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Scalp reconstructive flaps

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Abstract
Scalp reconstruction requires keen insight into underlying anatomy and surgical armamentarium. The reconstructive surgeon must consider a plethora of complexities to devise a safe and cosmetically maximized outcome. The purpose of this article is to review scalp reconstruction techniques and the current literature in the framework of the reconstructive ladder, with special emphasis on local flap consideration, design, and execution.

Keywords: Scalp reconstruction, scalp defects, local flaps, scalp flaps, reconstructive ladder

INTRODUCTION: SCALP COMPLEXITIES AND THE RECONSTRUCTIVE LADDER

There are many aspects of the scalp which make reconstruction difficult. The contour of the skull is primarily convex but variable per region and patient. Although highly vascular, the layers of the scalp are thick with an inelastic galea aponeurosis, limiting closure in certain areas. Additionally, the desire to save the hair-bearing scalp and maintain the integrity of a patient's hairline poses a unique cosmetic challenge.

Those challenges and others (i.e., the size of the defect, intact structures, history of radiation, *etc.*) have propelled many to propose algorithms on how to approach scalp defects[1-8]. While it is logical to have a template of the many options available and a decision tree for complicating factors, a more realistic approach involves the application of a reconstructive ladder [Figure 1]. Each step of the ladder represents

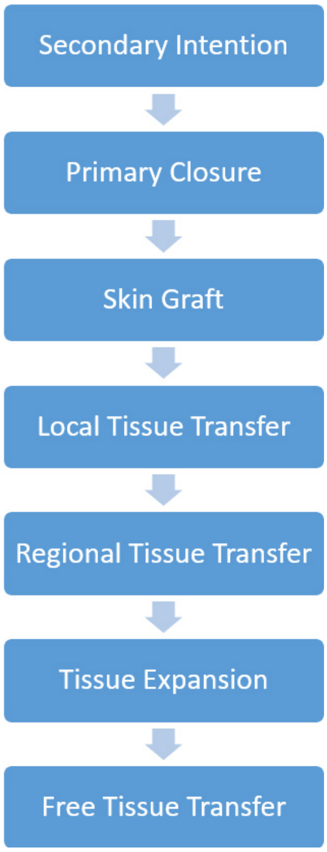

Figure 1. The reconstructive ladder algorithm representing increasing complexity with each additional step.

the increasing complexity of repair[9]. Therefore, when approaching reconstruction, the safest, then simplest, then most aesthetically pleasing option should be chosen dependent on each patient.

BRIEF ANATOMIC OVERVIEW

The skin has the greatest thickness on the scalp, ranging from 3 mm to 8 mm. The layers of the scalp listed from superficial to deep include the skin, subcutaneous tissue, the galea, loose areolar tissue, and periosteum. The complexity increases for the temporal scalp with the addition of the temporalis muscle and accompanying deep and superficial temporalis fascia. The galea gives the scalp its inelastic properties, and Raposio *et al.*[10] found that full-thickness galeotomies 1cm apart gave an average of 1.67 mm of extra flap length per galeotomy. Careful attention must be given while performing linear galeotomies as the vascularity of the flap lies in the layer just beyond where the galea is being incised.

The arterial supply of the scalp from an anterior to posterior orientation includes the supratrochlear artery, supraorbital artery, the anterior and posterior branches of the superficial temporal artery, the posterior auricular artery, and the occipital artery [Figure 2]. The frontalis muscle is innervated by the frontal branch of the facial nerve, the occipitalis by the posterior auricular branch of the facial nerve, and the temporalis by the anterior division of the mandibular nerve (V3). Sensation of the scalp is supplied by terminal branches of the trigeminal nerves, as well as the greater and lesser occipital nerves.

