An altered posterior question-mark incision is associated with a reduced infection rate of cranioplasty after decompressive hemicraniectomy

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OBJECTIVE Performing a cranioplasty (CP) after decompressive craniotomy is a straightforward neurosurgical procedure, but it remains associated with a high complication rate. Surgical site infection (SSI), aseptic bone resorption (aBR), and need for a secondary CP are the most common complications. This observational study aimed to identify modifiable risk factors to prevent CP failure.

METHODS A retrospective analysis was performed of all patients who underwent CP following decompressive hemicraniectomy (DHC) between 2010 and 2018 at a single institution. Predictors of SSI, aBR, and need for allograft CP were evaluated in a univariate analysis and multivariate logistic regression model.

RESULTS One hundred eighty-six patients treated with CP after DHC were included. The diagnoses leading to a DHC were as follows: stroke (83 patients, 44.6%), traumatic brain injury (55 patients, 29.6%), subarachnoid hemorrhage (33 patients, 17.7%), and intracerebral hemorrhage (15 patients, 8.1%). Post-CP SSI occurred in 25 patients (13.4%), whereas aBR occurred in 32 cases (17.2%). An altered posterior question-mark incision, ending behind the ear, was associated with a significantly lower infection rate and CP failure, compared to the classic question-mark incision (6.3% vs 18.4%; $p = 0.021$). The only significant predictor of aBR was patient age, in which those developing resorption were on average 16 years younger than those without aBR ($p < 0.001$).

CONCLUSIONS The primary goal of this retrospective cohort analysis was to identify adjustable risk factors to prevent post-CP complications. In this analysis, a posterior question-mark incision proved beneficial regarding infection and CP failure. The authors believe that these findings are caused by the better vascularized skin flap due to preservation of the superficial temporal artery and partial preservation of the occipital artery. In this trial, the posterior question-mark incision was identified as an easily and costless adaptable technique to reduce CP failure rates.

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KEYWORDS cranioplasty; decompressive hemicraniectomy; complications; wound infection; surgical site infection; aseptic bone resorption; osteonecrosis; surgical technique

DECOMPRESSIVE hemicraniectomy (DHC) is a routine neurosurgical procedure that can be lifesaving in cases of refractory increased intracranial pressure. Apart from classic indications for its use such as in severe traumatic brain injury (TBI)¹ and malignant cerebral ischemia,^{2–4} the procedure has become more common in

aneurysmal subarachnoid hemorrhage (SAH),^{5,6} and its effectiveness in intracerebral hemorrhage (ICH) is currently being investigated in a randomized controlled trial.^{7,8} The conditions requiring this sort of treatment are severe and often cause considerable neurological impairment. As indications for the procedure broaden, more patients will

ABBREVIATIONS aBR = aseptic bone resorption; CP = cranioplasty; CRP = C-reactive protein; DHC = decompressive hemicraniectomy; DM = diabetes mellitus; EVD = external ventricular drain; GOS-E = Glasgow Outcome Scale–Extended; ICH = intracerebral hemorrhage; ICU = intensive care unit; MMI = malignant middle cerebral artery infarction; PMMA = polymethylmethacrylate; SAH = subarachnoid hemorrhage; SSI = surgical site infection; STA = superficial temporal artery; TBI = traumatic brain injury; WBC = white blood cell.

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require cranial reconstructive surgery. After stabilization of the underlying condition and once the swelling has subsided, a cranioplasty (CP) is required to reconstruct the skull defect. This is to offer cerebral protection and cosmetic repair but also to restore CSF dynamics and normal pressure conditions within the cranial vault. CP may also improve neurocognitive functioning, and early CP can even enhance this effect.⁹ Although CP is a straightforward procedure, the complication rate remains rather high. Complications included surgical site infection (SSI) with or without wound dehiscence, aseptic bone resorption (aBR), postoperative bleeds, epidural fluid collections or hygroma, seizures, and late hydrocephalus.¹⁰ These complications can lead to severe additional morbidity and even death. Depending on what is considered a complication of the CP itself, complication rates in the literature range between 12.3% and 29.7%.^{11–14} Most complications trigger additional surgery consisting of bone flap removal, antibiotic treatment if necessary, and eventually the need for a secondary CP.

