Reconstruction of Acquired Scalp Defects: An Algorithmic Approach

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Learning Objectives: After studying this article, the participant should: 1. Understand scalp anatomy, hair physiology, and skin viscoelastic properties as they relate to scalp reconstruction. 2. Understand the principles that allow for aesthetic reconstruction of scalp defects. 3. Understand the use of local tissue rearrangement for reconstruction of specific areas of the scalp. 4. Understand the use of tissue expansion and free tissue transfer for scalp reconstruction.

Background: Reconstruction of scalp defects is required for acute trauma, tumor extirpation, radiation necrosis, and the repair of traumatic alopecia or cosmetically displeasing scars.

Methods: The proper choice of a reconstructive technique is affected by several factors—the size and location of the defect, the presence or absence of periosteum, the quality of surrounding scalp tissue, the presence or absence of hair, location of the hairline, and patient comorbidities. Successful reconstruction of these defects requires a detailed knowledge of scalp anatomy, hair physiology, skin biomechanics, and the variety of possible local tissue rearrangements. In nearly total defects, local tissues may be inadequate and tissue expansion or free tissue transfer may be the only alternatives.

Results: Plastic surgeons are now able to obtain coverage over the calvaria after the most devastating of defects; however, the challenge to the reconstructive surgeon today is to do so with excellent cosmetic results. Cosmetic scalp reconstruction requires restoration and preservation of normal hair patterns and hair lines.

Conclusions: Successful reconstruction of the scalp requires careful preoperative planning and precise intraoperative execution. Detailed knowledge of scalp anatomy, skin biomechanics, hair physiology, and the variety of available local tissue rearrangements allows for excellent aesthetic reconstruction. (*Plast. Reconstr. Surg.* 116: 54e, 2005.)

The reconstruction of scalp defects is necessary for acute trauma, tumor extirpation, radiation necrosis, and improvement of cosmetically displeasing scars or alopecia. The history of scalp reconstruction parallels developments in plastic surgery techniques. An interesting and detailed history of scalping injuries and their management was described by Koss et al.[1] Augustin Belloste, a French surgeon, in 1696 advocated early perforation of bare cranium to allow granulation tissue and subsequent epithelialization.[2] This was practiced until Netolitzky, in 1871, used skin grafting of the calvaria after the presence of granulation tissue.[3] In 1908, Robinson demonstrated the success of skin grafting on intact periosteum before the presence of granulation tissue.[4] Multiple authors shortly thereafter demonstrated successful reconstruction with local flaps.[5–9] Kazanjian demonstrated that galeal scoring allowed for further advancement of local flaps.[6] Orticochea published his four-flap technique

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for large scalp defects in 1967 and revised his technique to the use of three flaps in 1971.[10,11]

Neumann reported the first clinical use of tissue expansion in 1957 when he expanded the scalp for ear reconstruction.[12] Radovan[13] popularized tissue expansion in 1976 and demonstrated the usefulness of the technique. In 1984, Manders et al. reported reconstruction of nearly half the scalp with hair-bearing tissue using tissue expansion.[14]

Advances in microsurgery have also played a significant role in scalp reconstruction. In 1976 Miller et al. successfully replanted a totally avulsed scalp with return of normal hair growth and frontalis function.[15] Multiple authors have since presented series of patients who have had near total scalp defects reconstructed with free tissue transfer.[16–22]

Applied Anatomy

Scalp anatomy has been well characterized in a number of anatomy textbooks and recent review articles.[23–28] We have highlighted the salient aspects of scalp anatomy for the reconstructive surgeon.

Layers

The layers of the scalp are easily remembered by the mnemonic SCALP: *S* (skin), *C* (subcutaneous tissue), *A* (aponeurotic layer), *L* (loose areolar tissue), and *P* (pericranium) (Fig. 1).[24] The skin of the scalp is the thickest in the body, measuring between 3 and 8 mm, which makes it a useful donor site for split-thickness grafting.[29,30] The vessels, lymphatics, and nerves course through the subcutaneous layer just superficial to the galea. The galeal aponeurosis, the strength layer of the scalp, is contiguous with the paired frontalis muscles anteriorly, the paired occipitalis muscles posteriorly, and the temporoparietal fascia laterally. The loose areolar tissue plane is also known as the subgaleal fascia, the innominate fascia, and the subaponeurotic plane.[31,32] The loose areolar tissue of this plane allows for scalp mobility. As such, scalp avulsions routinely occur through this layer, thereby leaving pericranium intact.[33] This subgaleal fascia can be harvested for thin, pliable coverage of defects of the head and neck or can be used for free tissue transfer.[32] The pericranium is tightly adherent to the skull and should be left intact in scalp reconstruction to allow for "back-grafting" of the donor site or for a means of alternative reconstruction in the event of a failed local tissue transfer.

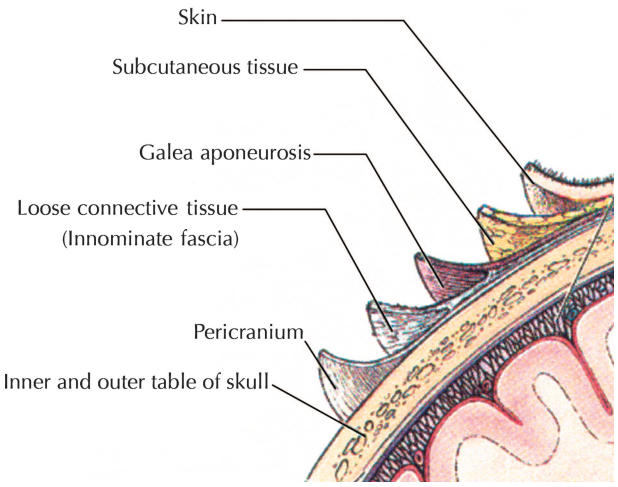

FIG. 1. Layers of the scalp.

The greatest amount of scalp mobility occurs in the parietal regions where the temporoparietal fascia overlies the temporalis fascia (Fig. 2). In general, the design of scalp flaps takes advantage of this feature so that tissue advancement is gained from the parietal regions. At the superior temporal septum in the lateral frontal region, the aponeurotic layer adheres to the pericranium, thereby greatly decreasing scalp mobility.[34] To gain tissue from this area, these ligamentous adhesions must be released. The occipital region can also contribute tissue for reconstruction, but significant advances often require undermining onto the trapezius and splenius capitis muscles.