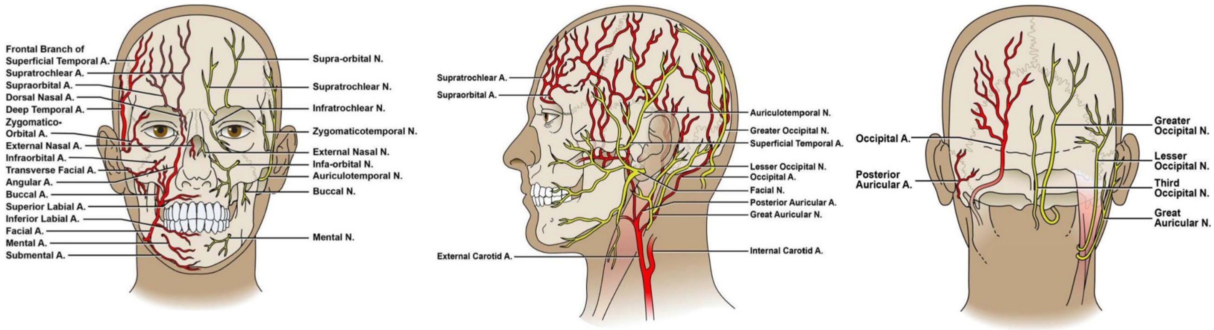

Figure 2. Innervation and arterial supply of the scalp and head.

SECONDARY INTENTION

Secondary intention is the first option when approaching the reconstructive ladder. This pertains to granulation and healing of the defect without attempting to close the tissue and skin with sutures. In patients who are not surgical candidates or have multiple defects, the potential final result of this method should not be discounted, even in terms of cosmesis [Figure 3]. Ideal conditions include lighter skin color, baseline alopecia, and a maintained periosteum; however, several studies have shown that secondary intention is possible yet delayed with an absent periosteum[11,12]. Prolonged wound healing time is an obvious disadvantage to secondary intention, with others including skin mismatch, telangiectasias, alopecia, and the risk of osteomyelitis.

Wound vacuum-assisted closure (VAC) has been used in exposed scalp wounds in several case reports, attesting that wound VACs can accelerate granulation via promoting vascularization, debriding dead tissue, removing excess fluid, and decreasing bacterial colonization[13-15]. These findings have been corroborated by a recent meta-analysis and systematic review pertaining to wound VACs *vs.* standard wound therapy in all parts of the body[16].

PRIMARY CLOSURE

Primary wound closure should be considered for small defects. Most defects with a diameter less than 3 cm on the scalp can be closed after wide undermining of the surrounding tissue in the subgaleal plane[17]. Wound tension on the hair-bearing scalp can lead to alopecia. Closure tension should be placed on the galea since it is the most inelastic layer and is deep to hair follicles[17]. As with all defects undergoing primary closure, a fusiform design with a 1:3 width to length ratio between the short and long axis is ideal[18]. Standing cutaneous deformities resolve over time generally and can be camouflaged in the hair-bearing scalp.

SKIN GRAFTING AND BIOMATERIAL

Split- or full-thickness skin grafting are reliable options in the setting of an intact periosteum or granulation tissue supplied by a vascular bed. Full-thickness grafts can be harvested from the skin overlying level V cervical lymph nodes depending on skin laxity and redundancy. A dermatome is required for split-thickness grafts, which are usually harvested from the anterior thigh. A recent case series of over 100 patients noted no significant difference in graft adherence or complications between the two graft options on the scalp[19]. A bolster, which is typically cotton wrapped in petroleum gauze and sutured to surrounding tissue to apply pressure to the graft, or a wound VAC is required for approximately one week to allow for plasmatic imbibition, inosculation, and revascularization.

Figure 3. Secondary intention over the course of 7 months.

In scenarios of very large full-thickness scalp defects, the crane principle can be used prior to skin grafting. This technique involves temporary locoregional flap coverage of a defect, with the return of the flap to its original location after at least one week, allowing for appropriate granulation of the defect before additional grafting[20]. It was first described for the scalp by Figi and Struthers[21] in 1955, then the term was coined by Millard[22] in 1969 for an abdominal flap in hand reconstruction, stating “a pedicle flap can be used as an engineering crane to lift and transport subcutaneous tissue from one area and deposit it to another”.

Biomaterials should be considered in cases with absent periosteum or a compromised vascular bed. Integra (Integra LifeSciences) is a dermal regeneration template composed of a superficial silicone layer and a deep composite layer. This composite layer is comprised of bovine type I collagen and shark chondroitin-6 sulfate glycosaminoglycan[23]. After 3-6 weeks on the scalp bed, appropriate host cell integration of the biomatrix will have occurred, and the silicone layer is removed[24]. It is then replaced with a split-thickness skin graft. A systematic review of success rates on the scalp favors the fenestration of Integra[25].

