinal Cord Injury and Tissue Regeneration Center Salzburg, Paracelsus Medical University, Salzburg, Austria

[5] Department of Neurosurgery, Karl Landsteiner University of Health Sciences, University Hospital St. Poelten, St. Poelten, Austria

[6] Department of Neuroradiology, Trauma Center Murnau, Murnau, Germany

Abbreviations

GCS Glasgow Coma Scale
CNS Central nervous system
CSF Cerebrospinal fluid
CT Computer tomography
MRI Magnetic resonance imaging

Introduction

Increased intracranial pressure (ICP) might arise from several neurosurgical emergencies. Severe edema can be encountered in patients with malignant middle cerebral or internal carotid artery occlusion, traumatic brain injury (TBI), subarachnoid hemorrhage (SAH), and intracerebral hemorrhage (ICH) [6]. Hence, decompressive craniectomy is a surgical option for several conditions in order to reduce ICP, increase survival, and potentially improve outcome [11, 12, 20, 21]. Intractable ICP ultimately results in reduced cerebral perfusion pressure (CPP) leading to further damage [6]. Decompressive craniectomy might be performed urgently in the very acute phase or if ICP remains elevated despite extensive medical management [1].

The extent of the craniectomy and subtemporal decompression are crucial surgical steps [9, 14]. However, in severe cases, cerebral herniation might arise. Cerebral herniation has been shown to be a negative functional outcome predictor after acute traumatic subdural hematomas (SDH) [10]. In some cases, the herniation is very pronounced and primary skin closure might be impossible without causing additional restriction. In other cases—such as exophytic erosive tumor invading the skull and scalp or traumatic laceration in TBI patients—primary skin closure might not be possible due to extensive skin defects. Recently, the use of a Gore-Tex patch for skin augmentation as a last resort maneuver during decompressive craniectomy in different diagnoses has been reported to increase skull volume and lower intracranial pressure [8].

We want to share our experience of nine consecutive patients treated with a temporary synthetic skin substitute after decompressive craniectomy. Epigard (Biovision, Germany) is an artificial temporary skin replacement that can be used as a wound dressing. It is used for the treatment of open wounds and for the preparation of better wound conditions for a consecutive closure. The upper surface is made of Teflon (polytetrafluorethylene), which makes it air-permeable, but serves as a barrier for bacteria or wound secretion. The lower surface consists of polyurethane, which rapidly adheres to the wound surface and should accelerate the cleansing phase. Hence, necrotic tissue and exudate are removed during the exchange of the Epigard along with the wound dressing. Epigard may be left in situ for up to 7 days, but needs to be changed rapidly in case of any irritation or signs of infection. Epigard has been successfully applied for a variety of non-neurosurgical diseases such as open long-bone fractures with extensive soft tissue damage, contaminated wound surfaces, and other extensive skin defects [19]. The use of Epigard in neurosurgery has not been reported so far.

Methods and materials

Setting

We performed this study at the Department of Neurosurgery of the Trauma Center Murnau (Germany)—a cross-regional level-1 trauma center, and at the Department of Neurosurgery at the University Hospital of St. Poelten (Austria)—a tertiary care institution.

Patient and surgical characteristics

This study represents a retrospective analysis between 2011 and 2016 consisting of all consecutive patients in need of a decompressive craniectomy, where initial skin closure was not possible due to severe brain swelling or contributed significantly to raised ICP values over time. In these cases, the temporary synthetic skin substitute Epigard (Biovision, Germany) was used for wound closure after dural closure with an allogenic substitue. In all cases, Epigard was chosen due to the inability of primary skin closure—without causing restriction to the tissue underneath—encountered during surgery. There was no planned use of Epigard prior to surgery. Patients were included regardless of age, sex, diagnosis, primary treatment, surgical indication, and anticipated and actual outcome.

Demographic and clinical data included sex, age, diagnosis, initial Glasgow Coma Scale (GCS), fractures, concomitant injuries, and cause of injury. Surgical characteristics included location of the decompressive craniectomy, secondary expansion, use of ICP probes, and use of external ventricular drainages. All patients were managed postoperatively at the local intensive care units. Assessment of Glasgow Outcome Score (GOS) [13] at follow-up was performed. All data were retrieved from medical records.