In recent years a multitude of studies have been published addressing the problem of complications after CP. Many trials have focused on patient-specific risk factors such as obesity, diabetes mellitus (DM), smoking, arterial disease, hypertension, alcohol abuse, and drug abuse.^{14,15} Although these are typical risk factors for SSI in general surgery or spine procedures, they do not play a major role in CP failure. Artificial allograft implants have been introduced that are made out of materials such as titanium, polyetheretherketone, polymethylmethacrylate (PMMA), and hydroxyapatite without any relevant effect on infection rates.^{16–18} The cryopreserved (at -80°C) autologous bone flap remains the gold standard for primary cranial repair as it is cheap, readily available, and has an ideal geometric fit. Longer operative times and temporalis muscle resection have been identified as modifiable risk factors of SSI.^{19–21} Blind antibiotic topical application during CP failed to reduce post-CP infection rates.²²

The focus of this analysis is on identifying modifiable patient- or surgery-specific risk factors contributing to CP failure.

Methods

Patient Population and Study Design

We retrospectively analyzed all patients treated by DHC in a single institution (University Hospital Aachen, Germany) between 2010 and 2018. Data were obtained from hospital records, extracting all relevant variables and documented complications. SSI was defined as an open or closed graft infection requiring surgical wound revision with or without the removal of the implanted material. This was due to either a visible wound infection or a positive infectious lumbar puncture. Aseptic superficial wound healing problems not requiring surgical intervention or antibiotic treatment were not included. aBR was defined as significant thinning of the bone flap on CT scan, palpable soft spot, or resorption leading to an unsatisfactory cosmetic result. If brain protection was compromised due to aBR, an allograft revision CP was considered. This study was registered as ISRCTN46696883 in the ISRCTN

registry (<http://www.isrctn.com/ISRCTN46696883>). This paper is written in accordance with the STROBE statement for reporting observational studies in epidemiology. The trial was conducted in accordance with the recommendations of the ethics committee of the Medical Faculty of the RWTH Aachen University.

The inclusion criteria were prefixed and defined as all DHC patients who were treated between 2010 and 2018 by autologous CP, between 16 and 90 years of age, for malignant middle cerebral artery infarction (MMI), TBI, SAH, or ICH. Clinical follow-up had to exceed 12 months after CP and had to include at least a clinical neurological examination with inspection of the wound and bone flap with or without CT. Patients were excluded when the DHC was performed for other reasons than named above, such as for infection (interference with infection rate) and after tumor surgery (usually secondary DHC). Bifrontal decompressive craniectomies, children younger than 16 years (before completion of skull growth), immunocompromised patients (iatrogenic or acquired), or patients with a follow-up of less than 12 months were also excluded.

Standard Treatment Algorithm

Prior to every procedure, patients received a single shot of third-generation cephalosporin (cefuroxime) during anesthesia induction, or in the case of allergy/cross-allergy, clindamycin was used. A unilateral frontotemporoparietal DHC was performed in a rapid closure technique without duraplasty.^{23,24} The anteroposterior diameter of the bone flap was always kept above 12 cm.²⁵ As first choice, independent of age, all patients received their cryopreserved (-80°C) autologous bone flap. The time point of CP was not fixed and depended on the development of the rehabilitation process. Ultra-early (< 30 days) CP was avoided if possible due to an observed higher rate of infections and CSF fistulas and hydrocephalus.²⁶ Prior to reinsertion, the autologous bone flap was defrosted, the skin incision was reopened, and the bony rims of the skull defect were prepared. The pseudodural plane was meticulously dissected to prevent CSF leaks. Additional attention was paid to preservation of superficial temporal artery (STA) branches. The bone flap was fixed with at least 6 nonabsorbable polyethylene sutures. A minimum of 5 central sutures were applied to fixate the dural layer to the bone flap. Two nonsuction drains were left behind in the subgaleal space during closure.