LOCAL AND REGIONAL FLAPS

Replacing excised tissue with similar tissue is a key pillar for optimizing results aesthetically. Unfortunately, there is no donor site that can replicate the thickness, biomechanics, and hair-bearing nature of the scalp. This makes local and regional flaps the ideal choice for replacing small to large scalp defects when possible.

Contraindications to local flap closures include scarcity of tissue for appropriate closure, uncleared malignancy, and other relative factors which may lead to poor wound healing, such as smoking, anticoagulation, and prior radiation[26,27]. Irradiated tissue is associated with slow wound healing, flap necrosis, wound dehiscence and increased local infection rates[28-30]. Rhomboid flaps have been reported to be a successful choice in head and neck reconstruction of irradiated tissue[28]. Preoperative assessment of defect size and the ability of the surgeon to create a tension-free closure is pivotal when considering locoregional flaps in previously radiated tissue[31]. If this is not feasible, free tissue transfer of healthy, nonradiated tissue should be favored. Advanced age of patients may be beneficial for tissue and skin laxity aiding in the success of local flaps; however, nutritional status should be evaluated regarding poor wound healing. Common complications of locoregional flaps include dehiscence, necrosis, hematoma, infection, pain, alopecia, and poor cosmetic outcomes resulting in subsequent surgeries. Newman *et al.*[3] reported overall complication rates of local flaps at 24.1% in their retrospective review of scalp defects. On review of the literature, there is no high-powered study that documents each specific complication and associated rates for local flaps.

When approaching scalp defects with locoregional flaps as a reconstructive option, decision making is dependent on the defect size and location. These factors can narrow the choices, with the understanding that other reconstructive options may also be successful. Therefore, the proceeding sections will begin with a picture of a defect to initiate the reconstructive thought process for the reader.

Vertex scalp defects

The vertex is the most inelastic portion of the scalp due to the confluence of the galea without an accompanying muscle layer [Figure 4]. Due to the biomechanics, increased undermining must be performed for either primary or local flap closure. Small defects under 2-3 cm in diameter should be closed primarily.

The triple rhombic flap, also known as a multiple Limberg flap, is a three pedicled transposition flap primarily used to close to medium-sized defects on the vertex of the scalp where laxity is scarce[32,33]. Derivatives of this flap include the rotational pinwheel and multiple O-to-Z flaps. The author has found the triple rhombic flap to be more effective than the derivatives due to better distal flap tip vascularity and less opportunity for central dehiscence. The triple rhombic flap is designed to close an approximate hexagonal defect[32]. Perpendicular lines are drawn from 3 equidistant locations around the defect, extending away from the defect to a length of approximately of one side of the hexagon. Once that length has been reached, 60-degree angles are drawn in a clockwise (or counterclockwise) fashion using this same distance. After scalp undermining and incisions, the flaps are rotated in the same direction to fill the defect [Figure 5].

Closure of larger defects up to 72 cm^2 have been reported with modified quadruple rhombic flaps[34]. A benefit of multiple rhombic flaps in this location is that rotating tissue into itself will recreate the natural "whorl" hair pattern seen at the vertex by recruiting tissue 360 degrees around the defect[2]. This pattern can also be recreated with a spiral rotational flap; however, this is more suitable for smaller defects[35]. Additionally, should a patient already have alopecia at the vertex, the triple rhombic flap has been successfully used for the sole purpose of cosmesis and hair restoration[36]. Because of the central design of this flap and the apical nature of the vertex itself, its high success rate and versatility with all defect sizes, the triple rhombic flap should be highly considered for any solitary vertex defect in a non-radiated scalp.

Other flap choices for larger defects of the vertex include double opposing rotational flaps with or without skin graft supplementation centrally. Still larger defects may require free flap coverage or tissue expansion.

Anterior scalp and forehead defects

Due to this cosmetically sensitive location, extensive communication with the patient should occur regarding reconstructive expectations [Figure 6]. Smaller defects under 1-2 cm in diameter can be closed primarily with appropriate undermining. The hairline and brow position must always be considered preoperatively. More extensive undermining should be performed posteriorly as not to disrupt these structures.