Vascularity

The scalp is supplied by arterial branches and vena comitantes of the internal and external carotid systems into four distinct vascular territories (Fig. 3).[24] Extensive collateralization of these vascular territories allows total scalp replantation based on a single vascular anastomosis.[15] The anterior territory is supplied by terminal branches of the internal carotid system: the supraorbital and supratrochlear arteries. The supraorbital arises through the supraorbital notch, which is located in line with the medial limbus. The supratrochlear arteries arise more medially, usually in a plane with the medial canthus. The lateral territory is the largest of the vascular territories and is supplied by the superficial temporal artery, the terminal branch of the external carotid system. This vessel bifurcates at the superior helix of the ear into frontal and parietal branches. The vascular supply to the posterior scalp varies with respect to the nuchal line. Cephalad to the nuchal line, the posterior scalp is supplied by the occipital arteries. Caudal to the

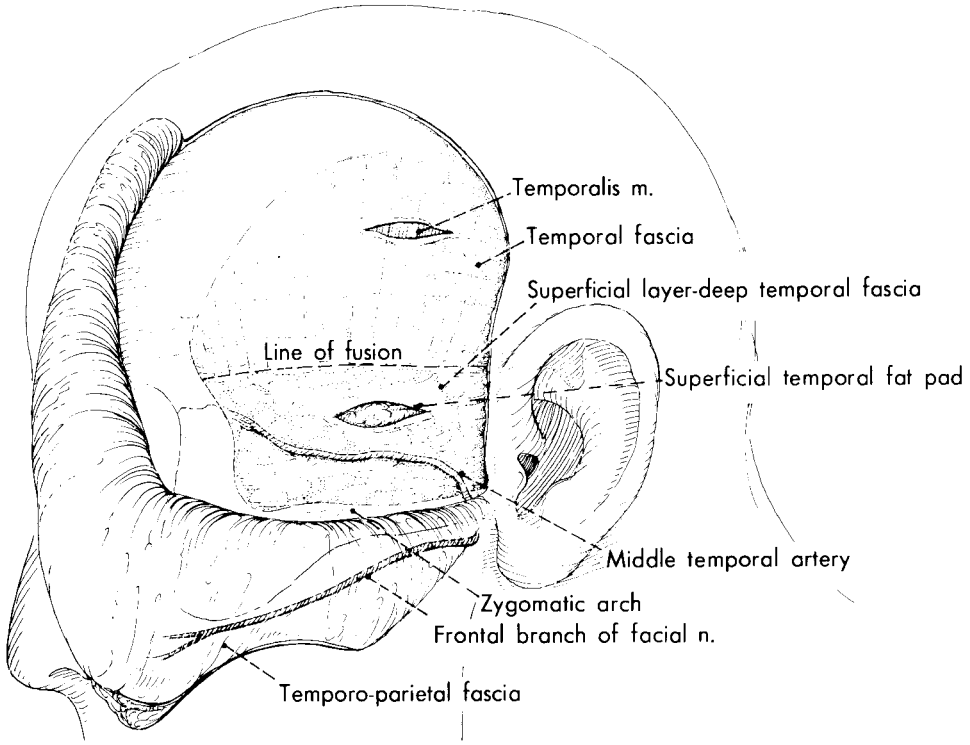

FIG. 2. Anatomy of the deep temporoparietal fascia. (Used with permission from Lippincott Williams & Wilkins. Stuzin, J. M., Wagstrom, L., Kawamoto, H. K., and Wolfe, S. A. Anatomy of the frontal branch of the facial nerve: The significance of the temporal fat pad. *Plast. Reconstr. Surg.* 83: 265, 1989.)

nuchal line, the posterior scalp is vascularized from perforating branches of the trapezius and splenius capitis muscles. The smallest territory, the posterolateral territory, is supplied by the posterior auricular artery, a branch of the external carotid system.

Local flaps for scalp reconstruction should be designed to incorporate at least one of these major scalp arteries to maintain an axial blood supply. In elective scalp reduction procedures for male pattern baldness, bilateral occipital artery ligation has been described to delay posterior scalp flaps before cephalad advancement.[35] It is conceivable that a similar procedure may be performed before elective scalp reconstruction, but we are not aware of any such description, nor do we have experience with this technique.

INNERVATION

The scalp is innervated by branches of the three divisions of the trigeminal nerve, cervical spinal nerves, and branches from the cervical plexus (Fig. 3). The superficial division of the supraorbital nerve pierces the frontalis muscle on the forehead and supplies the skin of the forehead and anterior hairline region. The deep division of the supraorbital nerve, as characterized by Knize, runs just superficial to the periosteum up until the level of the coronal suture, where it pierces the galeal aponeurosis approximately 0.5 to 1.5 cm medial to the superior temporal line to innervate the frontoparietal scalp.[36] Consideration can be given to preservation of this nerve in scalp reconstruction. A branch from the maxillary division of the trigeminal nerve, the zygomaticotemporal nerve, supplies a small region lateral to the brow up to the superficial temporal crest. The auriculotemporal nerve, a branch from the mandibular division of the trigeminal nerve, supplies the lateral scalp territory. The greater occipital nerve, from the dorsal rami of the cervical spinal nerves, and the lesser occipital nerve, from the cervical plexus, both innervate the occipital territory. The greater occipital nerve has been shown to emerge from the semispinalis muscle approximately 3 cm below the occipital protuberance and 1.5 cm lateral to the midline.[37]

HAIR

The hair is the most visible feature of the scalp; therefore, great consideration must be made in scalp reconstruction to preserve normal hair-bearing characteristics. Hair units, or

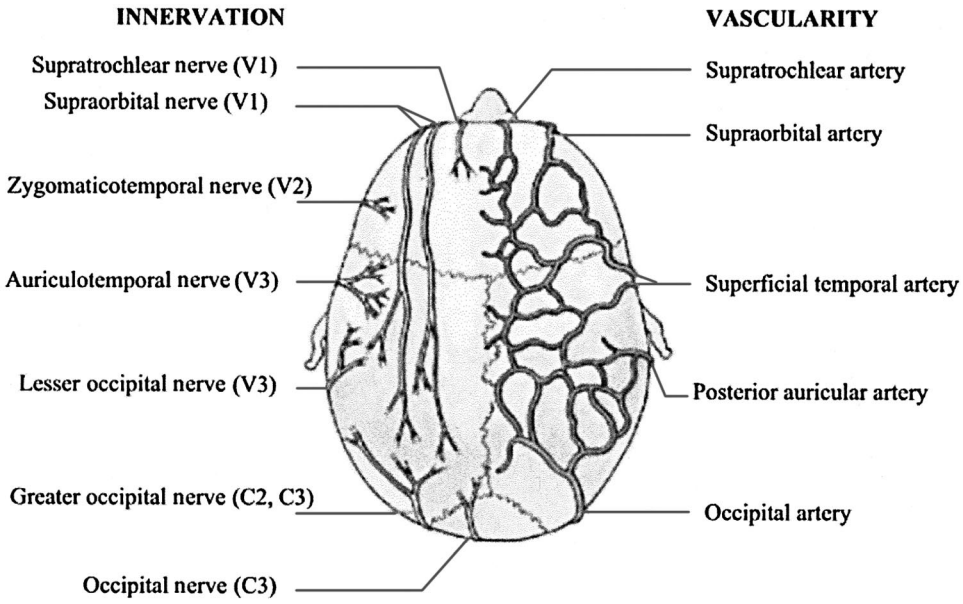

FIG. 3. Scalp vascularity and innervation.

pilosebaceous appendages, are located in the subcutaneous layer. They are each composed of the follicle, which includes the germinative bulb, the shaft surrounded by an epithelial sheath continuous with the epidermis, the sebaceous gland, and the arrector pili smooth muscle. The average scalp has more than 100,000 hairs.[38]

Hair physiology is well described in many review articles.[38,39] Hair follicles continuously cycle through three stages: anagen (growing phase), catagen (involutional phase), and telogen (dormant phase). At any one time, approximately 90 to 95 percent of hairs are in the anagen phase, 5 to 10 percent are in the telogen phase, and 1 to 2 percent are in the catagen phase.[40] The anagen phase of scalp hair lasts approximately 1000 days, during which the average hair grows 0.3 to 0.4 mm/day (or approximately 6 inches per year). In contrast, the telogen phase lasts an average of 2 to 3 months, whereas the catagen phase lasts only 2 to 3 weeks. Up to 100 telogen hairs are lost each day from the head, and approximately the same numbers of follicles enter anagen. Therefore, the amount of hair depends on the ratio of follicles in anagen versus telogen. Intrinsic and extrinsic factors can influence this ratio.