Incision Types

Three different incision types for the initial DHC were routinely used during the study inclusion period. The first consists of the standard large reversed question-mark incision starting 1 cm anterior to the tragus at the temporal root of the zygoma, curving posteriorly above and behind the ear extending to the midline at theinion, and then turning anteriorly to end at the widow's peak. During opening, a primary preservation of the STA was always attempted via careful dissection. Accidental scarification occasionally occurred in the case of a very posteriorly located main arterial stem, or partially in the case of a low branching-off of the parietooccipital portion of the STA.

An altered posterior question-mark skin incision was used starting behind the ear, slightly posterior to the base of the mastoid process. The incision is carried cranially across the lambdoid and along the sagittal suture to reach the widow's peak.²⁷

A third type of incision was implemented out of necessity, in cases in which a pterional craniotomy had been performed beforehand. This "n-type" incision is mostly used in patients with SAH previously treated by operative clipping.²⁸ The incision starts perpendicular to and at the middle of the previous frontotemporal incision and runs posteriorly to reach theinion, after which it curves laterally in the direction of the mastoid base. The "T-type" or "Kempe" incision was abandoned before 2010 due to frequent wound healing problems at the intersection of both linear incisions. In hydrocephalic patients, shunting was performed before or after, not during, CP due to documented reduced infection rates with timely separated procedures.^{29–31} The different incision types are depicted in Fig. 1. The diagnosis of relevant aBR or SSI resulted in bone flap removal, and in the case of the latter, antibiotic treatment for 2–4 weeks. Allograft PMMA computer-aided personalized implants were used as the secondary CP material. Our institutional treatment algorithm is illustrated in Fig. 2.

Risk Factors

Patient-specific risk factors were extracted from hospital records, such as prevalence of obesity (BMI > 30), DM, smoking, arterial disease (coronary or peripheral), hypertension, alcohol and drug abuse, length of initial intensive care unit (ICU) stay, as well as pre-CP white blood cell (WBC) count and C-reactive protein (CRP) levels (suggestive of concomitant underlying infections). In addition, the clinical neurological state defined by the extended Glasgow Outcome Scale (GOS-E) at the time of CP and whether the patient was bedridden or not was noted. Surgery-specific variables were registered, such as the time between DHC and CP dichotomized into early (< 90 days) and late (> 90 days) CP, the duration of CP surgery, and the incision type. The occurrence of SSI after DHC, the presence of an external ventricular drain (EVD) during the initial hospital stay, and the need for permanent shunt placement was also noted.

Outcome Parameters

The primary outcome was defined as the occurrence of SSI triggering surgical revision. Additional secondary outcome parameters were the occurrence of aBR and the need for allograft CP.

Statistical Analysis

All data are presented as the mean and standard deviation for normally distributed variables. Categorical variables are depicted as frequencies and proportions. A univariate analysis was applied to screen for independent variables affecting the occurrence of SSI, aBR, and the need for allograft CP. After normality testing via plotting and the Shapiro-Wilk test, the appropriate statistical test was selected. For nominal data, the chi-square test was

used, for normally distributed continuous data the unpaired t-test was used, and for nonnormally distributed data the Mann-Whitney U-test was used. Missing outcome data were not imputed. Predictive factors were further analyzed in a multivariate logistic regression model. All statistical analyses were performed using IBM SPSS (version 25, IBM Corp.). Statistical significance was defined as a two-sided p value < 0.05.

