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Long-term Effect of Cranioplasty on Overlying Scalp Atrophy

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Background: Scalp thinning over a cranioplasty can lead to complex wound problems, such as extrusion and infection. However, the details of this process remain unknown. The aim of this study was to describe long-term soft-tissue changes over various cranioplasty materials and to examine risk factors associated with accelerated scalp thinning.
Methods: A retrospective review of patients treated with isolated cranioplasty between 2003 and 2015 was conducted. To limit confounders, patients with additional scalp reconstruction or who had a radiologic follow-up for less than 1 year were excluded. Computed tomography or magnetic resonance imaging was used to measure scalp thickness in identical locations and on the mirror image side of the scalp at different time points.
Results: One hundred one patients treated with autogenous bone (N = 38), polymethylmethacrylate (N = 33), and titanium mesh (N = 30) were identified. Mean skull defect size was 104.6 ± 43.8 cm². Mean length of follow-up was 5.6 ± 2.6 years. Significant thinning of the scalp occurred over all materials ($P < 0.05$). This was most notable over the first 2 years after reconstruction. Risk factors included the use of titanium mesh ($P < 0.05$), use of radiation ($P < 0.05$), reconstruction in temporal location ($P < 0.05$), and use of a T-shaped or "question mark" incision ($P < 0.05$).
Conclusions: Thinning of the native scalp occurred over both autogenous and alloplastic materials. This process was more severe and more progressive when titanium mesh was used. In our group of patients without preexisting soft-tissue problems, native scalp atrophy rarely led to implant exposure. Other risk factors for scalp atrophy included radiation, temporal location, and type of surgical exposure. *(Plast Reconstr Surg Glob Open 2020;8:e3031; doi: 10.1097/GOX.0000000000003031; Published online 25 August 2020.)*

INTRODUCTION

Full-thickness cranial bone defects most commonly occur following infection, osteoradionecrosis, or head trauma. Repair of the calvaria with a rigid cranioplasty is usually warranted because it protects the brain from both penetrating and blunt injuries, restores aesthetics, and guards against the "syndrome of the trephined," a neurological deterioration resulting from the removal of the cranial bone flap.[1–3] Depending on the size of the defect, location, and other comorbidities, a cranioplasty may be performed either with autogenous bone or with alloplastic material. Due to the complex nature of these reconstructions, significant morbidity may be incurred.[4–15]

