# Anatomy, Physiology, and General Concepts in Nasal Reconstruction

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KEYWORDS

• Nasal reconstruction • Nasal anatomy • Skin physiology
• Wound healing • Facial lines

## ANATOMY, PHYSIOLOGY, AND GENERAL CONCEPTS IN NASAL RECONSTRUCTION

Nasal reconstruction has made great strides in the last 50 years. Nasal reconstructive surgeons have gotten away from the idea of "filling the hole" and now have multiple options, which enable them to achieve an aesthetically pleasing nose and good functional results.[1] As the central and often the most noticeable feature of the face, the nose is also one of the most difficult to reconstruct. Nasal reconstruction requires a thorough understanding of this complex, 3-dimensional structural and topographic anatomy. Also, key to this type of surgery is the relationship of the nose to the surrounding tissues of the face and how these tissues can be used for a reconstruction that is cosmetically normal for the patient and enables them to breathe properly.

The first step in nasal reconstructive surgery is an understanding of the nasal anatomy. The facial plastic surgeon must understand the intimate relationships between the underlying nasal support structures, the cover of the external skin, the function of the nasal lining, and the unique aspects of the location and contours of the nose.

### *Nasal Anatomy*

#### *Skin*

The skin thickness varies depending on the different locations of the nose. In fact, this variation is what originally determined the nasal subunits when described by Gonzalez-Ulloa and colleagues.[2] The thickest area is the caudal portion of the nose, on the nasal tip and ala, with its skin rich in sebaceous glands. This nasal skin progressively gets thinner until it reaches the rhinion, where it is the thinnest,[3] and again as it transitions from the tip to the columella and the alar rim.[4,5]

#### *Soft-tissue envelope*

The soft-tissue envelope is composed of 4 layers: the superficial fatty layer, the fibromuscular layer, the deep fatty layer, and the perichondrial/periosteal layer.[4] The superficial fatty layer is intimately connected to the dermis. Immediately deep to this layer is the fibromuscular layer. This construction is called the nasal superficial musculoaponeurotic system (SMAS) and is in continuity with the rest of the SMAS overlying the face. The mimetic muscles of the nose are within this layer. The next layer is the deep fatty layer, which encases the neurovascular system, supplying the skin-soft-tissue envelope.[6] Between this layer and the perichondrium/periosteum lies the avascular plane that is used to deglove the nose during rhinoplasty.

As mentioned previously, part of the soft-tissue envelope is composed of a muscular layer. The mimetic muscles of the nose are usually divided into 4 groups.[6,7] The elevator muscles shorten the nose and dilate the nostrils. They are the

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procerus, levator labii superioris alaeque nasi and anomalous nasi. The depressor muscles, which lengthen the nose and dilate the nostrils, consist of the alar nasalis and depressor septi nasi. The compressor muscles lengthen the nose and narrow the nostrils. They are the transverse nasalis and compressor narium minor. Finally, the minor dilator muscle, the dilator naris anterior, widens the nostrils.

### *Lining*

The nasal vestibule is lined by a strip of thin skin (stratified squamous keratinized epithelium). This epithelium loses its keratinizing nature and transitions into the nasal mucosa (pseudostratified columnar ciliated epithelium) as it moves further into the nose. This epithelium, called the respiratory epithelium, lines the sinonasal cavity with the exception of the area covered by the olfactory epithelium. The nasal mucosa has a rich vascular supply, which makes it an attractive option for flaps in reconstructing the inner lining of full-thickness nasal defects.[8]

### *Blood supply*

The blood supply to the nose comes from branches of both the external carotid artery (through the facial artery and the infraorbital artery) and internal carotid artery (through the ophthalmic and anterior ethmoidal artery) (**Fig. 1**).[4]

In the external carotid artery system, the facial artery has 2 terminal branches, the angular artery and the superior labial artery. The former passes in a deep groove between the nasal alae and the cheek, deep to the levator labii-superioris alaeque nasi muscle, and gives off the lateral nasal branch, which provides the blood supply to the lateral portion of the caudal nose. The angular artery then continues, following the rim of the pyriform aperture, giving off about 7 to 14 branches that perforate through the soft-tissue envelope to supply the nasal skin.[9] The superior labial artery courses medially to the columella, where it gives off septal branches to supply the anterior portion of the nasal septal mucosa, and it terminates as the columellar artery, which runs between the medial crus of the lower lateral cartilage (LLC) and is frequently transected during the transcolumellar approach for an open rhinoplasty. The infraorbital artery arises from the infraorbital foramen with the infraorbital nerve and supplements the blood supply with branches that give rise to the lateral nasal artery and the dorsal nasal artery.