Within our study period, we identified nine patients (three females) who were treated with unilateral or bilateral decompressive craniectomy and needed skin expansion or replacement due to severe brain herniation or extensive skin defects during the primary or secondary craniectomy. Two patients were treated at the University Hospital of St. Poelten (Austria), and the remaining seven patients received acute management at the Trauma Center Murnau (Germany). The mean follow-up period was 10.7 months (± 6.0 months; range 2–21 months).

Results

In our study cohort, the mean age was 48 (± 22) years and patients presented with a variety of neurosurgical emergencies: six patients with severe TBI (GCS range 3–6) (Figs. 1 and 2), one patient with an atypical intracerebral hemorrhage, and two patients with extraaxial tumors invading the skull (Fig. 3). Demographic and injury characteristics are provided in Table 1.

Most often (six out of nine cases), we have used Epigard as a temporary wound dressing for patients with extensive cerebral herniation after severe TBI (mean GCS 4, range 3–6). In these cases, skin closure was not possible without causing significant compression of the underlying brain tissue. Illustrative case presentations are provided in Figs. 1 and 2. In half of the patients with severe TBI ($n = 3$), Epigard was applied during the primary craniectomy and in the other half during a further more extensive craniectomy ($n = 2$) or during a wound revision due to tissue necrosis ($n = 1$), respectively. Unfortunately, we faced a high mortality rate in this cohort ($n = 3$; 50%).

In total, the Epigard was used during the primary craniectomy in five cases. In the remaining four patients, it was applied during an additional (more extensive) craniectomy (three cases) or during a wound revision surgery (one case) (Table 2). Twenty exchanges of the Epigard for wound conditioning purposes were necessary (range 1–4). In 7 patients (78%; 7/9) and in 16 exchanges (80%; 16/20), the Epigard-skin interface stayed tight and no CSF fistula was observed. The reaction with the underlying dura or allogenic dural substitute was none to minimal. Skin closure was possible around 21 days (± 10 days) post-injury in seven patients (two patients passed away before definitive skin closure). Four patients developed a wound infection over time and CSF fistula was encountered in two patients, both of them with TBI. Half of the surviving patients developed a shunt dependency over time. CNS infections occurred in three patients (one ventriculitis, one ventriculoperitoneal shunt infection, one intracerebral abscesses), whereas the abscesses in one patient were preexisting. Epigard details and complications are shown in Table 3. One third of our patients ($n = 3$) died within 1 month after the insult. All suffered from severe TBI. Data on the outcome is provided in Table 4.

Epigard is especially useful in the cleansing phase of wound healing but needs to be changed quite regularly (with any sign of irritation or after a maximum of 7 days). In our cohort of nine patients, we had to change it 20 times (range 1–4) before a secondary skin closure was possible. We observed CSF fistulas of the Epigard-skin interface in two patients (22%). In the other 7 patients, another 16 Epigard exchanges were necessary but showed no signs of CSF fistulas (80%). Watertight closure of the dura is a crucial step in these patients in order to prevent CSF fistulas. Noteworthy, two patients passed away before permanent skin closure could be achieved. Epigard may adhere to the wound surface. This probably contributes to the cleaning effect. The reaction with the dural substitute underneath was minimal in our cohort. However, due to the sensitive tissue underneath, this needs to be highlighted in this context when exchanges are performed.

Discussion

Sustained elevated ICP is a strong predictor of poor outcome and mortality after severe brain injury [15]. Decompressive craniectomy is an effective surgical technique to reduce ICP [16]. With this case series, we share our experiences with a synthetic skin substitute after craniectomy, where skin closure was not possible initially or required expansion over time. We