One of the most vexing cranioplasty complications is infection, which most often leads to implant or bone graft removal. Progressive scalp thinning is a significant risk factor for cranioplasty exposure (Figs. 1 and 2).[16,17] Soft-tissue atrophy has been reported to occur over a number of different materials in a variety of locations, including facial implants, breast prostheses, and tissue expanders.[18–21] However, to date, there are limited data on the soft-tissue atrophy, which occurs over materials used for cranial reconstruction. Although some authors have recognized this problem in the past, their reports are mostly anecdotal and their follow-up is short.[22–27] Thus, the pathophysiology and risk factors for this process remain largely unknown. The aim of this study therefore was to (1) describe and compare long-term soft-tissue scalp thinning over a variety of cranioplasty materials and to (2) examine risk factors for accelerated scalp changes over a variety of these reconstructions.
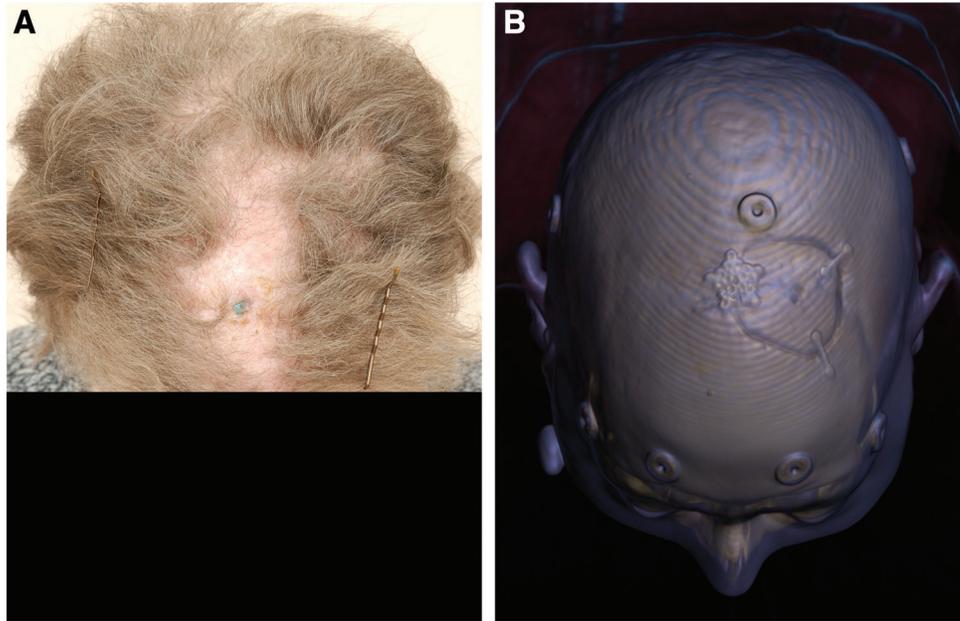
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Fig. 1. A 63-year-old woman with history of intracranial tumor excision and irradiation who presented 2 years later with progressive scalp thinning and extrusion of a prominent plate used for fixing the autogenous bone flap. A, Plate extrusion can be seen over the midline location. B, A three-dimensional (3D) computed tomographic image showing the size and location of the cranial reconstruction.
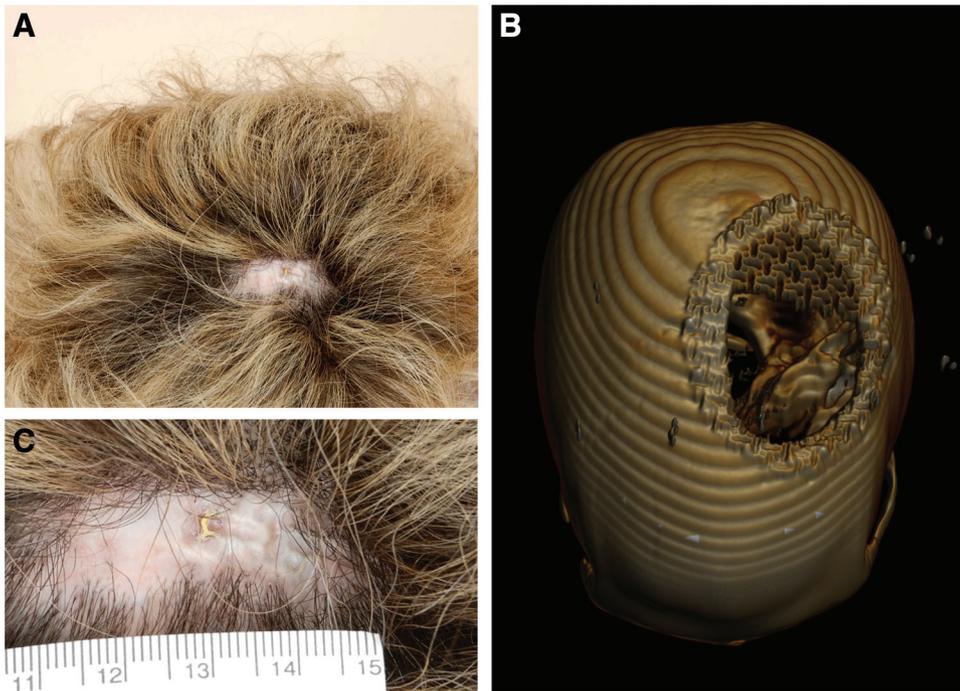
Fig. 2. A 45-year-old woman with history of intracranial tumor excision and titanium mesh cranioplasty. Considerable thinning of the scalp occurred over the mesh 1 year after reconstruction, leading to extrusion A, Photograph of the patient's head 1 year after surgery. B, Close-up of scalp thinning with implant exposure. C, A three-dimensional (3D) computed tomographic image showing the size and location of cranial reconstruction.