The internal carotid system also gives rise to an extensive vascular network that supplies the nose. The ophthalmic artery has both ocular and orbital branches. One of the orbital branches is the anterior ethmoidal artery, which provides the blood supply for the anterosuperior portion of the nasal cavity. After running in the skull base between the frontal sinus and the anterior ethmoid sinuses, it emerges between the cephalic edge of the upper lateral cartilage (ULC) and the caudal edge of the nasal bone, providing part of the blood supply to

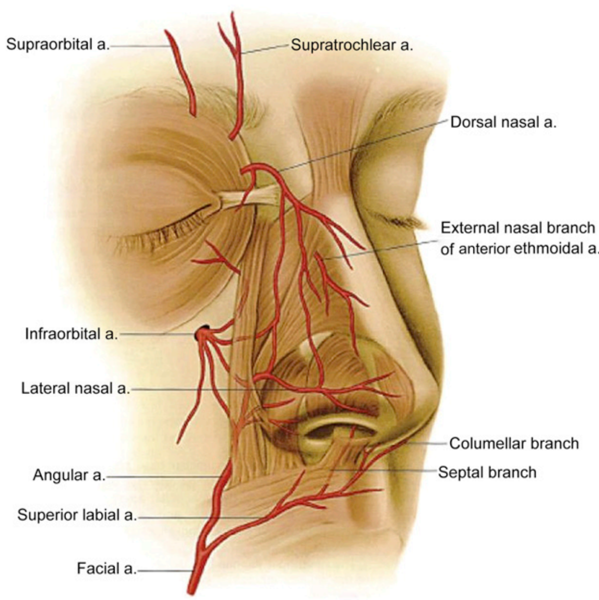


**Fig. 1.** Blood supply to the external nose. (*From* Jewett BS. Anatomic considerations. In: Baker SR, Naficy S. Principles of nasal reconstruction. St Louis (MO): Mosby; 2002. p. 19; with permission.)

the nasal tip, along with the lateral nasal artery. The ophthalmic artery finally gives rise to 2 terminal branches: the frontal artery and the dorsal nasal artery. The latter pierces the orbital septum and exits the orbit just superiorly to the medial canthal ligament and runs down to anastomose with the lateral nasal artery, creating a rich, axial arterial network.

### *Sensory nerve supply*

The skin overlying the nose is innervated by the ophthalmic ($V_1$) and maxillary ($V_2$) branches of the trigeminal nerve (**Fig. 2**). The cutaneous branches of the ophthalmic nerve are the supratrochlear, the infratrochlear, and the external nasal nerves. The supratrochlear branch exits at the supraorbital foramen, and the infratrochlear branch exits the orbit just superior to the medial canthus. They provide sensory supply to the skin of the nasion, radix, and rhinion and the cephalic portion of the lateral nasal sidewall. The external nasal branch comes from the anterior ethmoid nerve and emerges between the ULC and the nasal bone, accompanied by the anterior ethmoidal artery. This branch innervates the skin of the caudal nasal dorsum and nasal tip.

The branches of the maxillary nerve are the infraorbital nerve and the nasopalatine nerve. The infraorbital branch courses on the roof of the maxillary sinus and exits the cranium at the infraorbital foramen. It innervates the skin of the caudal portion of the lateral nasal sidewall, ala, and nasal vestibule. The nasopalatine branch enters the nose through the incisive foramen and innervates the nasal septal mucosa.

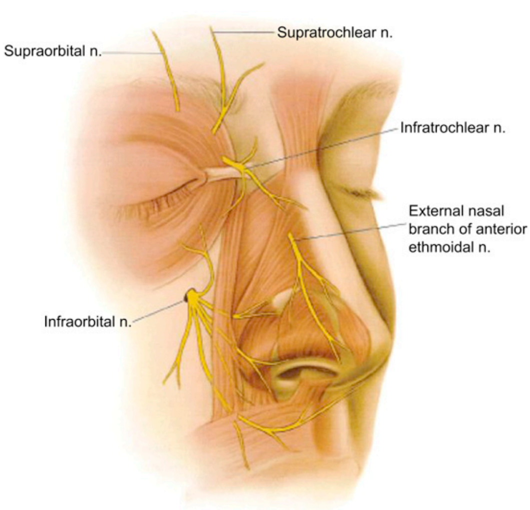


**Fig. 2.** The sensory nervous innervation to the external nose. (*From* Jewett BS. Anatomic considerations. In: Baker SR, Naficy S. Principles of nasal reconstruction. St Louis (MO): Mosby; 2002. p. 19; with permission.)