Results

Patients

Between 2010 and 2018, a total of 387 patients were treated by DHC in our department. Of those, 129 died before the CP could be performed. An additional 60 patients were lost to follow-up. Two patients were excluded because the DHC was performed for meningitis-caused generalized edema. Primary autologous CP was performed in 196 patients, and 10 additional patients in this group were lost to follow-up. This resulted in 186 patients treated with CP after DHC with a minimum of 12 months of clinical follow-up. The indications for DHC were MMI (83 patients, 44.6%), TBI (55 patients, 29.6%), SAH (33 patients, 17.7%), and ICH (15 patients, 8.1%). The study enrollment process is depicted in Fig. 3. Baseline characteristics of the cohort are summarized in Table 1. The mean patient age was 49 ± 16 years, with a female/male ratio of 77:109. The mean duration of follow-up was 1153 ± 703 days.

Complications

Post-CP SSI occurred in 25 patients (13.4%). aBR occurred in 32 cases (17.2%). Bone resorption triggered secondary CP in 12 patients (6.4%). In 2 cases, the autologous bone flap needed to be removed shortly after surgery due to unanticipated post-CP brain swelling. This led to a total of 43 patients (23.1%) requiring secondary allograft CP. In 2 SSI cases more than one causal pathogen was identified. *Staphylococcus aureus* was the most often encountered pathogen, in a total of 9 cases. Other common species in descending order of prevalence were *S. epidermidis* in 4 cases, *Escherichia coli* in 3 cases, and *Enterococcus faecalis*, *Pseudomonas* spp., and *Proteus mirabilis* each in 1 case. In 2 cases, multidrug-resistant bacteria were identified (methicillin-resistant *S. aureus* [MRSA] and multidrug resistant gram-negative bacteria). *Cutibacterium acnes* was identified as a common contaminant. Bone resorption triggered flap removal and direct allograft CP in 12 patients (6.4%), 8 of whom were younger than 30 years of age.

Primary Outcome

In a univariate analysis, significant predictors for SSI were patient age (p = 0.041), early CP (p = 0.025), and incision type (p = 0.034). No significant differences in age were observed between the SSI subgroup (mean age 46 ± 15 years) versus the no-SSI subgroup (mean age 50 ± 16 years, p = 0.226). Ten patients in the early-CP subgroup developed SSI (16.4%) versus 15 (12.0%) in the late-CP group (p = 0.493). In a multivariate regression analysis, only the incision type was associated significantly with the rate of SSI. The question-mark incision group (n =

FIG. 1. Illustrations of incision types for DHC and subsequent CP. **A:** The classic trauma flap question-mark incision. **B:** The altered posterior question-mark incision. **C:** The “n-type” incision. **D:** The “T-type” or “Kempe” incision. Copyright Dirk Traufelder. Published with permission.

87) and altered posterior question-mark incision subgroup ($n = 79$) were further compared. SSI was observed in 16 patients (18.4%) in the question-mark subgroup versus 5 patients (6.3%) in the posterior question-mark subgroup ($p = 0.021$). Consistent with results from previous trials, patient-specific risk factors such as obesity, DM, smoking, arterial disease, hypertension, and alcohol and drug abuse

did not have any effect on SSI occurrence. The occurrence of an SSI after the initial DHC, the presence of an EVD during the first ICU stay, the length of the initial ICU stay, and the need for permanent shunting also had no effect on the post-CP SSI incidence. Slight elevation of the WBC count and CRP pre-CP did not increase the incidence of post-CP SSI.

FIG. 2. Institutional treatment algorithm.

Secondary Outcome

In the multivariate analysis, the duration of CP surgery was significantly related to aBR ($p = 0.032$) and need for allograft CP ($p = 0.019$). Although the univariate analysis showed that surgical time for CP was longer in patients who developed bone resorption in the later course, the difference was not significant ($p = 0.078$). Other surgery-specific factors such as timing of CP or duration of DHC surgery, as well as patient-specific factors such as hydrocephalus, unfavorable outcome in the GOS-E, or confinement to bed had no effect on aBR occurrence. The only significant predictor of aBR was patient age, in which those developing resorption were on average 16 years younger ($p < 0.001$) than those without aBR. It should be

noted that the overall time of follow-up was significantly shorter in the posterior question-mark group compared to the question-mark group (809 ± 468 vs 1301 ± 741 days, $p = 0.001$). The CP operative duration in patients with a posterior question-mark incision was on average 15 minutes longer. All results are depicted in Tables 1 and 2.

