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ORIGINAL ARTICLE
Pediatric/Craniofacial

Cranial Reconstruction following the Removal of an Infected Synthetic Dura Mater Substitute

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Background: The objective of this study was to describe the outcomes of an algorithmic approach to cranial reconstruction following the removal of an infected synthetic dura mater substitute due to postcraniotomy infection.
Methods: A retrospective review was conducted of the cases of 12 patients who underwent cranial reconstruction from 2006 to 2013 after the removal of an infected expanded polytetrafluoroethylene sheet (a synthetic dura mater substitute) due to postcraniotomy infection.
Results: Average patient age was 46 years (range, 19–70 years). Follow-up was 4.6 years. The expanded polytetrafluoroethylene sheets were implanted after decompressive craniectomy or after combined resection of the dura mater and a tumor. Epidural, but not subdural, abscesses were found in 6 patients, in whom a sufficient capsule developed underneath the synthetic dura mater. Both epidural and subdural abscesses were found in the remaining 6 patients, and the capsule remained intact after debridement of the subdural abscesses in half of them. Secondary cranial reconstruction was safely performed by leaving the capsule intact in the 9 cases in which no additional dural reconstruction was performed. In the remaining 3 patients, in whom no capsule remained after debridement, secondary cranial reconstruction was carried out by leaving the pericranium over the brain surface. None of the patients developed postoperative complications in follow-up periods.
Conclusions: Staged cranial reconstruction after the removal of an infected synthetic dura mater substitute using an algorithmic approach is feasible and safe, produces satisfactory cosmetic results, and is not associated with any complications. *(Plast Reconstr Surg Glob Open 2014;2:e134; doi: 10.1097/GOX.0000000000000087; Published online 16 April 2014.)*

Many types of dural grafts have been suggested to be useful for closing dural defects during neurosurgery, including grafts derived from the pericranium, fascia lata, and synthetic materials.[1] Although synthetic materials have been widely used as dural substitutes, the use of such materials can lead to postoperative cranial infections.[1–3] In cases in which postoperative cranial infections lead to the development of epidural or subdural abscesses, thorough debridement including the removal of the infected synthetic dura and contaminated bone flaps is mandatory.[2,3] However, the reconstruction of dural defects remains a controversial issue among neurosurgeons and plastic surgeons.[2–7] Moreover, cranial reconstruction is challenging in patients who develop infections after surgery for dural defects be-

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Received for publication November 15, 2013; accepted February 26,2014.

DOI: 10.1097/GOX.0000000000000087

Disclosure: *The author has no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the author.*

cause the quality of the scalp can be compromised by the infection. Since 2002, the author has treated more than 20 patients with synthetic dura mater substitutes who developed cranial infections after craniotomy.[7] Thus, the author has developed an algorithmic approach for cranial reconstruction after the removal of infected dural substitutes and has employed this method since 2006. The purpose of this article is to report and evaluate the reconstructive outcomes of patients with infected synthetic dura mater substitutes who were treated using the above-mentioned algorithm from May 2006 through February 2013.

PATIENTS AND METHODS

Between May 2006 and February 2013, 12 patients who developed infections after craniotomy procedures in which expanded polytetrafluoroethylene (ePTFE) sheets (PRECLUDE; Gore & Associates, Flagstaff, Ariz.) were installed as synthetic dura mater substitutes were treated at Tominaga Hospital. Seven of these patients were men and 5 were women. The mean age of the patients was 46 years (range, 19–70 years). Synthetic dura mater substitutes were installed after decompressive craniectomy due to a cerebral hemorrhage or infarction in 8 patients and after combined resection of the dura mater and an arteriovenous malformation or meningioma in 4 patients (2 patients each). The skull was replaced with cryopreserved autologous bone in the patients who had decompressive craniectomy, and in the other 4 patients, the skull was replaced with fresh autologous bone at the time of craniotomy. All patients were initially treated with antibiotics for postoperative surgical site infection. Subsequently, conventional debridement and removal of the infected bone flap and synthetic dura mater were performed. The author's algorithm for dural and cranial reconstruction is shown in Figure 1. In cases in which a sufficient capsule had formed over the brain and no cerebrospinal fluid (CSF) leakage occurred, the scalp was redraped over the capsule after the de-