### *Bone and cartilaginous framework*

The bony framework is a pyramidal structure that consists of the paired nasal bones and the ascending process of the maxilla on either side. The cephalic portion articulates with the frontal bone superiorly and caudally, forming the cranial portion of the pyriform aperture (**Fig. 3**). The nasal bones are thicker superiorly and progressively become thinner until their free edge inferiorly.[10] The nasal bones are, on average, 25 mm, but their length can vary significantly. They fuse at the midline and give an internal projection that supports the perpendicular plate of the ethmoid bone. Inferiorly, the nasal bones articulate with the overlapped cephalic portion of the ULC, which are fused medially with the cartilage of the nasal septum. This area of confluence between the nasal bones, perpendicular plate of the ethmoid bone, ULCs, and cartilage of the nasal septum is connected by a dense fibrous tissue and is called the "keystone area."[11,12] This region provides critical support to the midvault of the nose.

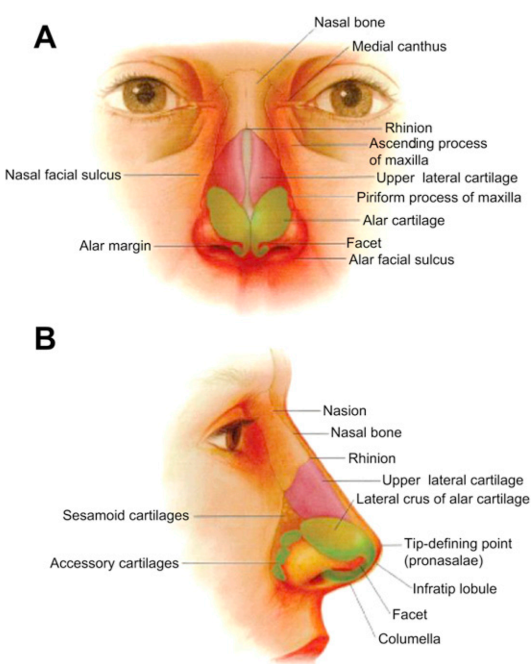


**Fig. 3.** (*A*, *B*) The bony and cartilaginous framework of the nasal skeleton. (*From* Jewett BS. Anatomic considerations. In: Baker SR, Naficy S. Principles of nasal reconstruction. St Louis (MO): Mosby; 2002. p. 19; with permission.)

The upper cartilaginous vault is made by the ULCs and the fused cartilaginous nasal septum. The cephalic two-thirds of the ULCs are fused with the nasal septum, and as they extend inferiorly, the ULC gradually separates and flares laterally from the septum.[13] The lateral portion of the ULC does not have any skeletal support because it does not articulate with the pyriform aperture but ends in an area called the external lateral triangle. This area is bordered by the pyriform aperture, the ULC, and the cephalic border of the lateral aspect of the LLC. It is covered by the transverse nasalis muscle and may contain one or more sesamoid cartilages. The most caudal aspect of the LLC ideally forms an angle with the nasal septum at the area of the internal nasal valve, which is described in more detail later in the article.

The lower cartilaginous framework is formed by the LLC. This paired cartilage morphology is made of 3 portions: the medial, middle, and lateral crura. The medial crus has 2 components: the footplate and the columellar portion. These segments rotate in 2 angles: the angle of cephalic rotation and the angle of footplate diversion. The medial crus has its configuration in 3 anatomic variations: the asymmetric parallel, flared symmetric, and straight symmetric.[14] Anteriorly, the medial crus transitions to the middle crus in the columellar breakpoint. The middle crus is made up of the lobular and the domal segments. The lobular segment is usually camouflaged by the overlying soft-tissue envelope. On the other hand, the domal segment is often visible and is critical in determining the tip-defining points. Its external expression depends on its angulation, the divergence of the 2 defining points, and the thickness of the overlying soft tissue. The middle crus is connected to the opposite side by the interdomal ligament. Superiorly, the LLC curves and transitions into the lateral crus. This portion of the LLC plays a major role in determining the shape of the alar region. It articulates superiorly with the caudal edge of the ULC in the “scroll area” where there is usually some degree of overlap, most commonly with the LLC coming externally to the ULC.[7] The LLC varies in shape and size,[15] and the longitudinal axis of the lateral crus approaches 45°.[3] This angle turns the LLC to a more cephalic position as it projects laterally, away from the alar rim, and that is the reason why the LLC provides support only to the medial half of the nasal ala.[16,17]

### *Nasal valves*

The nasal valves are the portion of the nose that regulates airflow, because they have the narrowest cross-sectional area of the entire airway.[18] They are usually described individually as the external and internal nasal valves. The resistance in the nasal airway can be divided between the nasal vestibule, internal nasal valve, and the turbinated cavity of the nasal passage. Whereas the nasal vestibule contributes only about one-third of the nasal resistance and the nasal passage with its turbinates contribute only minimally, the nasal valves comprise the major areas of resistance in the nasal cavity.[19]