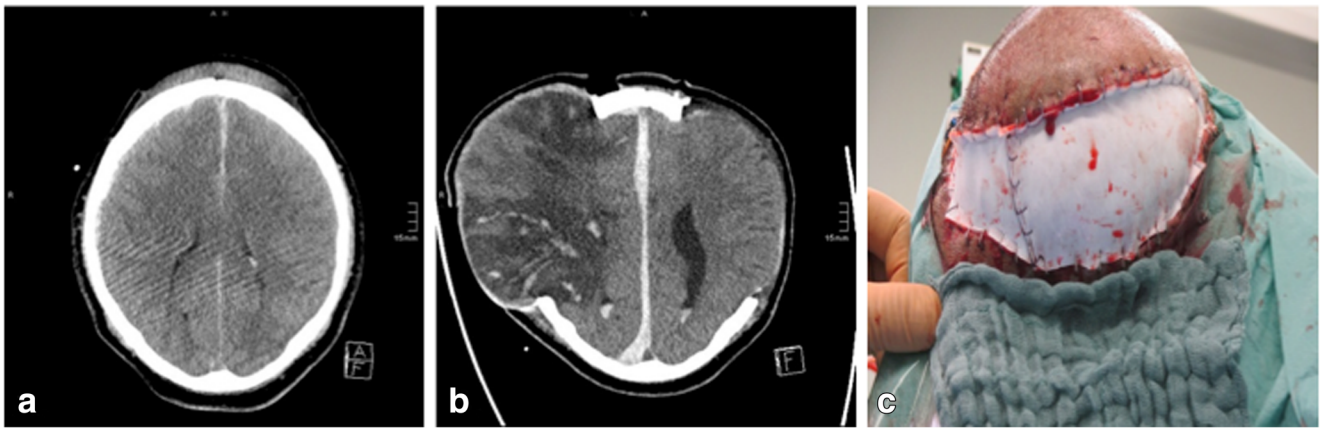

Fig. 1 Patient 9 presented with a severe TBI (initial GCS 3) after a collision as a pedestrian with a motor vehicle. **a** Diffuse edema, traumatic subdural hematoma, and traumatic subarachnoid hemorrhage on an axial view. **b** Axial postoperative CT images 2 days post-injury (dpi) with extensive brain herniation predominantly on the right side. **c** A representative image during an Epigard exchange 2 dpi. Treatment was withdrawn 7 dpi after respecting the patient's most probable wish and counseling the family