Extrinsic factors that promote follicular anagen arrest include, but are not limited to, physiologic or psychological stress, drugs, and child birth. *Intrinsic* factors include excessive tension on wound closure leading to localized ischemia and follicle involution.

SKIN BIOMECHANICS

Successful scalp reconstruction often requires intraoperative use of the intrinsic skin viscoelastic properties, specifically, stress relaxation and creep. *Stress relaxation* is defined as the decrease in the amount of force necessary to maintain a fixed amount of skin stretch over time.[41] *Creep* is the gain in skin surface area that results when a constant load is applied.[41]

The fundamental basis for these properties lies in the fact that as force is applied to a leading skin edge, tissue thickness decreases from extrusion of fluid and mucopolysaccharides, realignment of dermal collagen bundles, elastic fiber microfragmentation, and mechanical stretching of the skin.[42] The extent to which these occur depends on the inherent properties of the tissue and the amount of force applied. When used intraoperatively, the viscoelastic properties of the skin can greatly assist in reconstruction and allow for tension-free closure in circumstances where initial closure is difficult.

PRINCIPLES OF SCALP RECONSTRUCTION

The following basic tenets should be adhered to when selecting the appropriate method of scalp reconstruction.

Replace Like Tissue with Like Tissue

The best replacement for scalp tissue is scalp tissue. There is no other donor site in the body that will approximate the same hair-bearing qualities of scalp tissue. The goals of reconstructive surgeons in the past were to obtain calvarial coverage to prevent calvarial desiccation, sequestration, and sepsis. However, today, the reconstructive surgeon should strive for a cosmetically appealing result in addition to merely achieving coverage. This requires attention to hair growth patterns and hairlines so that reconstruction restores and preserves the normal anatomy.

Hair transplantation is an alternative technique to excisional surgery that can be used to restore the hair-bearing appearance of small areas of alopecia whether it be from trauma or from skin grafting.[43–45] Hair transplantation is perhaps most effectively used as a revisional secondary procedure. For example, it can be used to camouflage incisions within hair-bearing scalp or to reestablish a hairline that may have been slightly distorted from using rotational flaps.[45] Hair transplantation has been successfully demonstrated in large areas of burn alopecia; however, most reconstructive surgeons use scalp flaps, tissue expansion, or free tissue transfer.[46]

In patients who have developed radiation-induced necrosis of the scalp after receiving radiation therapy for cancer, the options for replacing "like with like" is limited. Neighboring scalp tissue is often fibrotic as a result of radiation therapy, thereby severely limiting the use of local flaps.[47,48] If local flaps are to be used, care should be taken to preserve the vascularity and minimize wound closure tension. Postoperative radiation therapy is often used for further treatment of scalp malignancies, and local tissue flaps may not be as reliable for durable reconstruction.[49–51] Therefore, in the scalp wound either previously subjected to radiation therapy or in the oncologic reconstruction that will be irradiated postoperatively, greater consideration should be given to free tissue transfer instead of local flaps.[49–51]

Consider Tissue Expansion

Tissue expansion should be considered if local tissue rearrangements are inadequate for reconstruction because of the size of the defect, traumatized local tissue, unacceptable rearrangement of hair patterns, or distortion of the hairline. In these instances, a scalp rotation flap can be used to transfer the defect to a less cosmetically sensitive area and then "backgraft" the donor site. Simultaneous placement of a tissue expander has been described in the literature, but this has not been the practice of the authors.[52]

Approximately 50 percent of scalp can be reconstructed with expanded scalp tissue.[14] It does require staged operations with a lengthy interval period and is potentially associated with expander complications, which vary from 6 to 25 percent.[53,54]

Stable scalp coverage must be obtained during the expansion process to prevent calvarial desiccation and subsequent osteomyelitis. If the periosteum is intact, it can be primarily skin grafted.[55] However, if there is exposed bone denuded of periosteum, the reconstruction becomes more complicated.

Options for the reconstructive surgeon in these instances include using pericranial flaps, using the loose areolar tissue subgaleal tissue, or burring the outer calvarial table. Pericranial flaps should be designed as large as possible, preferably with a bipedicled base, with incorporation of at least one major scalp artery.[55] They can be rotated to provide for calvarial coverage and skin grafted immediately. The loose areolar tissue plane, coined the "subgaleal fascia" by Tolhurst, has also been described for coverage of exposed calvaria.[32] He described designing the flap off a major artery or maintaining a bipedicled base. As a last resort, the outer table of the calvaria can be burred, thereby exposing the highly vascular diploic space, which can accept skin grafting immediately.[4] In addition, a cerclage suture, with heavy long-lasting suture material, may be placed to decrease the size of the defect before skin grafting.

When using tissue expansion, the largest expander possible should be placed in a subgaleal position. The shape of tissue expander bases affects the amount of tissue gain. Van Rappard et al. determined that expanders with a round base, a crescentic base, and a rectangular base give tissue gains of 25, 32, and 38 percent, respectively.[56] The appropriately sized and shaped expander[5] should be selected on the basis of the individual patient's defect. A single large expander is preferred over multiple smaller expanders, as this will give the greatest gain in tissue per volume of expansion and minimize the infectious risk by limiting the

number of operative sites. However, in scalp reconstruction, multiple expanders are frequently used in a single setting to gain the greatest amount of expansion per operative procedure. The expander should be positioned so that the expanded scalp, once advanced, will re-create normal hair patterns. In the repair of massive defects, expanded scalp can be reexpanded with acceptable cosmetic results.[57] Alternatively, an expander after maximal expansion can be exchanged for a larger expander before definitive adjacent tissue transfer to shorten the time required to achieve the aesthetic goal.[58] Expansion should be continued until the expanded flap is approximately 20 percent larger than the size of the defect to account for tissue recoil during advancement.[31] The expanded flap size can be calculated by subtracting the base of the expander from the length over the top of the expander.

In general, tissue expansion is a powerful technique for reconstruction of defects not amenable to local tissue transfer but requires a lengthy reconstruction. This must be weighed against a one-stage, cosmetically inferior reconstruction.

Critical Operative Details

As in all areas of plastic surgery, attention to detail optimizes results. Hemostasis is critical. Local anesthetic with dilute epinephrine will decrease intraoperative skin edge bleeding and can be used to hydrodissect the subgaleal plane. If possible, the use of hemostatic clips on the cut edges of the scalp should be minimized to prevent potential follicular damage and subsequent iatrogenic alopecia.[59] Electrocautery should be used judiciously at the cut edge of the scalp to prevent thermal injury to hair follicles. Full-thickness hemostatic sutures that are placed circumferentially 1 cm from the proposed incision have been described to minimize intraoperative blood loss.[60]

Camirand and Doucet in 1995 reported their comparison between parallel and perpendicular hairline incisions.[61] Incisions made perpendicular to the direction of the hair follicle allowed hair to grow through the hairline incision and thus give a softer, more natural appearance.[61] Incisions within hair-bearing scalp may be different. Skin incision made parallel to the direction of the hair follicles may improve cosmesis, as fewer hair follicles are disrupted.[62] This may allow for a less discernible scar in areas of hair-bearing scalp. In addition, immediate micrografting of hair follicles in a fresh incision has been proposed to camouflage the incision in hair-bearing tissue.[62,63]

Excessive tension at wound closure can cause alopecia from either hair follicle loss or anagen phase arrest. Therefore, as in all areas of plastic surgery, the optimal result is obtained with a tension-free closure. Again, to minimize wound closure tension, the skin viscoelastic properties of stress relaxation and creep should be used. This can be done with either hooks and manual force or by rapid intraoperative tissue expansion using expanders.[64]

The galeal aponeurosis is responsible for the majority of resistance to scalp flap advancement. By carefully scoring the galea perpendicular to the direction of desired tissue gain, additional advancement can be achieved.[65] According to Raposio et al., each galeotomy corresponds to a 40 percent reduction in scalp closing tension and approximately 1.67 mm of tissue gain.[65] Ideally, the galea is incised at 1-cm intervals and tested after each score to see whether adequate tissue length has been gained. Care should be taken to prevent inadvertent injury to the scalp arteries that lie just superficial to the galea. For this reason, we prefer to avoid electrocautery when performing galeal scoring to prevent potential thermal injury to these vessels.