The internal nasal valve corresponds to the area between the head of the inferior turbinate, the nasal septum, and the ULC.[20] A key portion of this valve is the angle between the nasal septum and the ULC, the normal range of which is 10° to 15°.[18] The internal nasal valve area is the flow-limiting segment of the nasal airway and comprises about 50% of the total airway resistance from the nasal vestibule to the alveoli.[21] Nasal resistance functions according to Poiseuille’s law; it is inversely proportional to the fourth power of the radius of the nasal passages (resistance = [viscosity $\times$ length]/radius$^4$).[22,23] This means that small changes in the size of the nasal valve can have exponential effects on the airflow resistance. As mentioned earlier, Bernoulli principle plays a key role in the physiology of the nasal valve. As the air flows across the narrowed nasal valve, the velocity increases and pressure decreases. This negative pressure in the valve area causes further nasal valve collapse.[24] Not only the internal nasal valve but also the external nasal valve or nasal ala may collapse from the increased negative pressures developed from inspiration.

The external nasal valve is formed by the nasal ala and its supporting structures. It consists of the columella (fixed portion) medially and the lateral crura of the LLC (mobile portion). This mobile portion tends to collapse with inspiratory flow by the Bernoulli effect, but this collapse is resisted by the action of the dilator nares and the levator labii alaeque muscles along with the intrinsic strength of the LLC. The flow in the external nasal valve is primarily determined by the position of the cartilage and is minimally influenced by the degree of mucosal engorgement.[25]

## *Subunit Approach to Cutaneous Anatomy*

In the early days of facial reconstruction, the main goal was to provide tissue coverage to the defect without significant concern with the cosmetic appearance. This concept started to change in the 1950s when surgeons started to advocate the use of “like tissue” to replace “like tissue.” They noted that, by giving the reconstructed defect an appropriate contour and color match, the viewing eye would more likely perceive the area as normal. As described earlier, the initial work for improving facial reconstruction was made by Gonzalez-Ulloa and colleagues,[2] when they observed that the face had distinct units with transition lines between them. They postulated that these units would be determined by differences in the underlying histologic characteristics between the adjacent areas. The skin characteristics include thickness, amount of subcutaneous fat, color, texture, and presence of hair. The transition lines, or aesthetic borders, include the anterior hairline, mental crease, melolabial crease, orbital rim, preauricular crease, and nasofacial groove. The investigators determined that the main aesthetic units of the face are the forehead, eyelids, cheeks, lips, mentum, auricles, and nose. Placing incisions along those transition lines would camouflage the reconstruction. Millard[26,27] expanded the concept, advocating that not only the incisions should be transition lines but also the entire unit should be reconstructed.

Building on those previous concepts, Burget and Menick[28] further developed this philosophy, dividing the nose into subunits (**Fig. 4**). In a landmark article, they identified the specific topographic subunits as the dorsum, tip, columella and the paired ala, sidewalls, and soft triangles. They suggested that when reconstructing nasal defects, replacing entire subunits generally provided better aesthetic results. Their results were supported by data from perceptive psychology.[29] They also described the "50% rule," advocating that, in patients in whom more than 50% of the involved subunit was removed, the reconstruction should encompass the entire subunit, which would include removing healthy skin from the surrounding area. For defects that were less than 50% of the subunit, the reconstruction should provide adequate contour and color match, without removing healthy tissue.

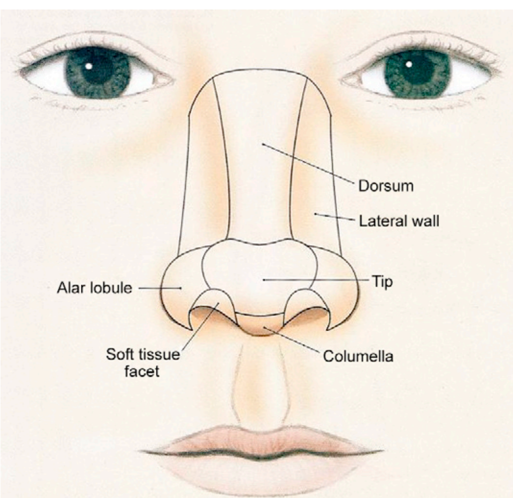


**Fig. 4.** The 9 aesthetic subunits of the nose consisting of the dorsum, tip, columella and the paired ala, sidewalls, and soft triangles. (*From* Baker SR. Flap classification and design. In: Baker SR, editor. Local flaps in facial reconstruction. Philadelphia: Elsevier Health Sciences; 2007. p. 76; with permission.)

