TITLE: Flaps in Facial Reconstruction
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Introduction

Options for the repair of facial defects include healing by secondary intent, primary closure, skin grafts, local and regional flaps, and free tissue transfer. The decision as to which method to employ in any given case should arise from the general health of the patient, the characteristics of the defect, and the patient's own expectations and desires. In other words, the repair should fit the patient and his or her defect.

For example, sites amenable to healing by secondary intent include small defects involving concave skin surfaces such as the medial canthus and temple, and occasionally the nasal tip. Local and regional flaps represent the most common method for repair of facial defects.

Local facial flaps provide an excellent skin color and texture match, they may be performed in a single stage, and their donor sites can be closed primarily with little morbidity the majority of the time. However, local flaps do have some disadvantages. Most involve a random blood supply, which limits flap length. There is a potential for distortion of surrounding structures. And, finally, local flaps alone often do not provide adequate bulk for the repair of deep defects. Once the patient understands the risks of local flap closure and has a defect that is unable to be closed primarily, local flap reconstruction will provide the best functional and cosmetic outcome in most instances.

Vascular Anatomy

The skin is supplied by two vascular plexuses. The deep vascular plexus, also referred to as the subdermal plexus, exists at the junction of the dermis and subcutaneous fat. Arterioles from the deep vascular plexus supply the pilosebaceous units. The superficial vascular plexus exists at the superior aspect of the reticular dermis, giving off capillary loops within the dermal papillae. This superficial plexus provides the majority of nutrients to skin.

There are two categories of arterial supply to the skin. Musculocutaneous arteries arise from segmental vessels, which are the large, named branches of the aorta that run deep to muscle masses. Musculocutaneous arteries pass through underlying muscles before reaching the skin, supplying blood to both muscle and skin. Musculocutaneous arteries run perpendicular to skin for much of their course, supplying only a small area of skin.

Direct cutaneous (i.e., septocutaneous, fasciocutaneous) arteries travel within the facial septae *between* muscles to pass directly to skin. These vessels supply blood only to the skin, and not to muscle. Typically, a direct cutaneous artery runs parallel to skin for much of its course, supplying a large area of skin.

Random flaps represent the majority of local facial flaps. The vascular supply to random flaps arises from the subdermal plexus, ultimately supplied by musculocutaneous arteries. Thus, the appropriate plane of dissection is subcutaneous fat.

Axial flaps derive their blood supply from the named direct cutaneous arteries. As a result, axial flaps are capable of a greater length:width ratio than random flaps. The plane of dissection is deeper, and must include the fascia containing the relevant named artery. Some additional length may be obtainable with axial flaps by including more tissue at the distal tip with blood supply of a random nature based upon the subdermal plexus. Examples of axial flaps include the paramedian forehead flap, based on the supratrochlear artery, and the nasolabial flap, based on the angular artery.

Flap Physiology

Because of its thermoregulatory function, the rate of blood flow through the skin is one of the most variable in the body. At baseline, blood flow to the skin is approximately 10 times that required for nutritional support. It is because of this relative oversupply that random flaps are able to survive.

Skin derives its nutrient supply from a network of capillaries. Flow through these capillaries is controlled by pre-capillary sphincters. Local hypoxemia and an increased level of metabolic products induce these sphincters to open.

Arteriovenous (AV) shunts also determine flow through the capillary network. Thus, pre-AV shunt sphincters control both thermoregulation and systemic blood pressure. These sphincters are under sympathetic control. For example, an increase in body temperature results in a decrease in norepinephrine release, which results in closure of the AV shunts and increased blood flow to the skin.

Following transposition and insetting of a flap, the first 48 hours are a critical period with respect to determining flap survival. During this time, there is a surge in the level of catecholamines locally, resulting in vasoconstriction; the supply of catecholamines from traumatized nerves is exhausted after 48 hours. In addition, the inflammatory cascade results in increased levels of Thromboxane A2 (also a powerful vasoconstrictor) and free radicals, as well as edema. All of these factors result in either ischemia or direct injury to the flap. A fibrin layer forms at the recipient site within the first 2 days. Neovascularization then begins at 3-7 days. Revascularization adequate for division of the flap pedicle has been demonstrated by 7 days.

Endothelial cells are responsible for the release of angiogenic factors responsible for neovascularization.