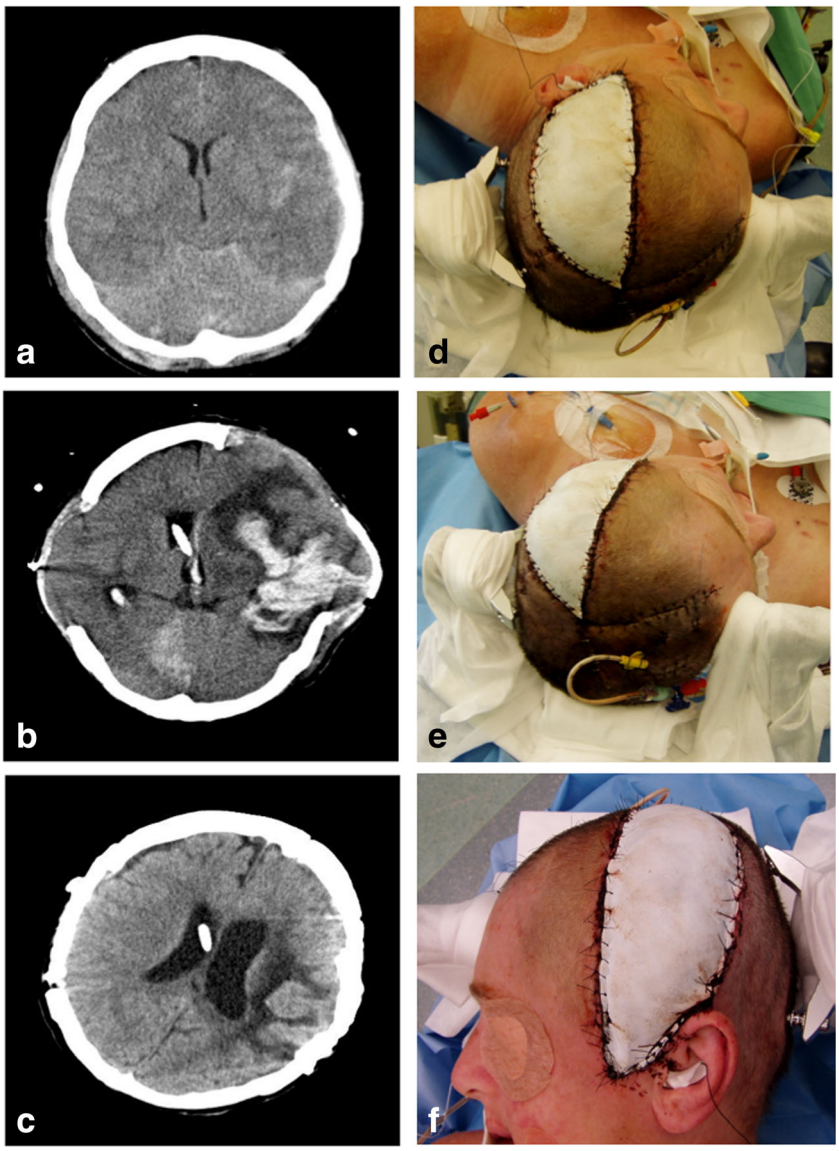

Fig. 2 Patient 1 presented with severe TBI (initial GCS 4) after a hay bale fell on her head. Initially, the patient was managed for 8 days in another hospital before being transferred for further treatment. Upon arrival, we enlarged the hemicraniectomy significantly on the left side. **a** Diffuse edema, traumatic subarachnoid hemorrhage, and brain swelling an axial view. **b** The enlarged hemicraniectomy on the left side, with intracerebral hemorrhage. **c** The patient at follow-up with the bone flab already replaced. **d**–**f** Representative images of the sewed Epigard from different views. At follow-up, the patient reached GOS 3

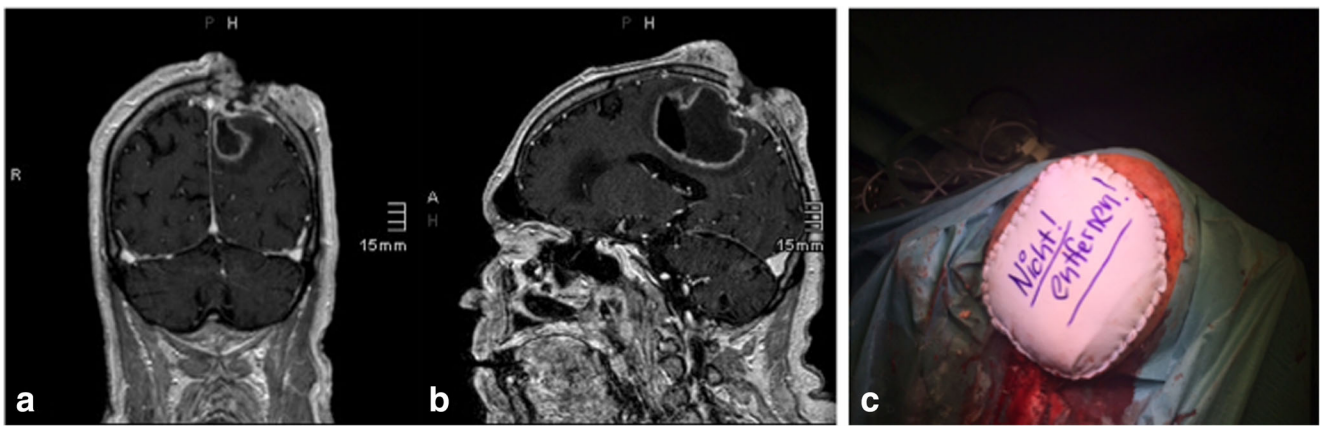

Fig. 3 Representative radiological and clinical images of patient 6. Contrast-enhanced T1 weighted MR images. **a** Coronar and **b** sagittal demonstrate a lytic infiltrative skull lesion with an underlying intracerebral abscess. **c** A clinical image during Epigard exchange over time. We wrote "Do not remove" (= "Nicht entfernen") on top of the Epigard since it was accidentally removed during bandage revision at the intensive care unit