MATERIALS AND METHODS

After institutional review board approval, a retrospective review of patients treated with isolated cranioplasty between 2003 and 2013 was performed. Data were collected from the electronic medical records and included patient demographics, comorbidities, risk factors (history of radiation, chemotherapy, involvement of the frontal sinus, and abnormal soft-tissue coverage), as

well as physical characteristics of the anatomic defects. To simplify analysis and to limit confounders, patients with any additional soft-tissue reconstruction, such as local tissue rearrangement, galeal scoring, local or free-flap procedures, were excluded from further analysis. Patients with no preoperative imaging and those with a radiologic follow-up for less than 1 year were also excluded.

Intraoperative data collected included location and size of the defect, type of exposure, and cranioplasty material used. Scalp thickness was measured on computed tomography (CT) or magnetic resonance imagining (MRI) preoperatively and then at additional time points postoperatively. Measurements were performed over the center of the defect in a plane perpendicular to the surface of the cranioplasty. Each measurement was repeated 3 times, and a mean value was calculated. This value was then presented as a ratio by dividing preoperative thickness by postoperative thickness in the same location or by the thickness of the contralateral side when a mirror image location was anatomically present. For example, the scalp overlying a right parietal cranioplasty was compared with the opposite and unoperated left parietal scalp region. Because the ratio comparison was used, this corrected for potential differences in imaging techniques over time. Two physician observers performed all measurements using EasyViz 4.1.12-40 software (Medical Insight A/S, Valby, Denmark).

Cranioplasty material exposures within 1 month of reconstruction were considered wound healing complications, and those patients were excluded from the final analysis. Extrusions after 1 month, but after normal wound healing was documented, were considered complications of scalp atrophy related to the underlying cranioplasty material. Those patients were further analyzed.

Statistical Analysis

All data are presented as a fraction or mean with SD. One-way analysis of variances was used to compare scalp thinning between different cranioplasty materials. Tukey's multiple comparison test was used for the post hoc analysis to determine which groups were statistically different.

Univariate analysis was conducted using the paired Mann–Whitney or Student t test for continuous variables, as deemed appropriate. Multivariate logistic regression was used to evaluate independent risk factors for accelerated soft-tissue atrophy. Accelerated scalp thinning was defined as loss of >50% of preoperative thickness or >50% difference when compared with the mirror image on the contralateral side. SPSS 16.0 for Windows (IBM Corporation, New York, N.Y.) was used for analysis. All tests were 2-tailed, with a P value of <0.05 considered significant.

RESULTS

Between 2003 and 2015, a total of 749 cranioplasties were performed at our institution. Of these, 527 procedures (70.4%) were performed in patients with calvarial defects only and 222 operations (29.6%) included some type of scalp reconstruction (Fig. 3). The latter patients were excluded from the study. Among the former group, 184 patients (34.9%) had a history of cranioplasty or soft-tissue reconstruction and were also excluded. One hundred one patients who had preoperative and postoperative CT or MRI and a minimum of one-year follow up were available for the final analysis.

Patient characteristics and comorbidities are shown in Table 1. Highlights of the results of Table 1 include the following: the mean age of our patients was 45.4 ± 14.1 years, and their mean defect size was 104.6 ± 43.8 cm². The most common etiology of the defect was neurosurgical brain decompression (81.2%) followed by ablation of tumor (11.9%), trauma (5.0%), and congenital malformation (3.0%). The most common materials used for reconstruction were autogenous bone (37.6%), polymethylmethacrylate (32.7%), and titanium mesh (29.7%). The mean length of the follow-up was 5.6 ± 2.6 years.