There are four important concepts pertaining to flap physiology: stress, strain, creep, and stress relaxation. *Stress* refers to the force applied per cross-sectional area. *Strain* refers to the change in length divided by the original length of the given tissue to which a force is applied. *Creep* refers to the increase in strain seen when skin is under constant stress. This occurs over a matter of minutes and is due to an extrusion of fluid from the dermis and a breakdown of the dermal framework. Meanwhile, *stress relaxation* is the decrease in stress when skin is held in tension at a constant strain for a given time. This occurs over a matter of days to weeks and is due to an increase in skin cellularity and the permanent stretching of skin components. The concept of serial excision is based upon the fact that skin closed under tension will display a certain amount of stress relaxation and creep over time.

The probability of tip necrosis is directly related to both length and tension. Thus, at equal closing tensions, longer flaps display a higher probability of tip necrosis.

Undermining may not always represent the best means of correcting for excessive tension. Beyond 4 cm, undermining has little effect on tension. Studies in animals suggest that excessive undermining may increase flap necrosis.

It is not true that the surviving length of a flap depends entirely on the width of the base. The surviving length of a random pattern flap is determined by the perfusion pressure within the arterioles and intravascular resistance. Widening the base of a flap does not affect either of these factors. Thus, there is no benefit to widening the base beyond a certain point. When perfusion pressure falls below the critical closing pressure of an arteriole, blood flow through that arterial ceases. In general, most authors agree that a length to width ratio of 3 or 4 to 1 will result in a viable random pattern flap on the face or scalp.

Delay of the insetting of a flap historically has been one of the only methods generally agreed to decrease the incidence of flap failure due to ischemia. For random flaps, one incises along the long axis of the flap and undermines without dividing either end of the flap. For axial flaps, one incises along all margins but the base of the flap (so as not to cut across the pedicle) without undermining. In both cases, the flaps are left in place at the donor site and then transposed and inset into the recipient bed after 1-2 weeks. The benefits of delay are lost if delayed beyond 3 weeks to 3 months. Three theories have been proposed to explain the delay phenomenon: first, that it improves blood flow primarily by the reorientation of vascular channels and the formation of vascular collaterals; second, that it conditions the tissue to ischemia; and third, that it closes the AV shunts.

Flaps

There are two basic categories of locoregional skin flaps as already discussed: axial and random. These two groupings are further broken down into 4 categories: rotation, transposition, advancement, and interpolated flaps.

In rotation flaps, the defect sits immediately adjacent to the flap. The flap is rotated in an arc about a pivot point. The flap becomes functionally shorter as it is rotated, thus the flap must be designed such that it is longer than the defect. Back cuts can be performed at the base of the flap, but must be performed judiciously to protect the vascular supply. A standing cutaneous deformity will nearly always form at the base of a flap requiring a Burow's triangle. The axis of movement is curvilinear. The defect for a rotational flap must be triangular (or made to be triangular), and should have a 2:1 height: width ratio. The advantages of a rotational flap are that it involves only 2 sides, making it easier to place all edges in relaxed skin tension lines (RSTL) or the junction between aesthetic units.

Transposition flaps represent a type of rotation flap, though the final axis is linear. Transposition flaps also rotate about a pivot point, but there is an area of partially intact skin (NOT a complete bridge of skin) intervening between the donor site and the recipient site. Transposition flaps are particularly useful when one wants to transfer tension away from closure of the primary defect and into the repair of the secondary defect. A trapdoor (pin cushion) defect is common with transposition flaps. This refers to a dome-like elevation of the flap as compared to surrounding tissue. A trapdoor defect is best avoided by the performance of wide undermining around the defect and the use of vertical mattress sutures in wound closure. Examples of transposition flaps include the rhomboid and bilobed flaps.

Rhomboid Flap

A rhomboid (Limberg) flap is used for defects made into a rhombus (or 2 equilateral triangles placed base to base). The first limb of the flap should be continuous with the short diagonal of the rhomboid. Of note, the length of the short diagonal will equal the length of each side of the rhombus, which should equal the length of both limbs of the rhomboid flap.

An important variation of the rhomboid flap is the triple rhomboid, useful for larger defects. Of note, any triple rhomboid may be designed in 2 different ways.