Table 1 Demographic and injury characteristics

Patient	Sex (F/M)	Age (years)	Diagnosis	Initial GCS	Fracture	Cause of injury	Concomitant injuries
1	F	53	Left ICH, bilateral contusions	4	Left occipital	Blunt head trauma	Thoracic injury
2	M	17	Left, aSDH, left ICH, multiple contusions on the left	3	Left skull base	Traffic accident	Bilateral lower extremity injuries
3	M	67	Right frontoparietal atypical ICH	11	n/a	n/a	n/a
4	M	21	Left aSDH, tSAH	5	Left temporal, skull base, left orbit	Traffic accident	Polytrauma
5	M	30	Bilateral aSDH, right frontal contusions	3	Bilateral frontotemporal, skull base	Traffic accident	Polytrauma
6	M	73	Infiltrative ulcerated basal cell carcinoma with intracerebral abscesses	15	Lytic lesion left parietooccipital	n/a	n/a
7	F	68	Left aSDH, bilateral tSAH, left frontoparietal ICH, bilateral contusions	6	Left frontal, left orbit, skull base	Fall from high altitude	Thoracic injury
8	F	63	Right frontal meningioma WHO grade III	15	n/a	n/a	n/a
9	M	36	Bilateral aSDH, bilateral tSAH, bilateral frontal contusion	3	Bilateral frontal	Traffic accident	Thoracic injury

F female, M male, GCS Glasgow Coma Scale, aSDH acute subdural hematoma, ICH intracerebral hemorrhage, n/a not applicable

encountered this problem during surgical procedures for different traumatic but also non-traumatic disorders. To the best of our knowledge, the potential use of this particular artificial skin substitute has not been reported in the neurosurgical literature.

As mentioned, we had to use Epigard most commonly in TBI patients. This seems to be attributed to the underlying severe TBI with extensive edema formation and consecutive cerebral herniation. Additionally, similar mortality rates have been reported after severe TBI [2]. Radiological and clinical signs of cerebral edema with herniation have been associated with a negative outcome after severe TBI in pediatric and adult patients [10, 22]. Recently, it has been shown that decompressive craniectomy in patients with refractory ICP results in lower mortality but higher rates of vegetative states, lower severe disability, and upper severe disability compared to medical management [12]. In our TBI cohort, all three surviving patients presented with severe disability (GOS 3) at the follow-up visit. The high mortality rate and the relatively poor outcome reflect the severity of these cases and need to be considered when treating these patients and counseling their families.

In three patients, non-traumatic causes forced us to use the temporary artificial skin replacement. In two patients (patients 6 and 8), tumors with extensive skull infiltration did not allow skin closure during the primary operation at our institution (patient 8 received prior management elsewhere and was sent to us for further management) (Fig. 3). We had to change the Epigard two and four times, respectively. In our experience, Epigard was very helpful in providing reasonable wound conditioning for a subsequent reconstructive flap surgery. Patient 3 sustained a large right frontoparietal atypical ICH (7.5 ×

Table 2 Surgical characteristics and timing of Epigard application

Patient	Primary decompressive craniectomy	Secondary expansion of decompressive craniectomy	ICP probe	EVD	Epigard (primary surgery or at follow-up surgery)
1	Bifrontal	Yes (bilateral frontotemporal)	Yes (primarily)	Yes (over the course)	At secondary craniectomy
2	Left frontotemporoparietal	No	Yes (primarily)	Yes (over the course)	At primary surgery
3	Right parietal	Yes (right frontotemporoparietal)	Yes (primarily)	No	At secondary craniectomy
4	Left frontotemporoparietal	Expansion left frontotemporoparietal	Yes (primarily)	Yes (over the course)	At secondary wound revision surgery
5	Bifrontal	Yes (bilateral frontotemporal)	Yes (primarily)	No	At secondary craniectomy
6	Left parietooccipital	No	No	No	At primary surgery
7	Bilateral frontotemporal	No	Yes (primarily)	Yes (over the course)	At primary surgery
8	Right frontal	No	No	No	At primary surgery (at our institution; previous resection elsewhere)
9	Bilateral frontotemporal	No	Yes (primarily)	No	At primary surgery