Figure 4 shows that significant thinning of the scalp occurred over all materials, including nonvascularized autogenous bone flaps ($P < 0.05$). After an initial increase in scalp thickness immediately following cranioplasty, there was a gradual decrease over the next 2 years. When all materials were analyzed together, scalp thickness remained relatively stable after that time. When changes
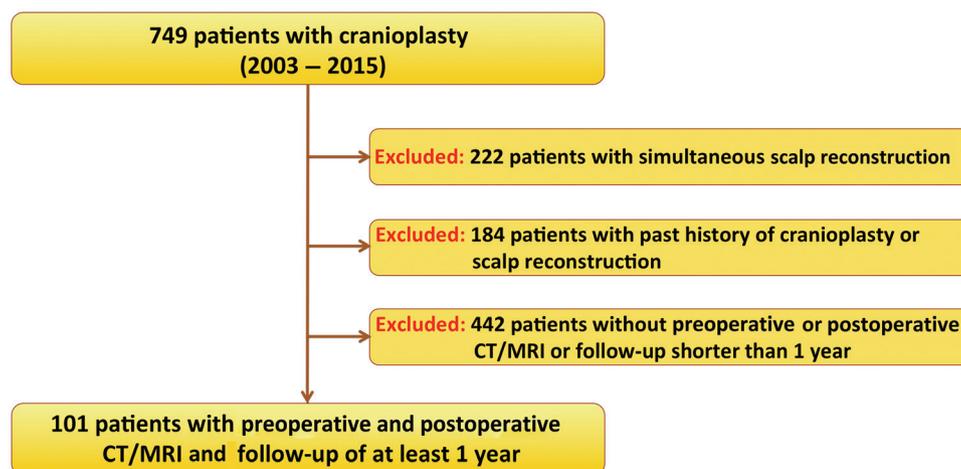
Fig. 3. Selection of patients for the study.

749 patients with cranioplasty (2003 — 2015)

Excluded: 222 patients with simultaneous scalp reconstruction

Excluded: 184 patients with past history of cranioplasty or scalp reconstruction

Excluded: 442 patients without preoperative or postoperative CT/MRI or follow-up shorter than 1 year

101 patients with preoperative and postoperative CT/MRI and follow-up of at least 1 year

Table 1. Patient Demographics and Defect Characteristics

Variable	No. Patients, %, Total N = 101
Age, mean ± SD, y	45.4 ± 14.1
Female	41 (40.6)
Smoking history	
Current	33 (32.7)
Former	11 (10.9)
Never	57 (56.4)
Etiology	
Craniectomy defect	81 (80.2)
Ablation	12 (11.9)
Trauma	5 (5.0)
Congenital	3 (3.0)
Size of defect, mean ± SD, cm²	104.6 ± 43.8
Location of defect	
Frontal	82 (81.2)
Temporal	56 (55.4)
Parietal	54 (53.5)
Occipital	6 (5.9)
Bilateral defect	15 (14.9)
Radiation	
Preoperative	2 (2.0)
Postoperative	9 (8.9)
Chemotherapy	
Preoperative	7 (6.9)
Postoperative	4 (4.0)
Cranioplasty material	
Autogenous bone	38 (37.6)
PMMA	33 (32.7)
Titanium mesh	30 (29.7)
No. postoperative radiologic scans, mean ± SD	8.6 ± 8.1
Length of follow-up, mean ± SD, y	5.6 ± 2.6

PMMA, polymethylmethacrylate.

in scalp thickness were stratified according to cranioplasty material, atrophy occurred over both autogenous bone and methylmethacrylate at similar rates during the first 2 years and then both remained relatively stable (Fig. 5). Scalp atrophy over titanium mesh was also most evident during the first 2 years. However, unlike autogenous bone and methylmethacrylate, it continued to progress over time (analysis of variance; $P < 0.01$).