Dufourmental Flap

This is another variation of the rhomboid flap in which all 4 sides of the defect are equal, but the angles differ from a Limberg flap. This defect is formed by 2 isosceles triangles placed base to base. The first limb of the flap is obtained by extending the short diagonal and the adjacent side and then bisecting the angle between these two lines. The second limb of the flap then parallels the long diagonal of the defect.

Bilobed Flap

This flap is particularly useful for circular defects involving the lower 1/3 of the nose measuring 1.5 cm or less in diameter. An angle of 45 degrees between lobes should be the goal with a final arc of transposition of 90-110 degrees. The first lobe should be ½ the width of the defect, and the second lobe ½ the width of the first lobe.A standing deformity is to be expected at the base of the flap, and a Burow's triangle is sometimes necessary. Wide undermining is important to avoid a trap door deformity. Another disadvantage of the bilobed flap is that the scar rarely follows RSTL.

Dorsal Nasal Flap

The important feature of this flap is that it must be much larger than the defect. It is useful for nasal defects less than or equal to 2.5 cm in diameter involving the middle or lower thirds of the nose. It is okay to use large back cuts because of good vascular supply to the nose. This flap can result in nasal tip elevation for midline defects, and asymmetric alar elevation for defects off midline. Thus, it is best applied to medial defects, and it is NOT good in patients with thick, sebaceous skin.

In advancement flaps, the movement of the flap is linear after wide undermining of the wound margins. It is often necessary to excise Burow's triangles near the base of the flap. The Burow's triangles often facilitate movement of the flap, but these should NOT be cut out until the advancing edge has been secured. The target length:width ratio of the flap should be approximately 1:2, and the distance the flap is advanced should approximate the width of the flap. Advancement flaps are useful for defects of the forehead and brow where RSTL are horizontal. Examples of advancement flaps are the monopedicle and bipedicle advancement flaps, the A-T flap, and the cheek advancement flap. The typical ratio of defect length to flap length for the monopedicle flap is 3:1. The bipedicle flap is usually employed when the monopedicle flap is not adequate.

Island Pedicle Flap

One type of advancement flap frequently referred to is the island pedicle (island advancement) flap, which is essentially a V-to-Y advancement flap. An island of skin is disconnected from its peripheral epidermal/dermal attachments such that it is only connected to the face by underlying subcutaneous tissue. The flap is then advanced into a defect that should be approximately the same size, and the donor site is closed in a V-to-Y fashion. One should NEVER undermine underneath an island advancement flap, though it is helpful to undermine *around* the flap. Island advancement flaps are especially good for defects of the lateral upper lip near the base of the nasal ala.

Interpolated flaps refer to axial pattern flaps where the donor site is separated from the defect by a complete bridge of intact skin. The flap may either pass over or under this skin. The flap may be divided after adequate blood supply is established. The paramedian forehead flap is an example.

Paramedian Forehead Flap

This flap is based on the supratrochlear artery, which is consistently located at a point 1 cm above the brow in a subdermal/subcutaneous plane approximately 2 cm from the midline. The pedicle for this flap may be narrowed to as little as 1.2 cm. A second procedure is required for division of the pedicle 3 weeks or more following the initial surgery. This is the flap of choice for large nasal defects. Disadvantages of this flap include the forehead donor site scar, limited length in patients with low hairlines, and the need for revision in many cases.

Melolabial (Nasolabial) Flap

Though not an interpolated flap, this flap, like the paramedian forehead flap, is an axial pattern flap. The nasolabial flap is based on the angular artery. This flap may be either superiorly or inferiorly based. The melolabial flap should not be used for superior nasal defects because doing so may result in lower eyelid ectropion. The major disadvantages of the melolabial flap is blunting of the nasofacial sulcus and asymmetry of the melolabial sulcus. The superiorly based flap is useful for defects of the central and lateral nasal dorsum as well as the nasal tip and ala. The inferiorly based flap is useful for upper and lower lip defects, the floor of the nose, and the columella, but particularly lateral upper lip defects NOT involving the vermillion border.

Preoperative Planning and Surgical Technique

Patient factors that reduce flap viability include increasing age, malnutrition, diabetes, hypertension, peripheral vascular disease, hyperlipidemia, smoking, immunosuppression, and a prior history of external beam irradiation (XRT). XRT delays but does not eliminate neovascularization.