The human eye usually focuses on the unexpected and glosses over the expected, taking it for normal appearance. The subunit principle was proposed with the goal of making the reconstruction look as close to normal as possible, so that the human eye would just gloss over and not be caught, like it might when the repair was by simply filling the defect. Observing the contralateral subunit would also aid in the reconstruction by providing information about the size and contour to achieve symmetry.

The actual point of transition between the nasal subunits is more subjective than with other facial units. The lines of transition are determined by the underlying structural framework rather than histologic difference. They are highlighted when an incident light is directed on the nasal surface, creating shadows on the borders of adjacent subunits. The nasal tip subunit is determined by the domal portion of the LLCs. Inferiorly it transitions to the columella, which extends inferiorly to the upper lip. Superiorly, the tip transitions to the nasal dorsum at the supratip depression, where the LLCs raise the skin. The dorsum extends superiorly to the nasion, where it transitions to the forehead unit. The lateral border of the dorsum is defined by the ULC and the junction of the nasal bones with the frontal process of the maxilla. This border creates a shadow that determines the subunit of the nasal sidewalls, which extends to the junction between the nose and cheek. Inferiorly, the sidewall ends at the alar crease where the nasal ala subunit starts, which is a smooth convexity that is supported by fibrofatty tissue without cartilaginous support. Between the nasal tip and the ala, there are the soft tissue facets that are defined by the shadow from the nasal tip.

Although the principle of nasal subunits is critical when planning nasal reconstruction, other factors should also be taken into consideration. These factors are skin color match, texture, contour, actinic damage, and the patient's comorbidities. The bilobed flap and the nasal dorsum rotation advancement flap are popular and useful techniques that innately violate the boundaries of the subunit principle. Recently, some investigators described modifications on nasal reconstruction with regard to the subunit principle. One study advocated that defects that include the nasal dorsum and tip consistently have better cosmetic results than defects isolated to the nasal tip or dorsum.[30] Another study by Singh and Bartlett[31] proposed that other factors would prevail over nasal subunits in certain conditions such as in patients with Fitzpatrick skin types I and II, prominent sebaceous glands on the nasal skin, and the presence of actinic damage.

## *Defect Analysis*

To accurately reconstruct a nasal defect, the surgeon must have a clear understanding of the layers of the nasal tissues and obstacles that can pose a threat to achieving an excellent aesthetic and functional reconstructive repair. One of the first aspects to consider is that in analyzing the defect to be repaired, the surgeon must evaluate and determine the layers of the nose that are involved in the defect and which are missing. Before beginning any surgery, especially complex nasal reconstructions, the surgeon must have a plan to execute and express to the patient so that the patient knows what to expect during the procedure and recovery period. Manson and colleagues[32] described nasal reconstruction as a 3-part approach, that is, the overlying skin, structural framework, and internal lining should each be evaluated individually before the final repair decisions are made.

When analyzing the defect in reference to the nasal skin, the surgeon must consider the location of the defect on the nose. For instance, defects found on the nasal dorsum may be reconstructed with a simple vertical closure, whereas others involving the nasal tip, ala, or free nostril margin may require more complex repairs and even multistage procedures. Along those same lines, certain areas of the nose, such as the supra-alar groove and alar-facial sulcus, have unique contours that are extremely difficult to reconstruct. Not respecting these borders can lead to a conspicuous and noticeable repair.

Defect size is also extremely important to evaluate before the surgeon chooses a reconstructive option. Defects smaller than 1 cm may be repaired with local flaps from within the same subunit or even with more basic options such as a primary closure or full-thickness skin graft (FTSG), whereas larger defects may require local tissue to be transferred from areas where it is more abundant, such as the cheek. The surgeon may also use multistage flaps to reconstruct the defect.

Other vital details of the nasal skin can affect how the reconstruction will eventually turn out. These aspects of the skin include color, contour, and type or texture. The surgeon must take into account that different parts of the nose differ in skin texture. The rhinion has the thinnest skin of the nose, with minimal sebaceous units, whereas the skin of the ala is thick with abundant adnexal structures. This detail is important in deciding the location from which to borrow the local skin for reconstruction. For example, a flap using the cheek skin would have a better texture match with the thicker skin of the nasal ala than it would with the thin-skinned nasal dorsum.

Color should also be matched when considering reconstructive options. It may be that the patient has erythematous nasal skin from a condition like rosacea, in which case a defect of the nasal supratip may be better reconstructed with a local bilobe flap, which uses skin of similar color, than with a paramedian forehead flap, which would likely not hide the borders of the flap because of the stark differences in skin color.