Univariate logistic regression was used to identify unadjusted risk factors associated with the accelerated scalp thinning over cranial reconstruction (Table 2). Significant factors included postoperative radiation [odds ratio (OR), 9.97; $P < 0.01$], postoperative chemotherapy (OR, 8.18; $P = 0.02$), temporal location (OR, 3.71; $P = 0.04$), T-shaped or "question mark" incision as opposed to coronal approach (OR, 4.15; $P < 0.01$), and use of titanium mesh material (OR, 4.92; $P < 0.01$).

Multivariate logistic regression analysis was used to identify independent predictors of scalp thinning while controlling for confounding effects of other risk factors (Table 3). The strongest independent predictor of scalp atrophy was the use of titanium mesh material (OR, 14.45; $P < 0.01$), postoperative radiation (OR, 13.13; $P = 0.04$), and the use of a T-shaped or "question mark" incision (OR, 10.18; $P < 0.01$). Patients with reconstruction in the temporal location were also more likely to have soft-tissue atrophy, but this was not statistically significant (OR, 2.44; $P = 0.09$).

No significant difference in complications between materials was demonstrated. Two patients with autogenous bone and polymethylmethacrylate cranioplasty underwent resection of the recurrent brain tumor 10 and 12 months

after reconstruction, respectively. Two patients with autogenous bone had bone resorption complicated by loosening of the fixation plates and extrusion 12 and 14 months after repair. This occurred at the periphery of the defect and was not considered as cranioplasty material extrusion. Both patients underwent removal of the affected fixation plates with primary closure, and they recovered uneventfully. One patient with polymethylmethacrylate had implant infection 10 months after reconstruction, without evidence of underlying soft-tissue problems. This patient subsequently underwent staged exchange.

DISCUSSION

The literature documents that an isolated cranioplasty performed in the absence of soft-tissue abnormalities or other risk factors can be performed with very low morbidity.[1,3] However, anecdotal reports have suggested that scalp thinning can occur over alloplastic cranial implant reconstruction and that this subcutaneous thinning can lead to ultimate implant failure.[15–17] These published studies often include small patient cohorts, highly variable methods of reconstruction, and short-term follow-up. For this reason, we attempted to (1) evaluate long-term scalp changes over various cranioplasties in a uniform cohort of patients to determine if scalp thinning occurred to a greater extent over a specific material and to (2) evaluate risk factors for accelerated scalp thinning over a variety of autogenous and alloplastic materials. If this could be delineated, use of reconstructive materials leading to more significant scalp thinning might be limited or avoided.

This study found that thinning of the native scalp occurs over both alloplastic and nonvascularized autogenous materials. Scalp atrophy of approximately 20% occurs when the reconstructed side is compared with the preoperative thickness or the opposite mirror image side in the first 2 years after reconstruction for autogenous bone, methylmethacrylate, and titanium mesh. While scalp atrophy stabilizes after this time period for both autogenous bone and methylmethacrylate, thinning continues to progress with titanium mesh constructs. Other risk factors include radiation and type of exposure and temporal location.