Double opposing rectangular advancement flaps, also known as H-flaps, can be used for anterior scalp and forehead defects greater than 2 cm. A major advantage of this flap is that the incisions are parallel and can camouflage with resting skin tension lines of the forehead. Its parallel orientation also optimizes brow and

Figure 4. Defect of the vertex scalp

Figure 5. Vertex scalp defect closed with a triple rhombic flap.

frontal hairline symmetry [Figure 7]. This flap has a length-to-width ratio of 2:1 and has been shown to adequately cover defects up to 6 cm in diameter[37]. Bilateral excisions of Burrow's triangles are required for the best cosmetic outcomes.

Other local flap considerations include V-Y flaps, bilobed flaps, and rotational advancement flaps for medium-sized defects. Again, due to the brow and hairline, skin laxity and vector appropriate undermining should be considered before flap execution.

The temporo-parietal-occipital flap, also known as the Juri flap, is a large monopedicled flap used to repair anterior scalp defects, deriving its vascular supply from the posterior (or sometimes anterior) branch of the superficial temporal artery[38]. This can be considered for anterior scalp defects greater than 20 cm^2. Generally, the majority of the donor site is in the parietal scalp, which has the most tissue laxity due to the

Figure 6. Defect of the anterior scalp and forehead.

Figure 7. H-flap used for a large, midline anterior scalp/forehead defect. Scarring reflected natural resting skin tension lines, and eyebrow symmetry was not distorted (note: digital presurgical markings were added to the leftmost picture).

temporoparietal fascia overlying the deep temporal fascia. The dimensions of the flap can reach up to 4 to 5 cm in width and 24 to 26 cm in length[39]. Careful surgical planning with arterial tracing via doppler and palpation is recommended. The Juri flap has the advantage of a robust vasculature and hair-bearing tissue transfer. It can also be used for free tissue transfer[40].

Occipital scalp defects

Defects and repairs of the occiput have the advantage of easier camouflage with long hair [Figure 8]. In addition, patients are less cosmetically sensitive to this area since it is not routinely visualized by them. The occipital scalp has moderate skin laxity with the advantage of posterior cervical tissue for advancement purposes. Defects ranging from 2-4 cm in diameter can be closed primarily with circumferential undermining.

Posterior cervical rotation flaps are the workhorse for medium-sized occipital scalp defects. Due to the contour of the scalp, longer incisions for rotational flaps may be needed, with some literature citing a length up to 6 times the greatest diameter of the defect[41,42]. The anterior cervical rotation flap has been used to repair midface defects due to its high success rate and excellent color and texture match[43]. Similarly, we

Figure 8. Defect of the occipital scalp (note: this image has been slightly altered to remove presurgical markings).

have found the posterior cervical rotation flap to have a high success rate, color/texture match, versatility, and hairline optimization for occipital scalp lesions [Figure 9].

For larger defects greater than 45 cm^2, Orticochea flaps have been described for this location. These flaps require vast undermining for advancement and are pedicled by bilateral superficial temporal arteries and occipital arteries, with a three flap technique favored over a four flap technique[44,45]. Other regional flaps for large tissue defects in this area include the temporo-parietal-occipital (Juri) flap, the trapezius myocutaneous flap, and the latissimus dorsi myocutaneous flap. The latter two have generally fallen out of favor due to their non-hair-bearing nature and restriction by pedicle length, especially in the era of free flaps; however, reliable results have been reported[46-49].

Temporoparietal scalp defects

As previously discussed, the temporoparietal scalp is the most mobile portion of the scalp with the addition of the temporoparietal fascia, making local tissue transfer an excellent choice for reconstruction [Figure 10]. However, due to the patient's hairline and proximity of the pinna, careful selection of local flap is needed. Defects ranging from 2-4 cm in diameter can be closed primarily with undermining and consideration of these structures.

The O-to-Z flap is a double rotation flap used to close a circular defect. The two opposing curvilinear pedicles are rotated toward each other, filling the defect and creating a "Z" shaped suture line. Buckingham *et al.*[50], based on their cadaveric research, proposed that to achieve minimal suture tension, the lengths of each curvilinear incision should be 4 radii of the defect, with successive polar angles of 45 degrees at 2, 3, and 5 radii from the center of the defect. However, these ideal lengths can be modified with surrounding tissue availability and laxity.