Discussion

In this observational analysis we have shown that the incision type is a significant predictor of post-CP SSI. The altered posterior question-mark incision, starting behind instead of in front of the ear, was shown to offer a protective effect against CP failure. We hypothesize that the

FIG. 3. Patient recruitment flow chart.

TABLE 1. Baseline characteristics, patient- and surgery-specific factors

Variable	All (n = 186)	No SSI (n = 161)	SSI (n = 25)	p Value*
Mean age $\pm$ SD, yrs	49 $\pm$ 16	50 $\pm$ 16	46 $\pm$ 15	0.226
Sex, n (%)				0.879
Females	77 (41.4)	67 (41.6)	10 (40)	
Males	109 (58.6)	94 (58.4)	15 (60)	
Indication for DHC, n (%)				0.986
MMI	83 (44.6)	71 (44.1)	12 (48.0)	
TBI	55 (29.6)	48 (29.8)	7 (28.0)	
SAH	33 (17.7)	29 (18.0)	4 (16.0)	
ICH	15 (8.1)	13 (8.1)	2 (8.0)	
Patient-specific factors, n (%)				
BMI >30 kg/m ²	26 (14.0)	23 (14.3)	3 (12.0)	0.759
DM II	14 (7.5)	13 (8.1)	1 (4.0)	0.472
Smoking	59 (31.7)	55 (34.2)	4 (16.0)	0.069
CAD/PAD	27 (14.5)	20 (12.4)	2 (8.0)	0.524
Hypertension	94 (50.5)	85 (52.8)	9 (36.0)	0.118
Alcohol abuse	19 (10.2)	17 (10.6)	2 (8.0)	0.694
Illicit drug use	12 (6.5)	10 (6.2)	2 (8.0)	0.735
Surgery-specific factors, n (%)				
Mean duration of DHC $\pm$ SD, mins	104 $\pm$ 63	106.5 $\pm$ 68.5	93.5 $\pm$ 36.8	0.344
Post-DHC SSI	17 (9.1)	14 (8.7)	4 (16.0)	0.250
Post-DHC hygroma	78 (41.9)	70 (43.5)	8 (32.0)	0.279
Post-DHC infections overall	123 (66.1)	109 (67.7)	14 (56.0)	0.488
UTI	34 (18.3)			
Pneumonia	98 (52.7)			
Sepsis	14 (7.5)			
Other	5 (2.7)			
EVD	59 (31.7)	51 (31.7)	6 (24.0)	0.439
Mean ICU length of stay $\pm$ SD, days	27 $\pm$ 19	26.8 $\pm$ 19.1	29.4 $\pm$ 21.0	0.477
Early CP	61 (32.8)	51 (31.7)	10 (40.0)	0.410
Permanent shunt	48 (25.8)	47 (29.2)	8 (32.0)	0.775
Pre-CP leukocytosis (>10.0/nl)	25 (13.4)	23 (14.3)	2 (8.0)	0.380
Pre-CP > CRP (>5 mg/L)	57 (30.6)	51 (31.7)	6 (24.0)	0.439
Unfavorable GOS-E score at CP, 1–4	146 (78.5)	128 (79.5)	18 (72.0)	0.396
Bedridden at CP	106 (57.0)	93 (57.8)	13 (52.0)	0.588
Mean duration of CP $\pm$ SD, mins	144 $\pm$ 46	146 $\pm$ 45	139 $\pm$ 52	0.471
Mean duration of follow-up $\pm$ SD, days	1153 $\pm$ 703	1159 $\pm$ 700	1125 $\pm$ 736	0.848

CAD = coronary artery disease; DM II = diabetes mellitus type 2; PAD = peripheral artery disease; UTI = urinary tract infection.