Patients who smoke 1 pack or more per day are three times more likely to develop flap necrosis, and if necrosis occurs, it tends to be more severe than in nonsmokers. This deleterious effect is due to vasoconstriction caused by nicotine, and systemic tissue hypoxia caused by increased levels of carbon monoxide. The patient should be sternly advised to abstain from smoking for 48 hours before and 7 days after a flap, otherwise another means of reconstruction should be sought.

Surgical factors that reduce flap viability include excessive thinning, aggressive electrocautery, crush injury secondary to rough handling, and damage to axial vessels secondary to tension or traumatic dissection.

Several general rules should guide the performance of local skin flaps on the face. The best color and texture match is obtained when the flap is taken from the same facial aesthetic unit as the defect. The skin to be moved should match the color, texture, and appendageal characteristics of the recipient site. Donor skin should be elastic. The majority of incisions for the flap should parallel the relaxed skin tension lines (RSTL). This also tends to direct wound tension parallel to the lines of maximal extensibility (LME), which sit perpendicular to the RSTL. Any incision is least conspicuous if it occurs at the junction of aesthetic units. Long, straight scars are best avoided unless they are hidden within the hairline, a deep skin crease, or the junction between aesthetic units. Do not obliterate critical anatomic lines or borders essential for aesthetics or function. Closure cannot result in an unacceptable level of tension. The secondary defect must be capable of satisfactory closure. Meticulous hemostasis should be obtained before final suturing. Skin hooks and fine-toothed forceps should be used in tissue handling to avoid blunt trauma. Dead space deep to flaps should be eliminated; tacking sutures should be used conservatively as needed.

When a defect crosses aesthetic units, it is best to compartmentalize the repair and design individual flaps to construct separate components of the defect such that the junction between aesthetic units is preserved.

Before the flap is incised, the surgeon should undermine around the defect and beneath the donor site. The surgeon should check skin laxity. On the one hand, primary closure might be possible. On the other hand, there might not be enough laxity, necessitating the design of a different flap. At this point, the flap is incised and undermined, and a few key sutures are placed. The face is then inspected for distortion, and flap blood supply is assessed. The donor site should be closed first, which usually will decrease tension at the distal tip of the flap. If excessive tension is present at this point, the key sutures can be repositioned, a back cut can be made, or one can undermine more tissue. Once the flap is in its final position (and not before), standing deformities can be excised as Burow’s triangles. Final closure is then performed in 2 layers.

Small defects of the forehead are generally amenable to primary closure. Larger defects of the forehead usually require local flap closure. Here it is important to avoid distortion of the eyebrow, and incisions should be placed in skin creases when possible. The hairline is available and should be used to hide incisions, although one must avoid transposing hair-bearing skin into a non-hair bearing area. Around the eyebrow unilateral or bilateral advancement flaps often work well because they take advantage of the horizontal skin creases of the forehead. In the central, superior forehead, an A-to-T flap works well because it takes advantage of the hairline. Similarly, in the temple area, A-to-T and rhomboid flaps both work well.

Defects of the medial canthus area measuring 1 cm or less may be left to heal by secondary intent. Otherwise, larger defects are usually best closed with transposition flaps from the glabellar region.

The landscape of the nose is not uniform, which can make flap selection more challenging. The skin of the upper 2/3 of the nose is thin and mobile, while the skin of the lower 1/3 is thick and immobile. For the upper nose, the bilobed or rhomboid flaps work well. If the defect involves the mid-dorsum, the dorsal nasal flap is a good bet. The bilobed flap is also very effective in closing defects 1.5 cm or less in diameter of the lower nose. For larger defects, the paramedian forehead flap is the workhorse, though a nasolabial flap may also be used. However, a major problem with the nasolabial flap is that it crosses the nasofacial angle and can result in blunting of this junction between aesthetic units.

The cheek enjoys abundant soft tissue and laxity, which affords many options for repair, including primary closure. For the lateral cheek, rhomboid and bilobed flaps may work nicely. For medial cheek or large defects, cheek advancement, as well as cervicofacial rotation/advancement flaps may work well. Incisions in this case may be hidden along the edge of the nose, in the nasolabial fold, along the infraorbital rim, and in the preauricular skin crease.