This flap can readily be used on the temporoparietal scalp, with flap design accounting for hair-bearing areas. Camouflage with adjacent hair can be used subsequently [Figure 11]. In larger defects or areas with less skin laxity, a skin graft can supplement the central portion after partial rotations of the flaps are achieved [Figure 12].

Figure 9. Posterior cervical rotation flap with flap limb designed along the hairline.

Figure 10. Defects of the temporoparietal scalp (note: these images have been slightly altered to remove presurgical markings).

Other suitable options for medium-sized defects up to 25 cm^2 in this area include V-Y flaps, rhomboid flaps, and bilobed flaps. For larger defects, tissue expansion will yield the best cosmetic outcomes[51].

TISSUE EXPANDERS

In larger defects where hairline distortion is likely with local flaps, a tissue expander should be considered. This is a staged operation that requires thorough patient communication and reliability, with an understanding that unsightly tissue expansion in the short term may give rise to the patient's best ultimate cosmetic outcome [Figure 13]. Close follow-up and risk/benefit counseling should be discussed with each patient.

Tissue expanders have been reported to cover a 50% scalp defect adequately[52]. Expanders are placed in the subgaleal plane through a small incision at a perpendicular orientation. The expansion process is recommended to begin between 7 and 14 days after implantation, as the galea loses its rigid, inelastic

Figure 11. O-to-Z local flap in the temporal region. Flap limbs were designed with respect to the hairline, and additional camouflage can be used after healing is complete.

Figure 12. O-to-Z local flap in the temporal region with centrally located split-thickness skin graft for closure of the defect. This demonstrates that the best aesthetic result may be achieved by a combination of techniques, mitigating the notion that complete flap closure must be achieved.

structure after approximately 11 days[53,54]. Expansion intervals should be approximately every 5-7 days for the scalp, and while additive volumes vary, they are generally around 10% of the volume goal for each session[53,54]. Desired expansion duration can take weeks to months based on surgeon preference. Rectangular base expanders are reported to give the largest tissue gains[55]. Several methods have been proposed in choosing the size of the expander based on the size of the defect for adequate coverage. These formulas vary from selecting an expander with a base twice the size of the defect[53] to more complex algorithms[56]. Others have simply proposed using the largest expander possible to minimize tissue recoil and eventual closure tension[57].

Figure 13. Temporal scalp defect closed with a skin graft from another surgeon, resulting in an unacceptable cosmetic outcome. A tissue expander was placed posteriorly in the parieto-occipital scalp. Starting on post-operative day ten, 20 mL injections of saline were initiated, with six additional 20 mL injections at 5-day intervals. After one month, the tissue expander was removed, the skin graft was excised, and the defect was closed with excellent cosmesis.

The complications of tissue expansion are well described in the literature[57]. Complication rates are 15%-20%, with failures estimated around 6%[54].

FREE FLAPS

For large and complex defects, free tissue transfer with microvascular anastomosis may be necessary for optimized closure. Cumulative factors favoring this option include large defects, irradiation, scalp inelasticity, unfavorable location, chronic wound infection, cranial defect, prior cranioplasty, and/or exposed implanted structures[58].

Flap selection should be dependent on the size of the defect, composite material, aesthetic contour, and surgeon's comfort. According to a 2015 pooled analysis of the literature, the most commonly used free flap on the scalp is the latissimus dorsi flap, with the anterolateral thigh flaps as the second most common[59]. Another study noted that the anterolateral thigh flap has been the most commonly reported scalp flap since 2000, inferring increasing popularity[60]. Although advanced age has not been shown to increase mortality or complications, patient condition and goals regarding other comorbidities should be discussed and considered[59,61].

CONCLUSION

Scalp reconstruction should be approached via the reconstructive ladder, with special consideration to safety, success probability, and aesthetic optimization. Choosing the best method of reconstruction is dependent on scalp complexities, defect size, location, tissue viability, hairline distortion, and surgeon expertise. The key cosmetic tenet of replacing "like with like" makes local flaps a preferred option when plausible.

DECLARATIONS

Authors' contributions

Made substantial contributions to conception and design of the study and performed literature review and interpretation: Brawley CC, Sidle D

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Both authors declared that there are no conflicts of interest.

Ethical approval and consent to participate
Not applicable.

Consent for publication
A written informed consent was obtained from all patients. Dr. Sidle obtained the copyright of Figure 2.

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