Assessing the underlying nasal framework and structure is also critical before outlining a plan for surgical repair. The surgeon must accurately analyze whether the defect interferes with the cartilaginous or bony framework of the nasal scaffold. If the LLCs are resected or altered, additional support for the nasal ala must be provided with grafts that are braced laterally on the pyriform aperture. Tip support mechanisms should always be evaluated and augmented when needed.

The mucosal lining of the nasal cavity must also be recreated when deficient. Failure to restore the nasal lining in the area of the defect can lead to severe wound contraction, adhesions, and significant distortion of the nose.[33] It is therefore critical to rebuild the nasal lining to prevent these issues. There are multiple techniques, such as flaps and grafts, which are beyond the scope of this article, used to provide nasal lining repair.

Finally, the reconstructive surgeon must look beyond the defect itself and take into account the status of the wound bed when considering nasal repair options. Sometimes, the patient's medical history can influence the surgeon's choices in wound repair. For example, smoking provides the largest challenge to the successful reconstruction of a patient's nasal defect. Active smokers are at an increased risk of flap or skin graft failure, especially if they are unable to quit smoking before the surgery.[34–36] Therefore, the surgeon may opt for an axial pattern flap with a more reliable blood supply rather than an FTSG, to repair the nasal defect. Similarly, a patient who has received previous head and neck irradiation may have a compromised blood supply to the face or nose. In these cases, similar to the case of a smoker, a more robust vascularized pedicle flap may be appropriately chosen. Besides the choice of flap, the surgeon may also decide to delay the flap or wait a prolonged period of time between the flap transfer and the pedicle division with insetting. This procedure allows the vascular supply from the surrounding wound site to have more time for neovascularization. Prior facial or nasal surgery may have previously used tissue for reconstructions and altered the vascular supply to some of the flap choices that could be selected. Accordingly, it is vital to elicit this surgical history from the patient and examine the patient's skin and scars to see what type of reconstruction or surgery was performed during the first operation.

## *Skin Flap Physiology and Skin Biomechanics*

Skin has 3 biomechanical properties that describe how it moves and heals: nonlinearity, viscoelasticity, and anisotropy.[37]

### *Nonlinearity*

This mechanical skin property means that skin stretch differs depending on how much force is applied; the more the skin is stretched, increasing amounts of pressure are required to further deform the skin.[38] Also, there is an asymptote or point at which the skin cannot be stretched anymore. These concepts are related to the amount of collagen, elastin, and ground substance that composes the skin. This nonlinear relationship is demonstrated with the stress-strain curve (**Fig. 5**). Stress is defined as force per unit of cross-sectional area, and strain is the change in skin length divided by its original length.[38,39] This curve can be broken down into 3 sections. The first section of the curve is flat, explaining that a small stress leads to a large skin strain or stretch, which is the result of deformity of the skin elastin network. The second section of the curve, sometimes called the transition section, shows that as more force is applied to the skin, it becomes harder to stretch it further. This difficulty could be because of the change in the collagen fiber orientation that occurs at this point. The third section of this graph demonstrates that once the skin has been stretched or strained a significant amount, a large force is required to even achieve a small amount of additional stretch. At this point, the recruitment of additional collagen fibers to shoulder the increased stress and the orientation of the fibers in the direction of the applied force create a detrimental situation of tension and poor wound healing.[39,40] Of note, the skin properties change further with age and sun damage. With these problems, the skin begins to lose both its collagen and elastin fibers, shifting the curve to the right.[40,41]

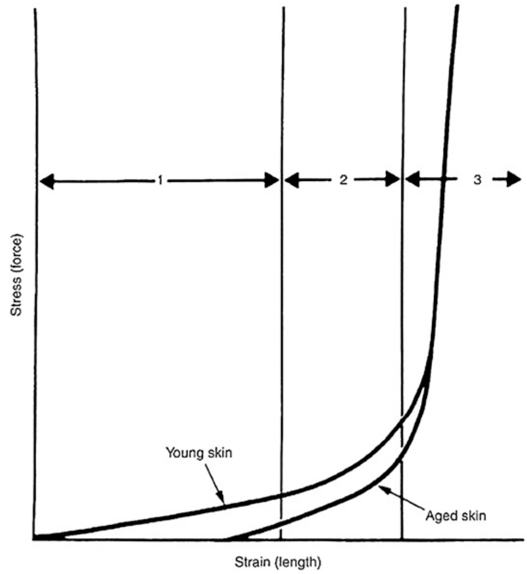


**Fig. 5.** Stress-strain curve demonstrating the relationship between the amount of force or stress needed to strain or deform young and aged skin. (*From* Larrabee WF Jr. Immediate repair of facial defects. Dermatol Clin 1989;7:662; with permission.)