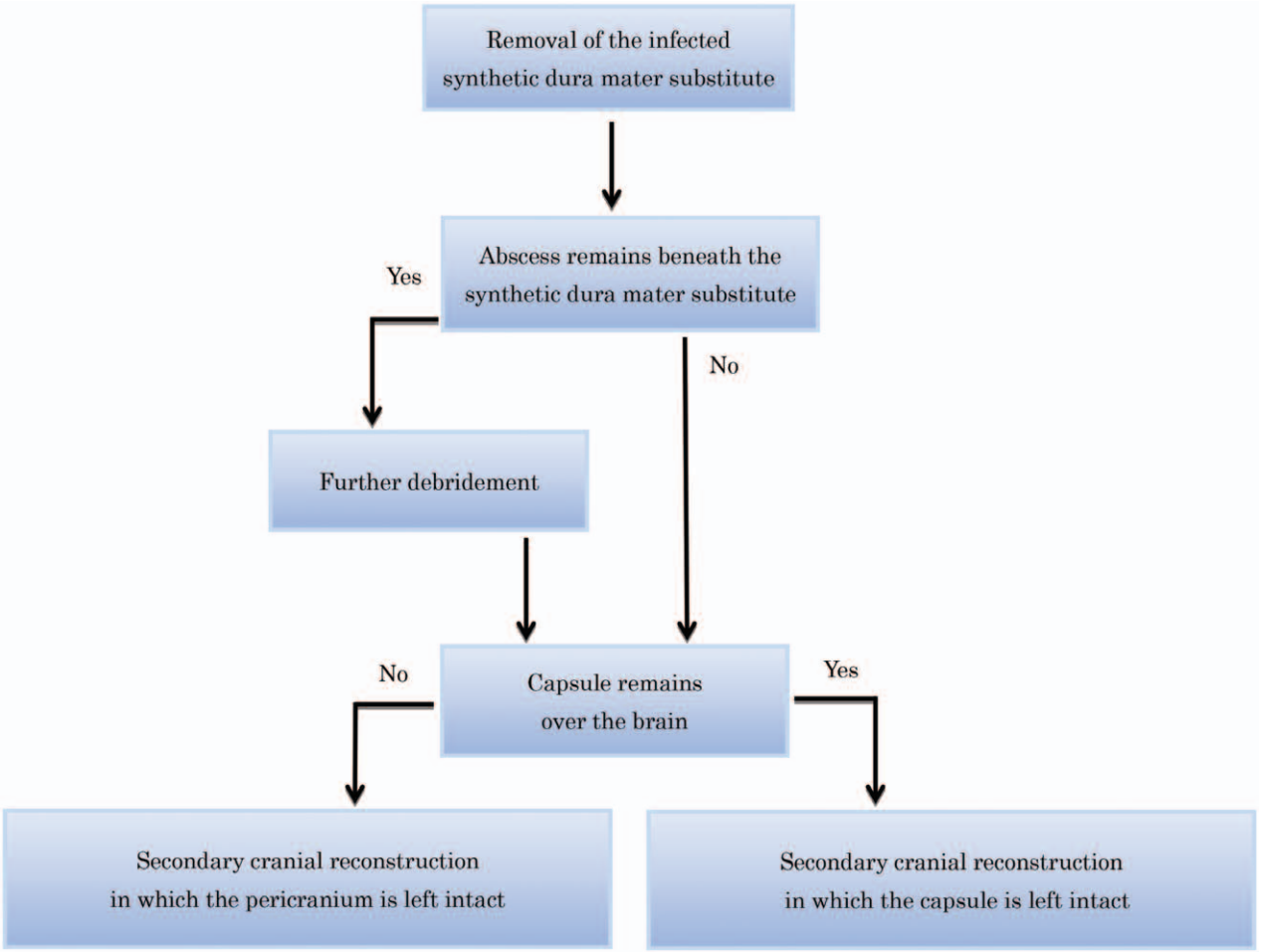

Fig. 1. Algorithm for cranial reconstruction following the removal of an infected synthetic dura mater substitute.