Cranioplasty Material

Titanium cranioplasty is frequently selected for moderate- to large-sized craniectomy defects because of the simplicity of reconstruction, as well as its rigidity.[28–30] Despite initial reports describing excellent short-term outcomes, more recent studies are less enthusiastic. Kwiecien et al[22] evaluated the use of titanium mesh for isolated and composite cranioplasties. They reported over 90% long-term implant retention rate for isolated cranioplasties. However, the retention rate was <50% when additional scalp reconstruction with a local or free flap was needed. Maqbool et al[17] reported significant scalp atrophy in 44% of their patients with titanium mesh cranioplasties and 14% extrusion rate of the implant. The median time to extrusion was 205 days. They concluded that thinning of the scalp was a significant risk factor for extrusion.
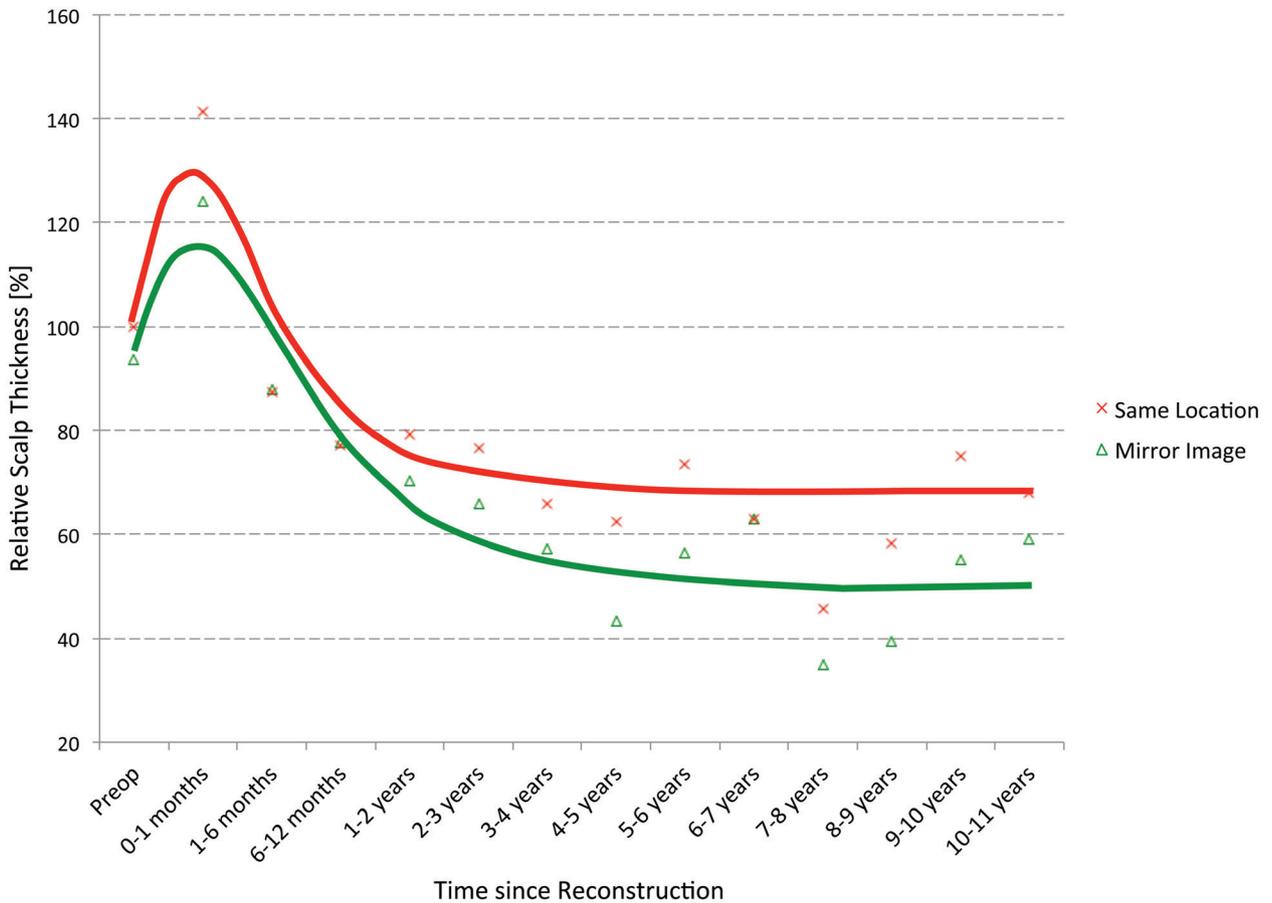
Fig. 4. Graph showing scalp thinning over cranioplasty material with time (all materials studied). The red line depicts percent scalp thinning when scalp over the reconstruction is compared with the preoperative scalp thickness in the same location. The green line compares percent scalp thickness when the scalp over the reconstruction is compared with the mirror image scalp at the same time periods.
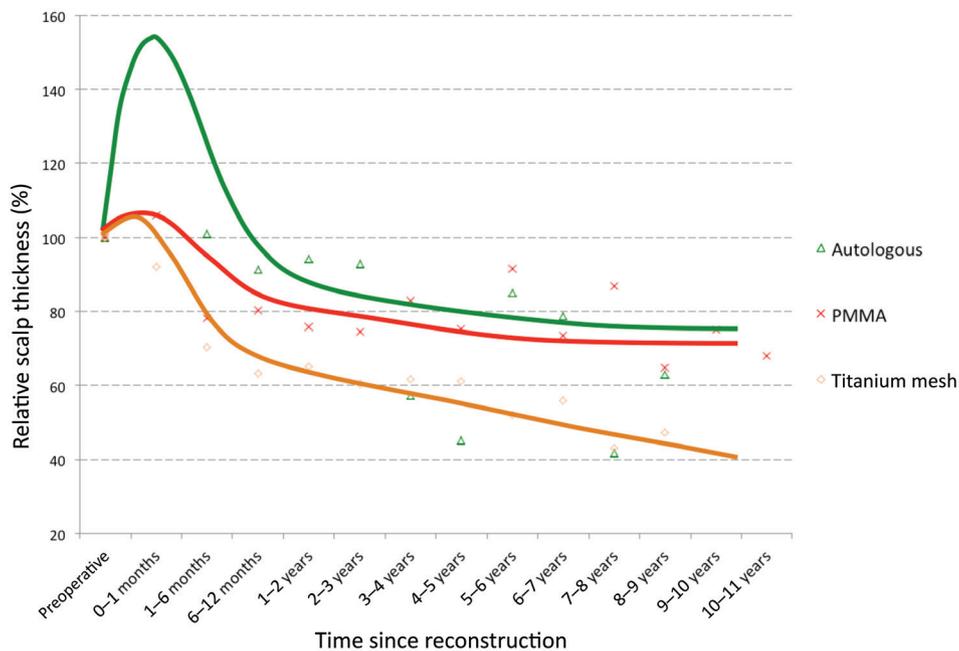
Fig. 5. Graph showing relative scalp thickness changes over different cranioplasty materials. Scalp atrophy is most evident during the first 2 years after reconstruction. Scalp over autogenous bone and polymethylmethacrylate thins during the first 2 years after reconstruction and then remains relatively stable. Scalp atrophy over titanium mesh is most evident during the first 2 years but continues to progress over time unlike other materials.