### *Viscoelasticity*

One of the viscoelastic skin properties is stress relaxation. If a constant force is applied over a period to stretch the skin to a given length and then maintained at that length, there is a subsequent decrease in skin tension.[42]

Another viscoelastic property of the skin is creep. This phenomenon occurs when an increase in skin length is noted over time, when a certain tension is applied to a segment of skin. Skin creep has been attributed to the parallel alignment of collagen fibers, fragmented elastin, and a displacement of extracellular fluid from within the dermis. The process of tissue expansion uses skin creep, not to create new skin but to recruit skin that is adjacent to the defect, allowing it to be closed with minimal tension.[39,40,43] Creep can also be subcategorized into biologic and mechanical types. Biologic creep refers to skin expansion from the slow application of a subcutaneous force, whereas mechanical creep occurs when the skin stretches beyond its normal extensibility in a shorter amount of time. It is the latter type that is commonly seen when using a tissue expander to recruit more skin.

### *Anisotropy*

This term refers to the fact that the mechanical properties of the skin vary with direction.[39,40] There may be tension on the skin when a defect is attempted to be closed in one direction, whereas closing in a different direction might allow that same area of skin to be closed without tension. This property comes into play largely when surgeons are thinking about the placement of their incisions for defect closures.

There is wide variation in facial skin tension among the different anatomic units. For example, the skin on the eyelids and cheek has much lower tension than that on the forehead and the nose. However, at any given point, the skin is under tension in every direction. This tension is present constantly and is modified by muscle action (it could increase or decrease the tension). This tension is the force responsible to separate the edges of a wound. Originally described by Borges and Alexander,[44] the relaxed skin tension lines (RSTLs) are a series of imaginary facial lines, along which the skin has the least amount of tension for closure (**Fig. 6**). These lines are usually not visible at rest, but can be seen as the furrows that form from pinching the skin together.[42,45,46] Incisions placed parallel to these lines heal without stress or tension on the wound closure.[44,47] A wound following these lines remains narrow, but if it is made perpendicular to the RSTLs, the edges may begin to widen or gap. Borges[46] advocated that no other single factor (not even surgical technique) is as important as the direction of the wound being parallel to the RSTLs for the formation of an acceptable scar. He recommended that if an incision should be done in an antitension line, it should be done in a zigzag pattern, better following the RSTLs. RSTLs are always parallel or concentric or meet at an acute angle. Their direction does not vary significantly among individuals. Around facial apertures, such as the nares and mouth, these lines tend to be radial. Also, they are not coincident with wrinkles in the glabella, the upper portion of the crow's feet, and the mentolabial fold.

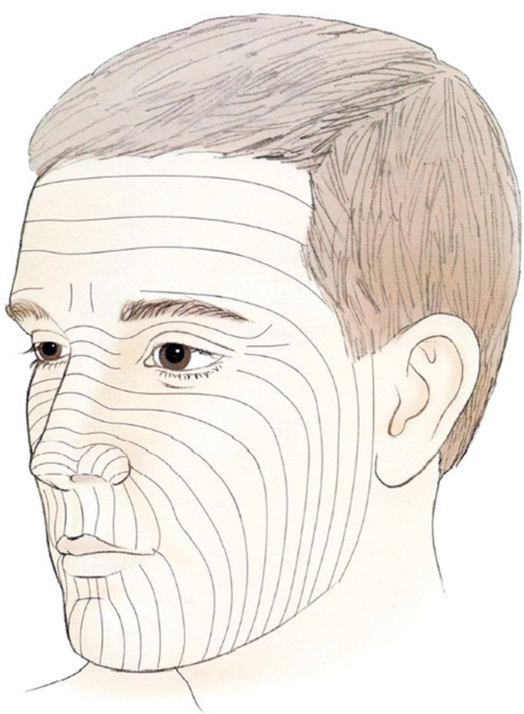

**Fig. 6.** The RSTLs of the face. These lines run in a perpendicular orientation to the lines of maximal extensibility. (*From* Baker SR. Flap classification and design. In: Baker SR, editor. Local flaps in facial reconstruction. Philadelphia: Elsevier Health Sciences; 2007. p. 73; with permission.)

Another series of lines that are important in the planning of incisions are the lines of maximal extensibility (LME), which run perpendicular to the RSTLs. Extensibility is defined as the lengthening of the skin under tension, caused by stretching of the elastic fibers on the skin. This extensibility varies depending on the direction in which the tension is applied.[48] The tension in the wound is the least in the plane parallel to the LME, which allows for the largest amount of skin stretch at the widest area of the defect to help with closure. Both lines, RSTL and LME, are important when recruiting adjacent tissues to close wound defects. The tension on the skin flap used for reconstruction is an essential consideration because excessive tension may compromise the blood supply in the distal portion of the flap.