Proper wound closure requires approximation of the galea, as this is the strength layer of the scalp. In scalp reduction surgery for male pattern alopecia, galeal-to-periosteum sutures peripheral to the incision can provide a "progressive-tension suture" effect to further decrease wound tension and minimize long-term scar widening.[66] This technique can be used in scalp reconstruction as well. Disregarding topical adhesives, staples are the least ischemic of skin closure techniques.[67,68] They are useful in closure of hair-bearing scalp because they limit the amount of follicular ischemia and subsequent incisional alopecia.

Rotational flaps for reconstruction often result in dog ears. These can be significant and can create some displeasing scalp contours on the operative table. When this occurs, *resist the temptation for excision.* Clinical experience has shown that dog-ears uniformly flatten with time.[69–71] In addition, excision of the dog-ear only increases the length-to-width ratio and places the distal aspects of the flap at risk. Tension is the greatest culprit for distal flap

ischemia, and excision of dog-ears will not decrease wound closure tension. If the contour deformity of the dog-ear is unacceptable to the patient after a trial period of observation, delayed excision can usually be performed in an office setting without difficulty.

Tailor the Reconstruction to the Patient

As always in plastic surgery, consider patient comorbidities and preferences in performing reconstructions—the treatment must always be tailored to the individual patient. For instance, the schizophrenic patient with a long-standing neglected scalp squamous cell carcinoma and subsequent large full-thickness wide local excision defect may be better served by a one-stage reconstruction despite distortion of hair patterns as opposed to a prolonged tissue expansion process.

Guidelines to Reconstruction

The reconstructive goals and available local tissue options vary depending on defect location and size. We present our algorithmic approach to these defects.

Anterior Defects

Scalp defects in the anterior region correspond to the area posterior to the anterior hairline and anterior to the plane of the superficial temporal vessels that lie just in front of the root of the helix. The principal goal of reconstruction in this area is the restoration of hair-bearing skin to re-create the anterior hairline. If the patient is bald, flap design can allow scar placement to parallel forehead rhytides. Although vertical scars on the forehead heal well, as is known from experience with paramedian forehead flaps for nasal reconstruction, subgaleal dissection onto the forehead will necessitate frontalis transection and possible weakness of medial frontalis muscle with subsequent forehead asymmetry. In addition, scalp flaps should be designed so that the subsequent dog-ear will lie on the scalp posterior vertex or laterally at the temporal crest. Dog-ears in these areas are less cosmetically disfiguring than dog-ears placed centrally on the high forehead. Lastly, any local tissue rearrangement for reconstruction of this region should be designed so as to not distort the remainder of the anterior or temporal hairline. (Fig. 4).

Small defects (< 2 cm^2). These defects are amenable to direct closure. Depending on the patient's forehead characteristics, closure can be performed by using redundant forehead skin, which often secondarily can result in the same cosmetic improvement as a forehead lift. If the patient has a high hairline, closure may be achieved by preferentially undermining posteriorly onto the vertex to prevent further ceph-

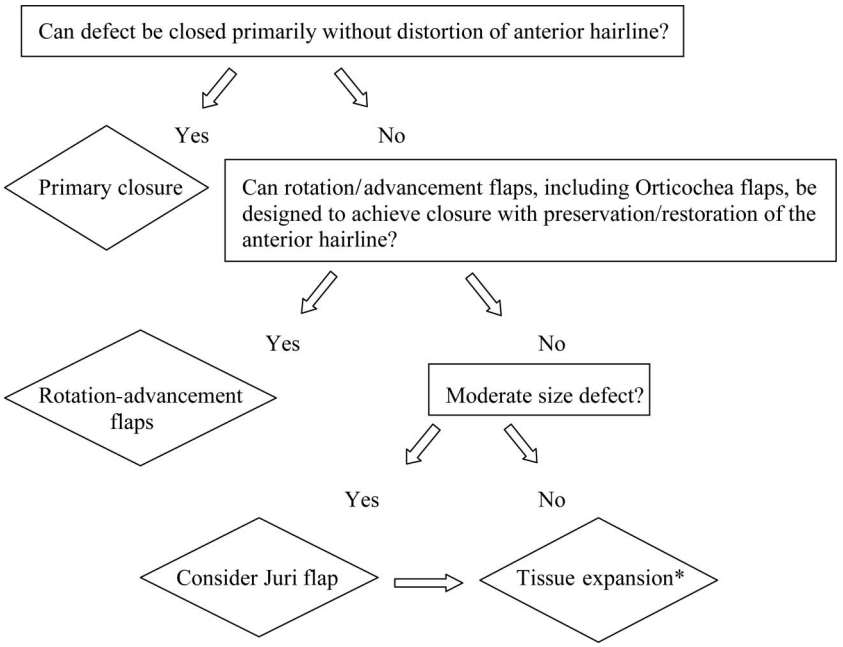

FIG. 4. Reconstruction Algorithm: Anterior Defects. * Rotation advancement flaps can be utilied to mvoe the defect to a less cosmetically sensitive area, such as the posterior vertex or occiput, with back-grafting and subsequent tissue expansion.

alad migration of the hairline. Additional galea-to-periosteum sutures may be placed to prevent scar widening.[66] Defects may be enlarged in an elliptical fashion to facilitate closure, but strict 3:1 length-to-width ratios are not as crucial because subsequent dog-ears are not problematic. The reconstruction should be designed so that the anterior hairline is not disturbed and the final scar is camouflaged as a part or a forehead rhytide or concealed within hair-bearing tissue. Advancement flaps based on subcutaneous pedicles are also possible.[71–73]

Moderate defects (2 to 25 cm^2). Successful reconstruction of these defects requires adjacent tissue transfer. For smaller defects of the anterior hairline, V-Y flaps, V-Y-S flaps, subcutaneous pedicled flaps, or rotation advancement flaps can be used (Fig. 5). [71–74] Bilateral rotation advancement flaps can be used to place the dog-ear in the location of a natural part. Ahuja describes the geometric design of bilateral rotation-advancement flaps.[75] For larger defects of the anterior hairline, temporoparietooccipital flaps or the lateral scalp flap as described for correction of male pattern baldness can be used.[76–78]

For defects just posterior to the anterior hairline, care should be given to prevent distortion of the hairline. Again V-Y flaps, V-Y-S flaps, and rotation advancement flaps can be used. In general, scalp rotation flaps for reconstruction of this area will require one large contralateral rotation flap based on the occipital vessels and another smaller rotation flap based on the ipsilateral superficial temporal vessels. The dog-ear is created on the ipsilateral side at the point of rotation of the superficial temporal-based flap. The anterior hairline is not distorted by this technique and the direction of the repositioned hair is usually acceptable.