* Comparison between the no-SSI and SSI groups.

better scalp vascularization due to complete preservation of the STA and partial preservation of the occipital artery is the main contributing factor. Thus, we were able to identify an easily applicable technique to reduce the CP infection risk. Based on these results, our department has abandoned the classic inverted question-mark incision in favor of the altered posterior type for DHC. A minor drawback of this altered incision type is a limited exposure of the anterior temporal region, due to the fact that the skin flap, when being folded over and retracted, is hindered by the attachment at the level of the external auditory canal. How pronounced this problem is varies considerably depending

on general skull morphology. However, as the temporal squama is removed with a rongeur in both the classic as well as the posterior incision type, this minor limitation does not compromise the ability to fulfill an adequate temporal decompression.

It should be noted that no significant difference in SSI rates after DHC were observed between the classic and posterior incision types. This could be attributed to the fact that the rate of wound infection after the initial decompression is low, making intergroup differences less explicit.

Some authors advocate the n-type incision as a first

TABLE 2. Results comparing the question-mark and posterior question-mark incision subgroups

Variable	T- or n-Type (n = 20)	Question Mark (n = 87)	Posterior Question Mark (n = 79)	p Value*
Mean age $\pm$ SD (range), yrs	49 $\pm$ 15	52 $\pm$ 16	47 $\pm$ 16	0.092
Sex, n (%)				0.420
Females	4 (20)	29 (33.3)	32 (40.5)	
Males	16 (80)	58 (66.7)	47 (59.5)	
Indication for DHC, n (%)				0.192
MMI	0 (0.0)	46 (52.9)	37 (46.8)	
TBI	0 (0.0)	31 (35.6)	24 (30.4)	
SAH	17 (85)	7 (8.0)	9 (11.4)	
ICH	3 (15)	3 (3.4)	9 (11.4)	
Surgery-specific risk factors, n (%)				
Mean duration of DHC $\pm$ SD, mins	106 $\pm$ 47	105 $\pm$ 79	102 $\pm$ 47	0.843
Post-DHC SSI	2 (10.0)	9 (10.3)	6 (7.6)	0.597
Post-DHC hygroma	11 (55.0)	35 (40.2)	32 (40.5)	0.972
Post-DHC infections overall	17 (85.0)	52 (59.8)	54 (68.3)	0.415
UTI	3 (15)	14 (16.1)	17 (21.5)	
Pneumonia	13 (65)	43 (49.4)	42 (53.2)	
Sepsis	2 (10.0)	3 (3.4)	9 (11.4)	
Other	1 (5.0)	2 (2.3)	1 (1.3)	
EVD	18 (90.0)	20 (23.0)	21 (26.6)	0.476
Mean ICU length of stay $\pm$ SD, days	32 $\pm$ 15	22 $\pm$ 18	30 $\pm$ 21	0.010
Early CP	9 (45.0)	31 (35.6)	21 (26.6)	0.243
Permanent shunt	9 (45.0)	18 (20.7)	21 (26.6)	0.604
Pre-CP leukocytosis ($>10.0/\text{nl}$)	2 (10.0)	9 (10.3)	14 (17.7)	0.261
Pre-CP $>$ CRP ($>5 \text{ mg/L}$)	4 (20.0)	20 (23.0)	33 (41.8)	0.012
Unfavorable GOS-E at CP, 1–4	14 (70.0)	60 (69.0)	72 (91.1)	0.001
Bedridden at CP	11 (55)	46 (52.9)	49 (62.0)	0.273
Mean duration of CP $\pm$ SD, mins	174 $\pm$ 38	134 $\pm$ 47	149 $\pm$ 43	0.023
Mean duration of follow-up $\pm$ SD, days	1011 $\pm$ 900	1301 $\pm$ 741	809 $\pm$ 468	0.001
Post-CP SSI	4 (20.0)	16 (18.4)	5 (6.3)	0.021
Post-CP aBR	5 (25.0)	15 (17.2)	12 (15.2)	0.834
Post-CP aBR triggering treatment	2 (10.0)	4 (4.6)	6 (7.6)	0.525
Allograft CP	4 (20)	25 (28.7)	14 (17.7)	0.126

Boldface type indicates statistical significance.