Table 2. Risk Factors Associated with the Scalp Atrophy over Cranioplasty: Univariate Logistic Regression

Variable	Accelerated Scalp Atrophy*	
	Odds Ratio (95% Confidence Interval)	*P*
Postoperative radiation	9.97 (2.41–41.23)	0.002
Postoperative chemotherapy	8.18 (1.48–45.14)	0.016
Temporal location	3.71 (1.29–10.55)	0.038
T-shape or "question mark" incision versus coronal incision	4.15 (1.30–13.20)	<0.001
Titanium mesh versus other materials	4.92 (1.91–12.68)	0.001
Size of the defect†	0.84 (0.75–0.95)	0.006

*Accelerated scalp atrophy was defined as the loss of >50% of preoperative soft tissue thickness or >50% difference when compared.
†Odds ratio adjusted for increase of each 10 cm² of cranioplasty size.

Table 3. Independent Risk Factors Associated with the Scalp Atrophy over Cranioplasty: Multivariate Logistic Regression

Variable	Accelerated Scalp Atrophy*	
	Odds Ratio (95% Confidence Interval)	*P*
Postoperative radiation	13.13 (1.10–157.20)	0.042
T-shape or "question mark" incision versus coronal incision	10.18 (2.47–41.91)	0.001
Titanium mesh versus other materials	14.45 (3.94–53.06)	<0.001
Temporal location	2.44 (0.92–6.47)	0.091†
Postoperative chemotherapy	2.41 (0.31–18.93)	0.402†
Size of the defect‡	0.90 (0.76–1.05)	0.170†

*Accelerated scalp atrophy was defined as the loss of >50% of preoperative soft tissue thickness or >50% difference when compared.
†Values not statistically significant and not included in the final regression equation.
‡Odds ratio adjusted for increase of each 10 cm² of cranioplasty size.