Large defects (>25 cm^2). Temporoparietooccipital flaps, as described by Juri, can be used to re-create the anterior hairline.[76,77,79] If the anterior hairline is not involved, large rotation advancement flaps achieve excellent results. As for medium sized defects, one large flap based on the occipital vessels and a smaller ipsilateral superficial temporal flap can be rotated into residual defect while directing the dog-ear out laterally. Alternatively, a large rotation flap with back-grafting of the donor site can be used to restore anterior hair and move the defect posteriorly. Subsequent tissue expansion can be used to remove the skin-grafted area.

If the defect is extremely large, approximately greater than 50 cm^2, the Orticochea flap is a useful alternative.[11,80–82] In this technique, two flaps are used to reconstruct the defect, each of which is based on the superficial temporal vessels, and one large flap based on the occipitals is used to fill the donor defect (Fig. 6). Orticochea initially described his technique using four flaps but updated his technique to the use of three flaps to maximize flap vascularity. The cosmetic outcome using Orticochea flaps is often inferior to the outcome that can be obtained with tissue expansion be-

FIG. 5. (*Left*) Medium anterior scalp defect in a 74-year-old man after Mohs' excision of a basal cell carcinoma with a 2.5 × 3.0-cm-diameter defect of the anterior scalp. The patient underwent reconstruction with a rotation advancement flap (*center*) and is shown (*right*) 2 weeks postoperatively.

cause of the unnatural resultant hair orientation. If the patient is a candidate for tissue expansion, consideration should be given to this technique in lieu of Orticochea flaps (Fig. 7).

Parietal Defects

Defects in the parietal scalp are amenable to local tissue rearrangement. Scalp tissue in the parietal region is more mobile than elsewhere because the temporoparietal fascia, the lateral continuation of the galea aponeurosis, overlies the deep temporal fascia instead of the periosteum. This allows the parietal scalp to provide for tissue advancement in designing scalp flaps (Fig. 8).

Small defects (<2 cm²). These can usually be closed directly. If the temporal sideburn needs reconstruction, V-Y, subcutaneous pedicle, and rhomboid flaps are possibilities.[83,84] Rhomboid flaps are particularly well suited for reconstruction of the temporal sideburn (Fig. 9).[83,84] The redirected hair follicles in the rhomboid flap match the missing hair-bearing pattern. In addition, the resulting donor scar is well concealed behind the superior helix of the ear.

Medium defects (2 to 25 cm²). As in anterior defects, rotation advancement flaps are favored. In general, a flap based on the ipsilateral occipital vessels and a larger flap based on the contralateral occipital and superficial temporal vessels can be used for reconstruction. In designing these flaps, consideration should be given to where the resulting dog-ear will be directed. If possible, the dog-ear should be positioned on the posterior lateral scalp as opposed to anteriorly. Bilobed flaps have also been described for reconstruction of parietal defects.[85]

Large defects (>25 cm²). The deep temporal fascia and the temporalis muscle provide additional calvarial coverage in the parietal region. Exposed bone is therefore rare, and skin grafting can usually proceed without difficulty. Tissue expansion often is the only technique available for satisfactory reconstruction of large parietal scalp defects. Orticochea flaps are not described for parietal defects because tissue advancement from the contralateral parietal scalp up over the vertex is often inadequate for defect closure. Large bipedicled fronto-occipital flaps have been described for coverage of these defects, but large areas of back-grafting are required and therefore these flaps are best reserved for single-stage reconstruction when excellent cosmesis is not required.[86]

Occipital Defects

The occiput is a region of moderate scalp mobility amenable to local tissue transfer. Re-

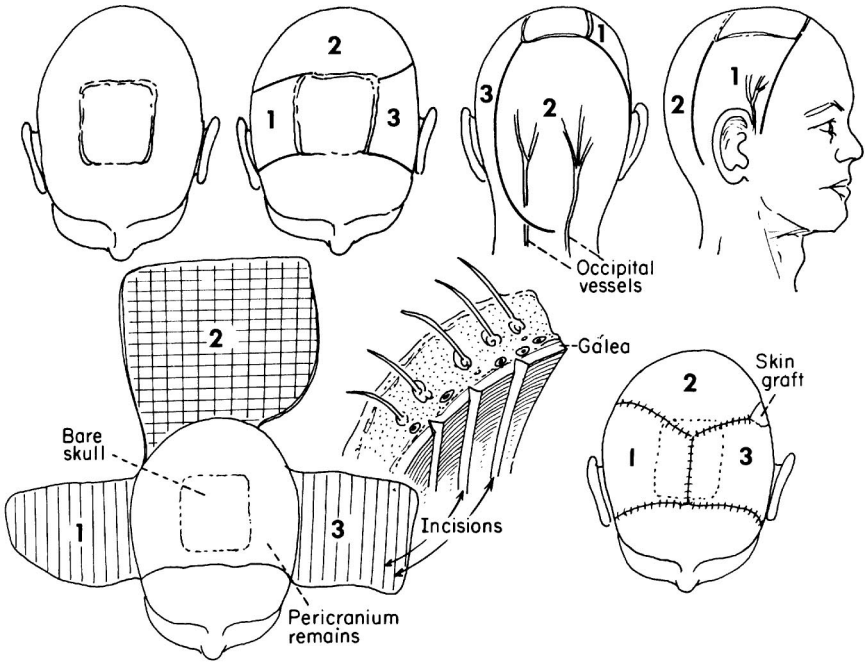

FIG. 6. Orticochea three-flap technique. (Used with permission from Lippincott Williams & Wilkins. Arnold, P. G., and Rangarathnam, C. S. Multiple-flap scalp reconstruction: Orticochea revisited. *Plast. Reconstr. Surg.* 69: 607, 1982.)

construction may involve restoration of the occipital hairline or flap design to preserve an intact hairline. The occipital scalp is not as cosmetically sensitive as other more forward-facing scalp regions and can be camouflaged with long hair (Fig. 10).

Small defects (<2 cm²). Similar to anterior defects, small occipital defects can be closed with

FIG. 7. A 35-year-old woman with a large anterior scalp defect after Mohs' excision. Reconstruction was achieved my means of split-thickness skin grafting followed by tissue expansion.

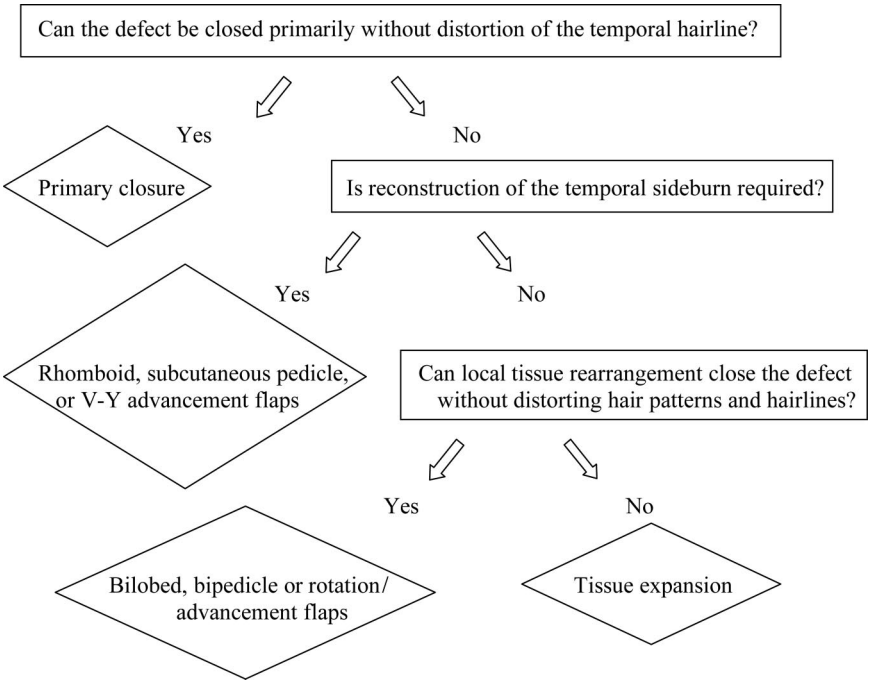

FIG. 8. Reconstruction Algorithm: Parietal Defects.

direct closure. Small dog-ears are not cosmetically significant and routinely improve with time.