bridement. Further debridement was necessary for patients in whom abscesses developed underneath the synthetic dura mater. This can sometimes result in the complete loss of the capsule. In such cases, the scalp was redraped over the brain, and no simultaneous dural reconstruction was performed. Cranial reconstruction was then scheduled for a few months after the debridement procedure. Before the cranial reconstruction, magnetic resonance imaging (MRI) was performed to ensure that no infectious foci existed. In the patients in whom a capsule remained over the brain, the layer between the capsule and the pericranium was dissected. On the other hand, for the patients without a capsule, the layer between the galea aponeurotica and pericranium was dissected. This was facilitated by the identification of the pericranium below the skin incision line. Custom-made hydroxyapatite implants were used for the cranial reconstruction. A custom-made artificial bone implant, the curvature of which was decreased by 50% compared with that of the original bone, was fabricated if markedly increased skin tension was anticipated after wound closure. Artificial bone implants with reduced curvatures were also produced for patients with ventricular shunts because it was expected that the epidural space would remain after the cranial reconstruction in these patients and that the resultant dead space could increase the risk of postoperative infections, hematomas, or hygromas. The pressure of the ventricular shunt was adjusted perioperatively to reduce the extradural space after cranioplasty. The shunt pressure was maximized at 1 or 2 days before the cranial reconstruction and then decreased to a normal level within a few postoperative days, providing that sufficient brain expansion was detected on a computed tomographic scan.

RESULTS

The mean length of the follow-up period after the secondary cranial reconstruction was 4.6 years. Epidural, but not subdural, abscesses developed in 6 patients, all of whom displayed sufficient capsule formation underneath the synthetic dura mater substitute (Fig. 2). Both epidural and subdural abscesses were found in the remaining 6 patients, and the capsule remained intact after debridement of the subdural abscesses in half of them (Fig. 3). In the 3 patients with missing capsules, small amount of CSF leakage occurred; however, it disappeared after redraping the scalp over the brain surface. Secondary cranial reconstruction was safely carried out within 3 months of the debridement. In the 9 patients whose capsules remained intact, no additional dural reconstruction was performed, and the capsule was left intact. In the remaining 3 patients without capsules, secondary cranial reconstruction was carried out by leaving the pericranium over the brain surface without any additional dural reconstruction (Fig. 4). Prefabricated artificial bone implants with decreased curvatures were installed in 5 patients in whom markedly increased skin tension was anticipated after wound closure. Three of these 5 patients had ventricular shunts. The pressure of these ventricular shunts was adjusted perioperatively in all 3 patients (Fig. 5). None of the patients suffered postoperative CSF leakage, infections, hematomas, or seizures during the follow-up period (Table 1).

CASE REPORT

Case 4

A 64-year-old man underwent a left decompressive frontotemporal craniectomy for a traumatic

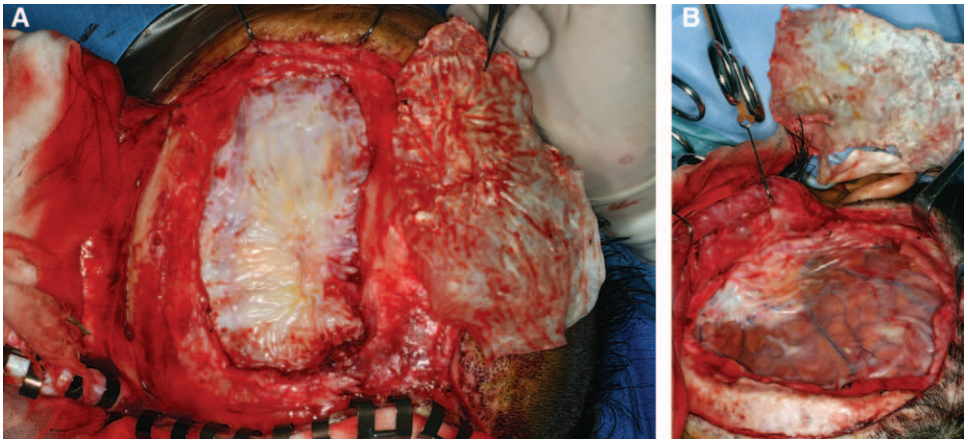

Fig. 2. Typical sufficient capsule underneath the synthetic dura mater. A, Intraoperative photograph of case 3 showing a thick whitish capsule on the brain surface and an ePTFE sheet being held with forceps. B, Intraoperative photograph of case 12 showing a mostly transparent and partially whitish capsule on the brain surface and an ePTFE sheet.