In our study, to evaluate the true impact of cranioplasty material on scalp atrophy, we excluded all patients with a history of any soft-tissue scalp reconstruction. Moreover, scalp thickness was measured uniformly over the center of the cranioplasty. This way, wound dehiscence or widening of the scar were not confused with the true atrophy and extrusion. While we demonstrated that the healthy native scalp overlying the titanium mesh undergoes continued and progressive atrophy over time, we can only hypothesize with regard to etiology. A recent study has suggested that titanium mesh is particularly prone to cause scalp thinning due to pressure gradient fluctuations between the atmosphere and the intracranial space. This gradient may exert stress on the soft tissues around the mesh holes.[31] Another possible explanation may be related to a decrease in blood supply. However, this is difficult to invoke, given that such progressive thinning did not occur over similar reconstructions using the other materials reviewed.

Further, it cannot be assumed from these data that these observations result in an increase in complication rates for a given material. Such a cause and effect relationship has not been shown. In fact, we were unable to demonstrate an increase in complications with any of the implants studied. This might be explained by the relatively small number of patients analyzed. As the cranioplasty failure rate may be as low as 1% in general population,[1,3] this study is clearly underpowered to evaluate this outcome.

Surgical Approach

The choice of surgical approach determines the extent of dissection required to complete a cranioplasty reconstruction. Our patients who underwent a coronal incision had less scalp atrophy than those who used other types of approaches. The significance of this finding is not completely clear. The coronal incision preserves all major blood supply, whereas "question mark" and "U-shaped" flaps used to expose temporal or parietal defects are often based on a single pedicle—superficial temporal vessels.[32,33] Autonomic denervation may also play a role in the differences seen. Small flaps with relatively narrow bases may undergo more significant denervation when compared with the widely based coronal flaps.

Location

Temporal hollowing is a common complication following surgical dissection in this region. Its reported incidence after decompressive craniectomy even without any cranial reconstruction is as high as 100%.[34] Suggested etiologies of hollowing are related to devascularization, denervation, and detachment of muscle, fascial, and ligamentous attachments. This leads to atrophy of the temporalis muscle, a decrease in volume of the superficial temporal fat pad, and its inferior migration.[33–35] We observed considerable soft-tissue thinning over cranioplasty material in the temporal location involving both temporalis muscle and subcutaneous fat. However, the rate of implant or bone graft loss in this area remains low because of the added soft-tissue coverage provided by the temporalis muscle and fascia.

Other Risk Factors

With regard to other independent risk factors leading to scalp thinning, our findings were consistent with those in previous studies.[16,17] A higher incidence of soft-tissue atrophy was found in irradiated patients and in those undergoing chemotherapy. Interestingly, the larger size of the defect in this study was not associated with more extensive soft-tissue atrophy.

Limitations

This study is not without limitations. It is retrospective in nature, which makes determining the influence of individual factors on the results difficult. Only

patients requiring longitudinal radiological follow-up were included. Therefore, our patient cohort was limited. Those who did not require repeated CT or MRI were not evaluated. This may have inadvertently introduced a selection bias. Finally, the relatively small number of patients in our cohort group may explain the inability of our study to demonstrate an increase in complication rate when titanium mesh was compared with other cranioplasty materials.

CONCLUSIONS

Thinning of the native scalp occurred over both autogenous and alloplastic materials. This was most evident in the first 2 years following reconstruction and then stabilized in the case of autogenous bone and methylmethacrylate. This process continued after 2 years when titanium mesh was used. Although we did not demonstrate an increase in complications when titanium mesh was used, this may have been due to the relatively small number of patients in our cohort groups. Other risk factors for scalp atrophy included radiation, temporal location, and type of surgical exposure.

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