Medium defects (2 to 25 cm^2). As in repair of defects of other regions, rotation advancement flaps can be used. If necessary, dissection can be carried over the trapezius and splenius capitis muscles. Care should be taken in design of these flaps to preserve a natural appearance of the occipital hairline.

Large defects (>25 cm^2). Larger rotation flaps can be used.[75] Orticochea flaps are classically described for reconstruction of the occipital scalp.[10] A three-flap technique provides improved flap vascularity over the four-flap technique and decreases postoperative alopecia and wound complications. However, unless the patient is not a candidate, tissue expansion routinely gives a superior result.

Vertex Defects

The scalp vertex is an area of limited scalp mobility and requires extensive undermining and recruitment of tissue from the more mobile anterior, parietal, and occipital regions. The scalp vertex typically has a characteristic "whorl" pattern of hair growth and attempts

FIG. 9. (*Left*) Medium temporal sideburn defect in a 54-year-old man with a 4-cm defect of the right temporal sideburn and a large cheek defect after Mohs' excision for recurrent basal cell carcinoma. The temporal sideburn was reconstructed with a rhomboid flap from the temporal scalp (*center*). A dog-ear created at the superior temporal crest resolved without requiring revision. (*Right*) The patient is shown 1 month postoperatively. Excessive tension superior to the ear at the time of closure created an area of alopecia. Further hair growth has minimized the deformity.

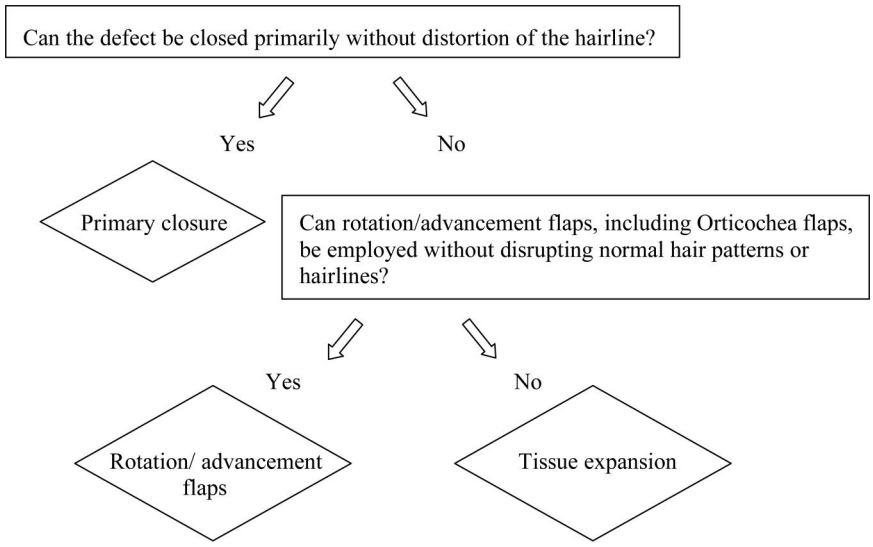

FIG. 10. Reconstruction Algorithm: Occipital Defects.

should be made to try to preserve this arrangement (Fig. 11).

Small defects (<2 cm²). For small defects, direct closure after subgaleal dissection may be possible. If not, local flaps such as pinwheel flaps and adjacent rhomboid flaps work particularly well to reconstruct the whorl pattern (Fig. 12). Elliptical excision, up to 4 cm wide, with galeal undermining can be performed similar to scalp reduction for male pattern baldness (Figs. 13 and 14).[66]

Medium defects (2 to 25 cm²). Pinwheel and rhomboid flaps are less useful but are still possible alternatives. Usually, larger amounts of undermining are required; therefore, double-opposing rotation advancement flaps are good alternatives. The incisions can be carried parallel to the hairline to prevent distortion. Consideration should also be given to rotation advancement from the occiput with back-grafting of the donor site. This can be reconstructed at a later time by tissue expansion and transposes the deformity to a less cosmetically sensitive area.

Large defects (>25 cm²). The only alternatives for these defects are very large rotation flaps,

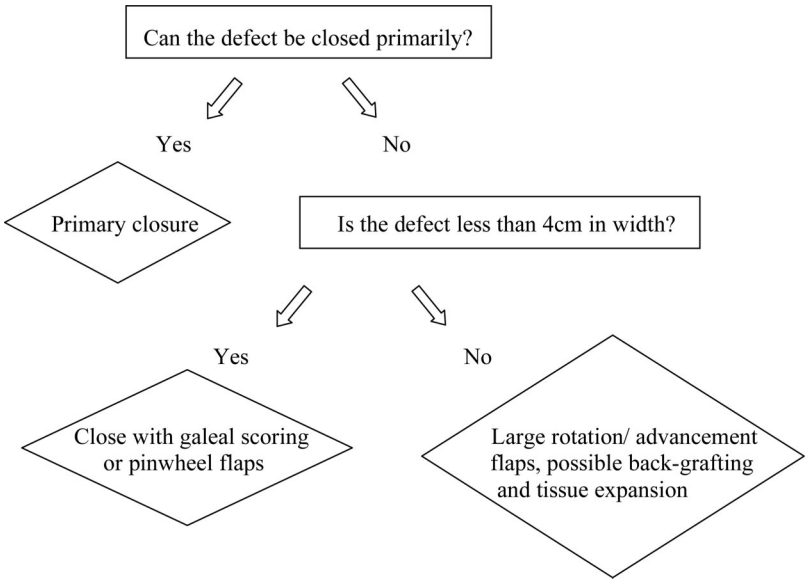

FIG. 11. Reconstruction Algorithm: Vertex Defects.

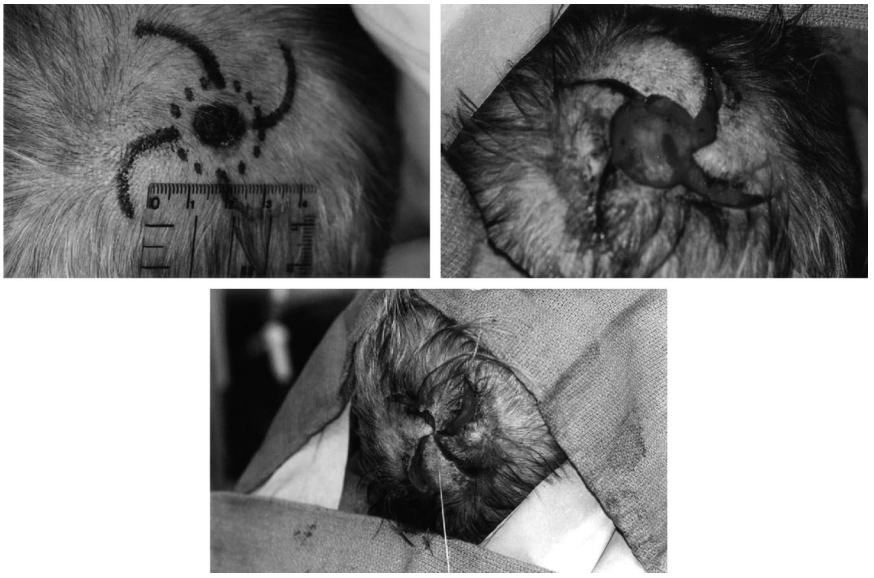

FIG. 12. Pinwheel flaps. (Used with permission from Lippincott Williams & Wilkins. Dowbak, G. V-Y-S plasty for scalp defects. *Plast. Reconstr. Surg.* 113: 1889, 2004.)