ICP intracranial pressure, EVD external ventricular drain

Table 3 Required Epigard exchanges and complications

Patient	Epigard exchange (*n*)	Skin closure (dpi)	Wound infection	CSF fistula	Shunt dependency	CNS infection
1	2	19	No	No	Yes	Ventriculitis
2	1	8	Yes	Yes	Yes	No
3	4	30	Yes	No	No	No
4	1	37	No	No	Yes	VP-shunt infection
5	1	n/a	No	No	n/a	No
6	4	23	Yes	No	No	Intracerebral abscess
7	3	18	Yes	Yes	n/a	No
8	2	14	No	No	No	No
9	2	n/a	No	No	n/a	No

dpi days post-injury, CSF cerebrospinal fluid, CNS central nervous system, n/a not applicable, VP ventriculoperitoneal

4.5 × 3.5 cm) without any underlying vascular malformation. Due to the superficial lobar location and the volume, we performed early surgery [18]. At the first stage, the patient underwent an osteoplastic craniotomy with hematoma removal. Due to a persistent mass effect with midline shift, we performed a secondary decompressive craniectomy. Here, we encountered delayed cerebral herniation with the need for expansion using a temporary skin substitute. Skin closure was possible after four Epigard changes and edema regression.

Undoubtedly, we faced a high complication rate (Table 3). Decompressive craniectomy per se bears a relatively high complication rate [17]. Almost half our patients (4/9) developed a wound infection. This was complicated in the two cases with CSF fistula. Although Epigard should theoretically reduce wound complications, we cannot exclude that it even contributed to the high rate in our population. Of the surviving six patients, three patients needed a shunt procedure over time. The initial pathology but also the decompressive craniectomy per se disturb the meningeal anatomy and alter CSF physiology. Hence, shunt dependency is a known potential sequel after decompressive craniectomy and repeated surgeries are a risk factor for secondary infection afterward [4]. In our opinion, the incidence in our case series also reflects the severity and complexity of the encountered pathologies and is not in particular relation to the Epigard application.

Table 4 Outcome and mortality

Patient	Follow-up (months)	Mortality	GOS at follow-up
1	9	No	3
2	21	No	3
3	7	No	3
4	11	No	3
5	n/a	Yes	1
6	17	No	3
7	n/a	Yes	1
8	2	No	3
9	n/a	Yes	1

GCS Glasgow Coma Scale, GOS Glasgow Outcome Scale, n/a not applicable

When interpreting the results of this case series, several limitations need to be acknowledged. With the data being collected in only two centers, our results cannot be necessarily extrapolated to other settings with different intensive care capacities, therapeutic regimens, and different end-of-life decisions [3, 7]. Furthermore, one could speculate that—in some cases (patients 1, 3, 4, and 5)—a more extensive craniectomy could have prevented a secondary procedure with the need for a temporary wound dressing. In TBI, the important role of the craniectomy size and additional subtemporal decompression—eventually with temporal lobectomy—has been demonstrated [5, 9, 14]. We have to admit that appropriate surgical planning (especially for the non-traumatic cases) with the potential inclusion of plastic surgeons might have prevented the necessity of applying this skin substitute. Further, the high morbidity and mortality need to be highlighted, since ethical challenges and dilemmas need to be carefully considered. The scope of this article is to describe the possibility of temporary skin replacement for a variety of different neurosurgical diseases. Due to the low incidence over a relatively long study period, we cannot provide valid data about the efficacy. It seems that only a multicenter approach could help with this.

In conclusion, we demonstrate that temporary artificial wound closure is feasible in neurosurgical conditions. This article shares our experience where direct skin closure was not possible without causing further damage. In the non-traumatic cases, appropriate preplanning might have reduced the rate of Epigard application. In patients with severe TBI and extensive edema formation, Epigard is an alternative compared to violent skin closure and is a temporary measure until definite closure is possible. The high complication and mortality rate need to be kept in mind in surgical decision-making as well as in counseling the patient and their families.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. After reviewing the study protocol, the ethical committees at both institutions approved the study (2018–076 and 1011/2018).

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Comments

substitute called Epiquard in patients where a decompressive craniectomy was done and primary skin closure wasn't possible (or not safe to be done) because of brain swelling or due to its contribution to refractory intracranial hypertension. As expected, outcome was frequently unfavorable, morbidity was high and many complications existed. Although some patients eventually survived, the use of these substitutes should be reserved only for limited cases following careful consideration and after every possible effort (both conservative and surgical) has been made to avoid reaching this extreme condition.

Parmenion P. Tsitsopoulos

Thessaloniki, Greece