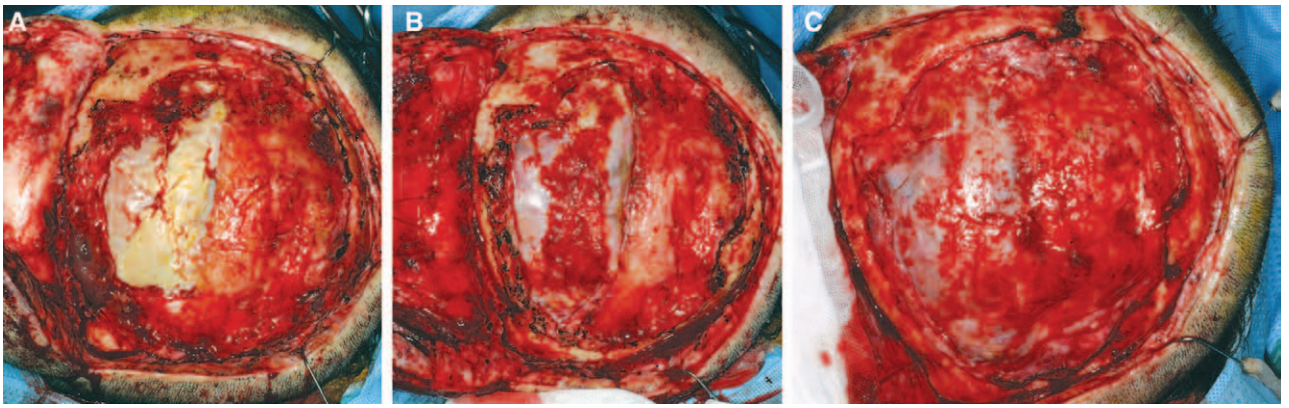

Fig. 3. Case 2 (which involved epidural and subdural abscesses). A, Intraoperative photograph showing a contaminated ePTFE sheet after the removal of an abscess. B, After removing the ePTFE sheet and the abscess beneath the sheet, an identifiable capsule was still present. The granulation tissue on the capsule indicates the site from which the abscess was debrided. C, Intraoperative photograph taken during cranial reconstruction showing a sufficient capsule.

subdural hematoma. An ePTFE sheet was used to close the dura. After 1 month, cranioplasty was performed using a cryopreserved autologous bone flap. The patient did not suffer any perioperative complications; however, after 5 months, his surgical wound split, and a discharge emanated from it. A staged operation was planned because the infection was resistant to routine antibiotic treatment. In the first operation, the infected bone was removed, and the epidural empyema was irrigated. After the removal of the implanted ePTFE sheet, a subdural empyema was found and irrigated, and the capsule over the brain was debrided. After debridement, no identifiable capsule remained, and small amount of CSF leakage was observed (Figs. 4A, B). Thus, the scalp flap was redraped over the brain and the wound was closed with suction drain to minimize the dead space between the leakage points of brain surface and the scalp. The patient did not show continuous CSF leakage postoperatively. Two months later, cranial reconstruction was performed after it had been confirmed that there were no signs of infection at the surgical site on MRI. The layer that was going to be replaced with a custom-made hydroxyapatite block, which was located between the galea and the pericranium, was dissected without CSF leakage (Fig. 4C). After the cranial reconstruction, the wound healed uneventfully, and no complications occurred during the follow-up period.

DISCUSSION

Several synthetic materials have been used as dural substitutes. However, the implantation of such materials can lead to infections. Infected synthetic materials should be removed as soon as possible; however, the reconstruction of the resultant dural defects is still a controversial issue among both neurosurgeons and plastic surgeons.[2–7] Although the author has identified 2 patterns of abscess formation related to synthetic dura mater substitutes among his patients, the development of epidural abscesses alone (ie, when abscesses develop on the synthetic dura) and the development of a combination of epidural and subdural abscesses (when abscesses develop both on and beneath the synthetic dura), the optimal treatments for these types of abscess have never been discussed. To the best of our knowledge, a report of 12 cases, in which every patient suffered epidural infections, is the largest study of such abscesses to have been reported.[4]