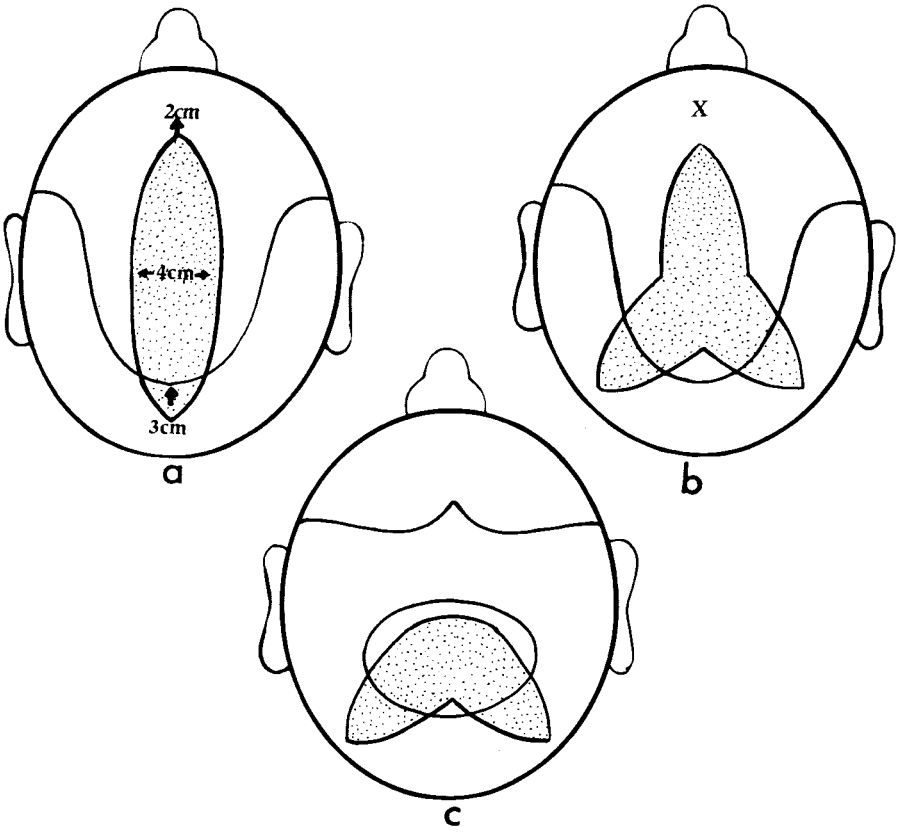

FIG. 13. Elliptical closure of vertex defects. Available patterns for scalp reduction. (Used with permission from Lippincott Williams & Wilkins. Bell, M. L. Role of scalp reduction in the treatment of male pattern baldness. *Plast. Reconstr. Surg.* 69: 272, 1982.)

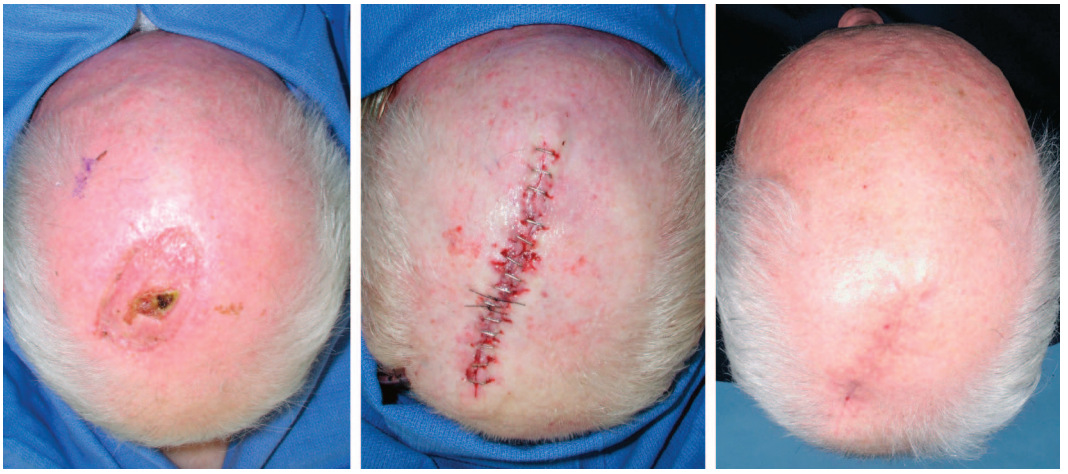

FIG. 14. (*Left*) Medium posterior vertex defect in a 77-year-old man who underwent split-thickness skin grafting with a posterior vertex defect after Mohs' excision of a basal cell carcinoma but suffered graft loss from trauma with resulting exposed calvarium. (*Center*) The defect was reconstructed with an elliptical excision of the grafted area, which created a defect 3.5 cm in width. Closure was performed after wide subgaleal undermining with galeal scoring. (*Right*) The patient is shown 2 months postoperatively. The small dog-ear created on the central vertex improved without requiring revision.

which require near complete scalp undermining and galeal scoring (Fig. 15). True Orticochea flaps are not well suited for repair of these defects because the location does not allow for a large third flap for coverage of the donor-site defect. Alternatively, large rotation flaps with significant dog-ear deformities can be used with donor-site back-grafting, if necessary. Despite

FIG. 15. (*Above, left*) Large anterior vertex defect in a 47-year-old schizophrenic man with longstanding scalp melanoma. (*Above, center*) Wide local excision created a 6.5-cm-diameter scalp wound. Reconstruction was performed by means of a large rotation advancement flap based on the contralateral occipital vessels and a smaller ipsilateral superficial temporal artery–based rotation advancement flap. (*Above, right*) Notice the marked improvement in the right frontal dog-ear with time. (*Below, left* and *right*) Lateral views of the patient shown intraoperatively and 2 months postoperatively demonstrating resolution of the dog-ear over 2 months.

these options, tissue expansion uniformly will yield the best results (Fig. 16).

Nearly Total Defects

Straith and Beers give a colorful account of a physician using pinch allografts from his own arm in attempt to reconstruct a scalp avulsion in 1889.[9] When this failed, an allograft from the patient's sister and then a xenograft from the abdomen of a dog were attempted unsuccessfully.[9] Fortunately, since this initial report, many advances have been made.