The chin does not have as much subcutaneous tissue. The sublabial crease is useful in scar camouflage (e.g., with an A-to-T flap), but one must avoid incisions crossing this crease, which can result in a webbed scar.

Complications and their management

Potential complications following the use of local skin flaps include infection, hematoma, ischemia, flap necrosis (most frequently partial necrosis of the distal flap/tip necrosis), dehiscence, and an undesirable cosmetic result.

Cyanosis of flaps occurring in the immediate post-operative period is usually secondary to insufficient venous drainage. Signs include an edematous, purplish or bluish flap with dark colored blood on pinprick. In this case, tight sutures should be removed. In some cases it may be worthwhile to explore the vascular pedicle to see if it is kinked or being compressed by a hematoma. In addition, multiple punctures may be made with a 22-gauge needle to relieve venous hypertension. One can also apply heparin-soaked gauze or medicinal leeches. If medicinal leeches are applied, antibiotic prophylaxis should be administered to prevent Aeromonas infection.

Signs of ischemia (arterial insufficiency) include a pale flap with poor capillary refill, decreased temperature, and an absence of bleeding with pinprick. Flaps can withstand arterial insufficiency for up to 13 hours, but venous congestion can kill a flap within 3 hours. If arterial insufficiency is due to mechanical pressure, one can loosen a wound dressing, drain a hematoma, or correct a kinked pedicle. Delaying the inset of a flap is beneficial only if insufficient perfusion is determined *before* leaving the operating room; otherwise, returning the flap to its original position may not achieve anything other than a necrotic flap in its original position.

Hyperbaric oxygen (HBO) is an important means of combating flap ischemia, demonstrating proven benefit in both animals and humans. HBO involves the systemic delivery of 100% oxygen at 2-3 times atmospheric pressure. HBO results in an increased amount of dissolved oxygen in plasma, which results in a 10-20 fold increase in oxygen levels in the tissues. In order for HBO to work, the patient must have a competent cardiopulmonary system for oxygen delivery. Transcutaneous oxygen measurements (TCOM) predict the success of hyperbaric oxygen in a given patient. TCOM at room air is compared to TCOM with the patient breathing 100% oxygen. If there is an increase, then the patient is likely to benefit from HBO. HBO is thought to be effective because it stimulates capillary ingrowth, decreases tissue reperfusion injury, and induces vasoconstriction in healthy tissue (decreasing edema) but not ischemic tissue. More importantly, HBO is thought to decrease hypoxia and retard cellular death until the first 72 hours have passed and neovascularization has begun. In humans, HBO has demonstrated a 90% salvage rate when performed 1-2 times per day for 3-5 days.

Complications of HBO include barotrauma to the middle ear, pneumothorax, seizure, pulmonary toxicity, myopia (which typically resolves within 6 months following treatment), and an increased rate of cataract formation (particularly in patients with preexisting cataracts). The incidence of oxygen-induced seizure is approximately 1:10,000 patients. Relative contraindications to HBO include emphysema, chronic lung disease, and seizure disorder. Patients with a history of seizure disorder must be maintained on antileptic medications during HBO.

The risk of flap necrosis is increased in the presence of tension. Transposition flaps in general result in less tension on the distal flap as compared to other types of flaps. In addition, thickening a flap may be more helpful than widening the base of a flap in preventing tip necrosis. At the end of a case, the flap should be pink and capillary refill immediate. In progression to necrosis, blanching and capillary refill become progressively more prolonged until there is no capillary refill at all. The natural course of this process without intervention will move from ischemia to cell death to superficial and/or full thickness eschar formation, to separation of the eschar, to healing by secondary intent. Absolutely no debridement should be performed until the wound has marginated and the eschar has begun to slough on its own. If managed conservatively, the eschar will act as a biological dressing. In cases of partial necrosis of the distal flap, local wound care is typically all that is needed. Debridement is rarely, if ever needed. Of course, another reconstructive surgery is always an option if more conservative measures fail.