* Comparison between the question-mark and posterior question-mark incision groups.

choice.²⁸ In our series, the infection rate of this incision was comparable to that of the classic question-mark incision and should therefore only be reserved for cases in which a previous curvilinear frontotemporal incision forces one to do so. In this cohort, however, the n-type incision was never used as a first option, so results could be different if used as the primary incision type.

The only significant predictor of aBR was patient age. Revision surgery with allograft CP was necessary in 13 cases (7.0%); of those, 8 cases were younger than 30 years. Conversely, there were 20 patients younger than 30 in the cohort, of whom the other 12 did not show relevant bone resorption. In this case, the subjectivity in defining what is relevant resorption is relevant and creates observer and detection bias. Some authors advocate the primary use of allograft CP in younger patients.³² A cost-effectiveness

analysis could help shed light on this dilemma. Due to the still high success rate, low cost, and availability of this procedure, we still opt for primary autologous CP, also in younger patients.

Although *C. acnes* has been identified as a cause of osteolysis, possibly due to a slow low-grade infection, it was treated in our series as a contaminant. This was justified by the lack of additional inflammatory signs. The results of the recent analysis by Butenschoen et al.³⁴ should, however, trigger more vigilance toward less virulent bacteria in patients with CP.

We anticipated that unfavorable GOS-E scores and especially confinement to bed would have a promoting effect on wound healing problems and infection. This belief comes from the observation that in many cases, wound dehiscence or infection sites in bedridden patients appear in

the occipital region where continuous pressure decreases blood flow. In our analysis, this hypothesis was not confirmed. However, vigilant attention should continue to be paid to patients who are not able to indicate signs of postoperative complications and discomfort themselves.

Obvious weaknesses of this study are its observational and retrospective nature without randomization. Even if subgroups proved to be comparable, due to the long recruitment period and heterogeneous follow-up, there is the possibility of selection as well as detection bias. The minimal duration of follow-up was arbitrarily set at 12 months. It could be that late SSI and aBR in the posterior question-mark group was not reported due to the shorter follow-up. Nonetheless, the average follow-up of the posterior question-mark group still exceeds 2 years, and due to the low prevalence of late SSI, the bias caused by this difference in follow-up is estimated to be minimal.

In general, the follow-up duration might have been too short to identify all cases of aBR, as a previous study showed that bone flap resorption occurred in a pediatric population after an average of 13.3 months after primary CP.³³ Additionally, being a single-center study, these results cannot simply be extrapolated to other institutions because of potentially other unidentifiable factors involved. Finally, some relevant factors have not been examined, such as cosmetic result, nonspecific operative complications such as deep vein thrombosis, or the seniority of the operating surgeon. However, in an observational trial, supervised residents were as likely as board-certified neurosurgeons to have postoperative complications.¹⁰

Conclusions

Complications after autologous CP for patients who were treated by DHC are common and bothersome. This trial focuses on CP complications exclusively after DHC. We showed that the altered posterior question-mark incision is associated with a lower infection and CP failure rate. Based on these results, the classic question-mark incision in our institution has been superseded by the altered posterior type.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Veldeman, Clusmann. Acquisition of data: Veldeman, Daleiden, Hamou. Analysis and interpretation of data: Veldeman, Daleiden, Hamou, Clusmann. Drafting the article: Veldeman, Daleiden. Critically revising the article: Veldeman, Daleiden, Hamou, Clusmann. Reviewed submitted version of manuscript: Veldeman, Daleiden, Hoellig, Clusmann. Approved the final version of the manuscript on behalf of all authors: Veldeman. Statistical analysis: Veldeman, Hoellig. Administrative/technical/material support: Veldeman, Hoellig, Clusmann. Study supervision: Veldeman, Hoellig, Clusmann.

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