At about 1 month after the implantation of an ePTFE sheet, a capsule composed of granulation tissue is generally found between the sheet and the brain surface.[8] Some previous reports have stated that the capsule should be left as a dural substitute after the removal of infected synthetic dura mater substitutes.[4,7] However, another report recommended that contaminated capsules should be removed if abscesses form beneath them.[5] The author agrees with both statements. According to the author's strategy, if the capsule is not contaminated, it should be left intact and no additional dural reconstruction should be performed. A previous report of a large series of cases in which the patients underwent decompressive craniectomy without duraplasty showed that the procedure was technically feasible and safe.[9] The latter report also stated that no subpial injuries due to the attachment of the brain to the scalp were noted during the subsequent cranioplasty procedures. The latter study demonstrates that dural defects that are covered with connective tissue do not cause any complications, providing that no CSF leakage occurs. In

Table 1. Patient Summary

No.	Age/Sex	Original Disease	Debridement (Y/Mo)	Abscess Location	State of the Capsule after Debridement	Cranioplasty (Additional Procedures)	Shunt	Complications	Follow-up (mo)
1	70/F	Meningioma	2006/5	Epidural and subdural	Moderate	2006/8	–	–	87
2	51/M	Meningioma	2006/7	Epidural and subdural	Moderate	2006/9	–	–	86
3	33/M	AVM	2006/8	Epidural	Sufficient	2006/10	–	–	85
4	64/M	DC (ASDH)	2007/5	Epidural and subdural	Poor	2007/7 (pericranial duraplasty)	–	–	76
5	37/F	DC (ICH)	2007/7	Epidural and subdural	Poor	2007/9 (pericranial duraplasty)	–	–	74
6	19/M	AVM	2007/10	Epidural and subdural	Poor	2007/12 (pericranial duraplasty)	–	–	71
7	39/F	DC (SAH)	2009/3	Epidural	Sufficient	2009/5 (reduced curvature)	+	–	54
8	65/F	DC (CI)	2009/11	Epidural and subdural	Moderate	2010/1 (reduced curvature)	–	–	46
9	30/M	DC (SAH)	2010/3	Epidural	Sufficient	2010/6	–	–	41
10	56/M	DC (CI)	2012/5	Epidural	Sufficient	2012/7 (reduced curvature)	+	–	16
11	50/M	DC (ICH)	2012/5	Epidural	Sufficient	2012/8 (reduced curvature)	–	–	15
12	40/F	DC (SAH)	2012/12	Epidural	Sufficient	2013/2 (reduced curvature)	+	–	9

ASDH, acute subdural hematoma; AVM, arteriovenous malformation; CI, cerebral infarction; DC, decompressive craniectomy; F, female; ICH, intracerebral hemorrhage; M, male; SAH, subarachnoid hemorrhage.

addition, the fact that the patients in the present study who did not undergo dural reconstruction remained free of complications indicates that the capsules that form underneath synthetic dura mater substitutes act as dural substitutes.

On the other hand, the capsule should be debrided if it is contaminated. Among the patients in the present study whose capsules were debrided, half did not suffer CSF leakage and possessed an identifiable capsule after the debridement. The other half exhibited small amount of CSF leakage and did not have an identifiable capsule. Dural defects should be reconstructed with autologous tissue if CSF leakage occurs. If a postcraniotomy infection develops in the early stages before capsule formation, dural reconstruction is necessary after debridement. There is a consensus among reconstructive surgeons that vascularized tissue is preferable to nonvascularized tissue for reconstructing defects after local wound infection. In fact, the author experienced a case (before 2006) in which a recurrent infection developed after dural reconstruction using a fascia lata graft, that is, nonvascularized tissue, following debridement of the infected capsule.[7] A free vascularized skin or muscle flap with or without fascial tissue is often used for dural reconstruction after the removal of an infected synthetic dura mater substitute[2,3,5,10,11]; however, using such a free flap results in a lengthy operation and poor cosmetic results.[12] The only other reported option for dural reconstruction is the transposition of a pericranial flap from a neighboring site.[6] Of course, autologous pericranial tissue is generally recommended as a dural substitute in neurosurgery,[13] and pericranial flaps are more useful than pericranial grafts; however, they are not always available, and their vascularity is not always reliable. On the other hand, leaving pericranium on the brain surface is always a possibility during secondary cranial reconstruction, and the pericranium has reliable vascularity. Accordingly, dural defects produced by debridement of the capsule do not need immediate reconstruction. And it is common that small amount of CSF leakage will stop after redraping the scalp if cranial reconstruction is not carried out simultaneously.