Infection is relatively rare in head and neck local flaps because of the rich blood supply in the region. However, the results of infection can be devastating, leading to dehiscence, widening or thickening of scar, flap necrosis, and sepsis. Prevention of infection is paramount by observing sterile technique, employing gentle tissue handling, avoiding aggressive hemostasis, performing a tension-free closure, and cleansing the wound postoperatively with hydrogen peroxide (crusts enhance local bacterial load). Staph Aureus is the most common single pathogen isolated from infected wounds. Antibiotic prophylaxis has proven effective for clean-contaminated surgery (e.g., delayed wound closure), but not necessarily for clean wounds. Infection typically presents around post-operative day 3 to six. Appropriate management should include opening of a small area of the incision with drainage of pus. The drainage should be sent for culture and sensitivities and the patient started on antibiotics. A wick and/or packing should be placed in the wound until no more drainage occurs.

A hematoma may also lead to disastrous results. The most common causes of excessive bleeding leading to hematoma include inadequate hemostasis at the time of surgery and drug-induced coagulopathy. Medications associated with increased bleeding include aspirin, non-steroidal anti-inflammatories (NSAIDs), and herbal remedies (e.g., Vitamin E, garlic, and feverfew). To be absolutely safe, the patient should be instructed to eliminate these medications for 2 weeks before and 1 week after the flap. For intraoperative control of bleeding, careful and selective electrocautery should be the first step. If this does not work, then reverse Trendelenberg positioning and the application of cotton pledgets soaked with an anesthetic combination containing epinephrine along with gentle pressure can be tried. If oozing still occurs, then a sterile rubber band drain may be left in place overnight and the patient held for observation. Administration of antiemetics and elevation of the head of the bed are helpful in the recovery room. If significant bleeding occurs in the recovery room, the wound should be explored and hemostasis obtained. Hematomas cause increased tension on the wound closure (potentially resulting in ischemia and dehiscence), increased risk of infection, and an inflammatory response that directly interferes with flap circulation. Evacuation is easiest within the first 1-2 days by creating a small opening and performing manual compression and lavage. Alternatively, a 22-gauge needle and a 10-cc syringe may be tried first. If bleeding persists despite these measures, then the wound must be reexplored. Beyond 2 days, the clot organizes and evacuation may require mechanical debridement. Resorption of the hematoma begins after 10-14 days.

Dehiscence typically results from hematoma, infection, or tip necrosis, or from dynamic facial movement. The wound is weakest at 1 week when inflammation subsides and collagen deposition begins. This is also approximately the time of suture removal, thus it is prudent to apply steri-strips at the time of suture remove to bolster the wound. If recognized within 24 hours, a simple dehiscence can be repaired. Otherwise, it is best to allow either an old dehiscence or a complicated dehiscence to heal by secondary intent.

Several options exist for an undesirable scar or cosmetic result. Dermabrasion is good for smoothing height differences between the flap and surrounding skin. It is especially useful in areas with thick, sebaceous skin such as the nasal tip. The best results are obtained at 6-9 weeks post-operatively, when fibroblast activity is greatest.

For trapdoor defects, hypertrophic scarring, and keloids, steroid injection (kenalog-40) every six weeks may be helpful. By definition, hypertrophic scars are confined within the original wound, while keloids extend beyond the original wound.

Scar contracture is a normal event. However, it can lead to functional and/or cosmetic deformities when contracture results in tension on free edges (e.g., ectropion, nasal ala asymmetry, etc.). If this occurs, the problem should be corrected sooner rather than later. Avoidance is important and may be achieved via a tension-free closure and the replacement of cartilage support when cartilage has been removed.

Surgical scar revision is another option. This is best delayed for at least 6 months, although scars tend to improve over a course of 1-3 years, so it may be appropriate to wait longer. Simple excision of a scar is good for widened scars that parallel RSTL or lie within the junction of aesthetic units. Long, straight scars may be excised and revised with a W-plasty or geometric broken line closure. A Z-plasty is useful in lengthening and changing the direction of a scar, which is very helpful in revising contracted scars. A Z-plasty can also be performed at the initial reconstruction to ensure the long axis of the incision parallels the RSTL.

Conclusion

Both patient factors and defect factors should be taken into account when planning for the repair of facial defects. An understanding of skin flap anatomy and physiology is vital to the performance of successful local flap reconstructions for facial defects. Proper preoperative planning and surgical technique are very important in minimizing flap ischemia and other complications. Surgical delay and hyperbaric oxygen are two important tools available to the surgeon when confronted with flap ischemia.

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