Furthermore, the orientation of a wound has a direct correlation to the scar appearance. The orientation of fusiform excisions should be closed in the direction of the LME, so that the scar or incision is situated in the facial RSTLs,[38,46] allowing for the most optimal tissue healing and scar outcome. At present, RSTLs provide the most acceptable orientation for the placement of surgical incisions.

## *Blood Supply to Local Skin Flaps*

Understanding the vascular supply to the skin and soft tissue is vital to the operative planning of the reconstructive surgeon. When designing local flaps for nasal defect repair, they can be described based on the blood supply into random and axial pattern flaps. Random skin flaps receive their blood supply from musculocutaneous and septocutaneous vessels, running deep to the muscles or in the muscular fascia, respectively, and then perforate through the muscles or muscular septae to provide the blood supply for the dermal-subdermal plexus of the skin. These flaps are known as random because they are not raised in a specific direction to account for the cutaneous vascular supply. The survival of these random pattern flaps is based on the perfusion pressure of the underlying vessels. Because of this requirement, the length-width ratio for flap design should maximally approach 3:1.[49] To this end, care must be taken to perform the dissection in a subcutaneous plane when raising these flaps, to preserve the subdermal blood supply.

Axial pattern flaps, on the other hand, have a blood supply that comes from direct cutaneous vessels that run in the subcutaneous tissue along the directional axis of the flap. The survival of these flaps is based on the actual axial vessel length.[40] When raising these types of flaps, they should be oriented and aligned specifically so that the long axis of the flap parallels the blood vessel of interest. Any skin territory outside of the distribution that is supplied by this artery becomes a random flap and again relies on the nourishment from the dermal-subdermal plexus. The rich and reliable vascular supply provided by this axial blood supply makes these flaps more amenable to primary thinning and contouring.

Furthermore, significant wound tension can affect the blood supply to a skin flap. Because it has been shown that the blood supply is inversely proportional to the distance from the flap base, a flap that is stretched with significant tension can suffer distal necrosis.[50] This is one reason why local skin flap closures should be reconstructed without tension on the closure.

## *Wound Healing Phases*

### *Inflammatory phase (0–5 days)*

The wound healing process begins immediately after tissue injury and once hemostasis has been achieved. For the blood of the wound to clot, a combination of local vessel vasoconstriction, fibrin deposition, and platelet aggregation must take place.[40,51] Fibrin deposition relies on the extrinsic coagulation pathway, and the platelets begin to deposit on the vessel walls once they have been exposed to the local collagen and tissue factors circulating in the wound bed. Once 10 to 15 minutes have elapsed, the initial vasoconstriction changes to a period of vasodilation, caused by the release of histamine, leukotrienes, and prostaglandins from the endothelium.[52]

The inflammatory phase gets its name from the infiltration of neutrophils that begin to predominate the wound bed. These cells patrol the wound and help to prevent local infection by debriding foreign particles and digesting bacteria. These cells peak between days 1 and 2 and then begin to decline as the monocytes and macrophages move into the area, peaking around days 4 to 5.

### *Proliferative or granulation phase (6–14 days)*

The next phase in wound healing works to repair the epithelium, synthesize collagen, and promote the development of new blood vessels. It has been said that reepithelialization can occur about 12 hours after the initial wound injury. Reepithelialization occurs through the migration of the epithelial cells near the wound edges along the fibrin scaffold to again cover the wound bed.[40] In superficial wounds, the adnexal structures also participate in the reepithelialization process.

Epithelial cells play an important role in this phase, and fibroblasts, crucial to the synthesis of elastin, proteoglycans, and collagen, start to become active during this period in wound healing. Initially, fibroblasts produce collagen type III, abundant in an early wound, which is later converted to type I collagen. Fibroblasts also change into myofibroblasts, which are critical in the contraction of wounds, seen around days 7 to 14.[53]

Finally, the wound produces several angiogenic growth factors, such as vascular endothelial growth factor, which help to promote angiogenesis. It is this new blood vessel formation that is necessary to support the generation of the granulation tissue that exists in the wound bed.

### *Remodeling or maturation phase (15 days–1 year)*

The final stage in wound healing is known as the remodeling or maturation phase. This is also the longest stage of the process and can last for up to a year. It is for this reason that many surgeons wait 1 year before attempting any surgical wound or scar revision procedure. Beginning 2 weeks after the creation of the wound, the collagen arrangement changes from the disorganized fibrils of the immature scar to the more parallel, thicker collagen fibril organization that is seen in a mature scar. In addition, the type III collagen that was originally present in the wound bed now becomes replaced by the type I collagen, which is the major component of the scar.[40] Neovascularization stops, and the erythema that was originally seen in the wound from the vasculature turns a whitish color as the vessels regress.

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