There is no consensus regarding the optimal time to perform delayed cranial reconstruction after treatment for an infected synthetic dura mater substitute.[12,14,15] The author recommends that the interval should be within 3 months following an evaluation of the surgical site using MRI. Early cranial reconstruction might reduce the risk of complications associated with the syndrome of the trephined. When skin tightness is anticipated after wound closure, especially in patients with compro-

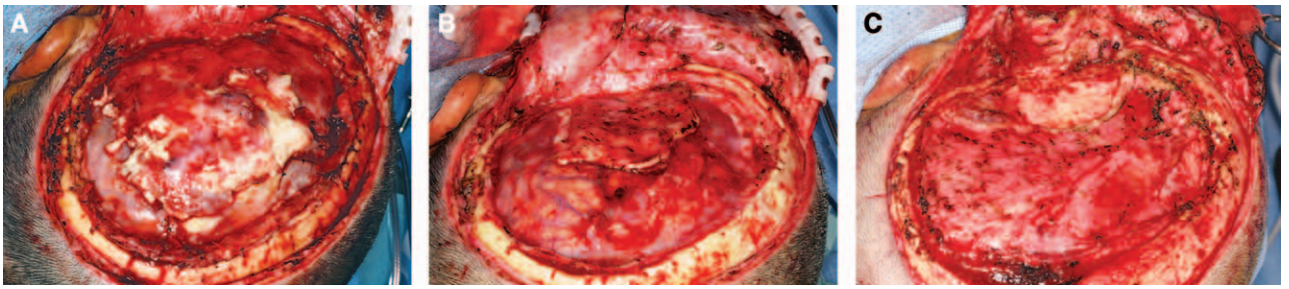

Fig. 4. Case 4 (which involved epidural and subdural abscesses). A, Intraoperative photograph showing the abscess and contaminated capsule after the removal of the ePTFE sheet. B, After debridement of the abscess and capsule, the original dura mater could be seen in the center of the brain surface, but no capsule was identifiable. Subsequently, the scalp was redraped without immediate dural reconstruction. C, Intraoperative photograph taken during the cranial reconstruction showing the pericranium covering the brain surface. The original dura mater was located in the center of the temporal base.