The best technique for reconstruction of nearly total defects of the scalp is free tissue transfer. There have been case reports of such defects reconstructed with Integra followed by skin grafting, but as described, this technique requires hyperbaric oxygen therapy and has not been supported elsewhere in the literature.[87] Free tissue transfer allows for complete scalp reconstruction in a single stage and can be performed at the time of tumor extirpation. An ample supply of head and neck vessels provide multiple alternatives for donor vessels. The most readily available vessels are perhaps the superficial temporal vessels. If these are inadequate, other arterial branches of the external carotid system and the internal jugular vein may be used. The latissimus dorsi muscle provides arguably the best flap for coverage because of its large surface area and long vascular leash (Fig. 17).[50] The serratus anterior muscle can be included with the latissimus dorsi muscle to increase the flap surface area if necessary (Fig. 18). With time, free muscle flaps atrophy and contour nicely to the skull and are less likely to require significant debulking than myocutaneous or fasciocutaneous flaps.[50] However, over the long term, muscle flap atrophy may lead to recurrent skull exposure. Composite flaps can prevent this undesirable sequela and therefore may

be desirable to muscle-only flaps even if secondary debulking procedures are required.[88] Besides free muscle flaps, free tissue transfer using the radial forearm, parascapular, and anterolateral perforator flaps and other free flaps such as omentum, Scarpa adipofascial flap, and scalp from an identical twin have been described.[16,19,22,89,90] In addition, when used for flap coverage, skin grafts should be unmeshed to give the best possible appearance. However, most patients will resort to wigs (Fig. 19).

Discussion

From ancient management strategies of scalp avulsion injuries that used trephination of the outer table of the calvaria[2] to the advances in microsurgery that allow for free tissue transfer, the techniques for scalp reconstruction have paralleled advances in plastic surgery. We are now able to obtain coverage over the calvaria after the most devastating of defects; however, the challenge to the reconstructive surgeon today is to do so with excellent cosmetic results. Adhering to the principles of scalp reconstruction presented in this article, the reconstructive surgeon will be able to achieve this goal. First and foremost, cosmetic scalp reconstruction requires restoration and preservation of normal hair patterns and hair lines. In addition to obtaining calvarial coverage, all reconstructive endeavors should strive for this goal.

Most scalp defects can be reconstructed with local tissue rearrangements. Rotation-advancement flaps using scalp mobility from the parietal regions are the workhorse of reconstructive techniques. Proper design of these flaps requires preservation of the native hairline, redirection of hair follicles in acceptable patterns, incorporation of major vascular pedicles, and closure without excessive tension, which

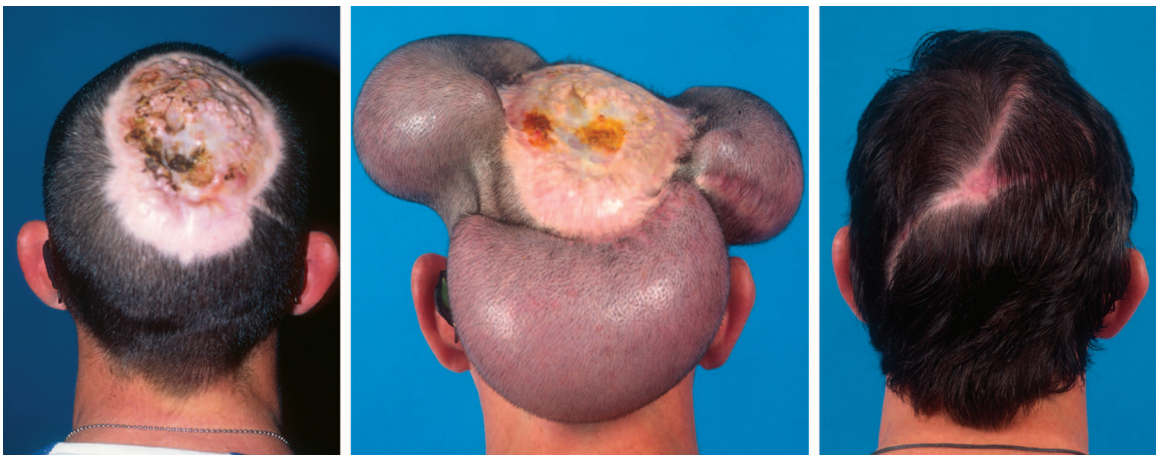

Fig. 16. Large vertex defect in a 38-year-old man with an approximately 20 × 14-cm vertex defect after an electrical injury. Reconstruction was achieved by means of multiple tissue expanders.

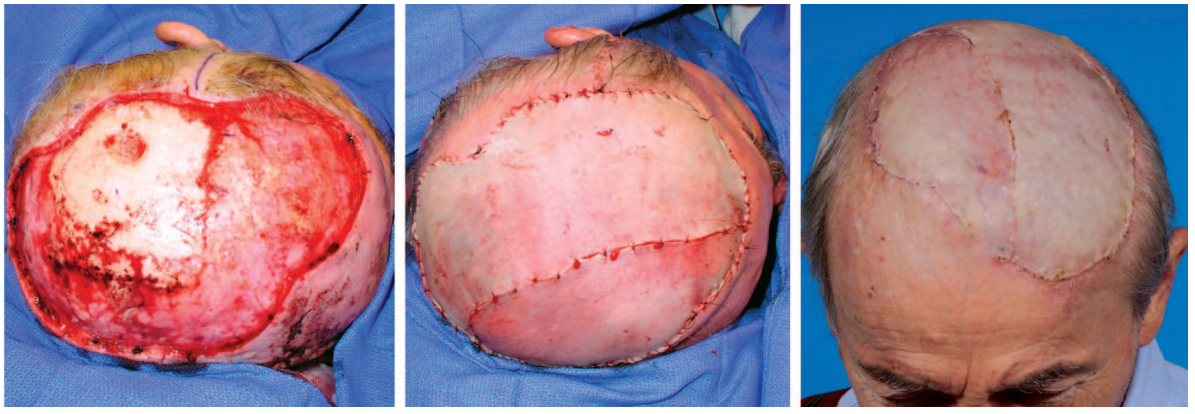

Fig. 17. Nearly total scalp defect in a 76-year-old man with recurrent squamous cell carcinoma and radionecrosis of the scalp who underwent wide local excision with free latissimus reconstruction and unmeshed split-thickness skin grafting. The patient is shown intraoperatively (*left* and *center*) and 2 months postoperatively (*right*).

FIG. 18. (*Above*) Scalp avulsion in a 5-year-old girl who suffered a scalp avulsion from a dog attack. She required bilateral free latissimus serratus flaps. (*Below*) The patient is shown 6 months postoperatively.

FIG. 19. Wig use after nearly total scalp reconstruction in a 16-year-old girl who sustained nearly total scalp avulsion during a farming accident. Scalp replantation was unsuccessful secondary to trauma to the avulsed scalp tissue. Reconstruction was performed with a free latissimus serratus flap. She is seen 8 months after her initial injury. A left browpexy was subsequently performed to restore brow symmetry.

can be accomplished with galeotomies or use of stress relaxation and creep.

In many instances, local tissues are inadequate for rearrangement and defect reconstruction. This may occur if the defect is prohibitively large, if local tissues are traumatized, or if rotation-advancement flaps would require disruption of normal hair patterns and hairlines. When this occurs, as long as hair-bearing scalp remains, tissue expansion is the reconstructive technique of choice. Tissue expansion can reliably replace damaged scalp tissue with like tissue that maintains native hair patterns. If inadequate scalp is present to allow for tissue expansion, free tissue transfer offers the best reconstructive option. Muscle flaps are useful for this purpose because they contour well to the calvaria over time as they atrophy from denervation.

CONCLUSION

Successful reconstruction of the scalp requires careful preoperative planning and precise intraoperative execution. Detailed knowledge of scalp anatomy, skin biomechanics, hair physiology, and the variety of available local tissue rearrangements allows for excellent aesthetic reconstruction.

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