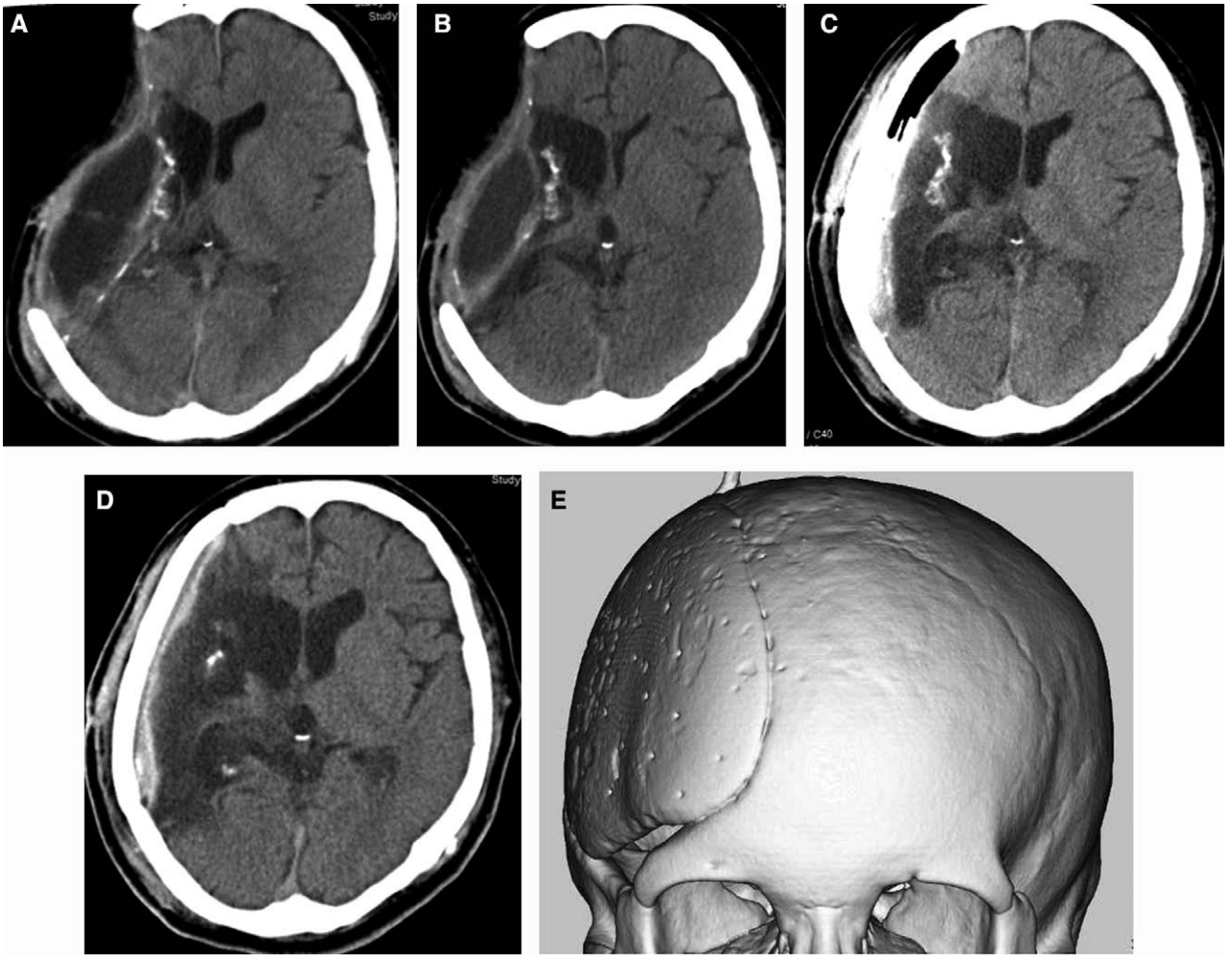

Fig. 5. Case 10 (which involved a ventricular shunt). A, Preoperative computed tomographic scan showing overshunting and epidural seroma. B, Computed tomographic scan obtained after the shunt pressure had been increased showing the expanded subarachnoid space. C, Computed tomographic scan obtained immediately after cranial reconstruction with a custom-made hydroxyapatite implant with a reduced curvature showing the resolution of the epidural space below the implant. D, Computed tomographic scan obtained after the readjustment of the shunt pressure to within the normal range within a few days of the cranial reconstruction. The image demonstrates the normalization of ventricular size and the filling of the epidural dead space. E, Three-dimensional computed tomographic scan demonstrating a typical reduced curvature custom-made hydroxyapatite implant on the right side.

mised scalps or large bone defects, it is better to wait approximately 3 months until the scar is matured. Although closure can be aided with a local flap, tissue expansion, or free flaps, the prefabrication of custom-made artificial bone implants with reduced curvatures is another option. This method is preferable for defects affecting the temporal and parietal regions, rather than the frontal region, because of cosmetic considerations. The author considers that this method is also useful for patients with ventricular shunts because the epidural spaces of these patients are likely to remain after cranial reconstruction, and the resultant dead space can increase the risk of postoperative infections or hematomas.[16] Although high rates of brain reexpansion and gradual resolution of the epidural space below the implant after cranial reconstruction have been reported,[17,18] large dead spaces can become infectious foci, especially in patients with ventricular shunts.[19,20] Moreover, adjusting the pressure or occluding the ventricular shunt tube is also recommended to reduce the risk of potential complications, including epidural hematoma, effusion, and infection.[21,22] The pressure of ventricular shunt should be maximized at least 1 or 2 days before the cranial reconstruction even if the patient's consciousness permits. And temporary ligation of the shunt tube is another option to make brain expand sufficiently if maximizing the shunt pressure does not have enough effect. After cranial reconstruction, the pressure of ventricular shunt should be decreased to a normal level following confirmation of decreased epidural fluid collection. Although the use of free tissue transfers before cranial reconstruction to obliterate endocranial dead space remains controversial,[17] the author recommends temporarily adjusting the shunt pressure before performing cranial reconstruction as a primary choice because this encourages brain expansion and reduces the size of the extradural space.

CONCLUSIONS

Staged cranial reconstruction after the removal of an infected synthetic dura mater substitute using an algorithmic approach is feasible and safe, produces satisfactory cosmetic results, and is not associated with any complications.

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