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Structure and function of the skin

The functions of the skin include:

- 1 Physical protection
- 2 Protection against UV light
- 3 Protection against microbiological invasion
- 4 Prevention of fluid loss
- 5 Regulation of body temperature
- 6 Sensation
- 7 Immunological surveillance.

The epidermis

- The epidermis is composed of stratified squamous epithelium.
- It is derived from ectoderm.
- Epidermal cells undergo keratinization in which their cytoplasm is replaced with keratin as the cell dies and becomes more superficial.

The epidermis is composed of the following five layers, from deep to superficial.

1 Stratum germinativum

- This is also known as the basal layer.
- The cells within this layer have cytoplasmic projections, which firmly link them to the underlying basal lamina.

- This is the only actively proliferating layer of skin.
- The stratum germinativum contains melanocytes.

2 Stratum spinosum

- The stratum spinosum is also known as the prickle cell layer.
- This layer contains large keratinocytes which produce keratin.
- The cells within this layer are joined to each other by tonofibrils (prickles).

3 Stratum granulosum

- The stratum granulosum contains mature keratinocytes, which possess cytoplasmic granules of keratohyalin.
- This layer is called the stratum granulosum because of these granules.
- The stratum granulosum is the predominant site of protein synthesis.

4 Stratum lucidum

- This is a clear layer.
- The stratum lucidum is only present in the thick skin of the palms and feet.

5 Stratum corneum

- The stratum corneum contains non-viable keratinized cells.
- The thick cells of this layer protect against trauma.
- The stratum corneum:
 - Insulates against fluid loss
 - Protects against bacterial invasion.
- Sebum produced by the sebaceous glands of the stratum corneum is bactericidal to both streptococci and staphylococci.

Cellular composition of the epidermis

- Keratinocytes are the predominant cell type in the epidermis.
- Langerhans cells form part of the immune system and function as antigen-presenting cells.
- Merkel cells are mechanoreceptors of neural crest origin.
- Melanocytes:
 - Are neural crest derivatives
 - Are usually located in the stratum germinativum
 - Produce melanin, which protects the surrounding skin by absorbing UV light.

The dermis

- The dermis accounts for 95% of the thickness of the skin.
- The papillary dermis is superficial and contains more cells and finer collagen fibres.
- The reticular dermis is deeper and contains fewer cells and coarser collagen fibres.

The dermis is composed of the following.

Collagen fibres

- These fibres are produced by fibroblasts.
- They are responsible for much of the strength of the skin.
- The normal ratio of type 1 to type 3 collagen is 5 : 1.

Elastin fibres

- These are secreted by fibroblasts.
- They are responsible for the elastic recoil of the skin.

Ground substance

- This consists of the glycosaminoglycans (GAGs), hyaluronic acid, dermatan sulfate and chondroitin sulfate.
- GAGs are secreted by fibroblasts and become ground substance when hydrated.

Vascular plexus

- This separates the denser reticular dermis from the overlying papillary dermis.

Skin appendages

The skin contains the following appendages.

Hair follicles

- Each hair is composed of a medulla, cortex and outer cuticle.
- The hair follicle consists of an inner root sheath, derived from the epidermis, and an outer root sheath, derived from the dermis.
- Several sebaceous glands drain into each follicle. Discharge from these glands is aided by the contraction of erector pili muscles.
- Velus hairs are fine and downy.
- Terminal hairs are coarse.
- Hairs are in either the telogen or the anogen phase.
- 75% of hairs are in the anogen (growth) phase at any one time.
- The remaining 25% of hairs are in the telogen (resting) phase.

Ecocrine glands

- These sweat glands secrete an odourless hypotonic fluid.
- They are present in all sites of the body.
- Ecocrine glands occur more frequently in the eyelids, palms, feet and axilla.

Apocrine glands

- These are located in the axilla and groin.
- They emit a thicker secretion than ecocrine glands.
- They are responsible for body odour.
- Hidradenitis suppurativa is an infection of the apocrine glands.

Sebaceous glands

- These are holocrine glands that usually drain into the pilosebaceous unit.

- They drain directly onto the skin in the labia, penis and tarsus (meibomian glands).
- They occur more frequently on the forehead, nose and cheek.
- Sebaceous glands are not the sole cause of so-called sebaceous cysts. These cysts are in fact of epidermal origin and contain all of the substances secreted by the skin (predominantly keratin).
- Some authorities maintain that they should therefore be called epidermoid cysts.

Types of secretion from glands

- Eccrine or merocrine glands secrete opened vesicles via exocytosis.
- Apocrine glands secrete unbroken vesicles which later discharge.
- Holocrine glands secrete whole cells which then disintegrate.

Histological terms

- Acanthosis—hyperplasia of the epithelium.
- Papillomatosis—an increase in the depth of the corrugations at the junction between epidermis and dermis.
- Hyperkeratosis—an increase in the thickness of the keratin layer.
- Parakeratosis—the presence of nucleated cells at the skin surface.

Blood supply to the skin

Anatomy of the circulation

- The blood reaching the skin originates from deep vessels.
- These then feed interconnecting vessels which supply the vascular plexuses of fascia, subcutaneous tissue and skin.

Deep vessels

The deep vessels arise from the aorta and divide to form the main arterial supply to the head, neck, trunk and limbs.

Interconnecting vessels

The interconnecting system is composed of:

- Fasciocutaneous (or septocutaneous) perforating vessels
 - These vessels reach the skin by traversing fascial septae.
 - They provide the main arterial supply to the skin in the limbs.
- Musculocutaneous vessels
 - These vessels reach the skin via direct muscular branches from the deep system.
 - These branches enter muscle bellies and divide into multiple perforating branches, which travel up to the skin.
 - The musculocutaneous system provides the main arterial supply to the skin of the torso.

Vascular plexuses of fascia, subcutaneous tissue and skin

Vascular plexuses of the fascia, subcutaneous tissue and skin are divided into six layers.

- 1 Subfascial plexus
 - A small plexus lying on the undersurface of the fascia.
- 2 Prefascial plexus
 - A larger plexus particularly prominent on the limbs.
 - Predominantly supplied by fasciocutaneous vessels.
- 3 Subcutaneous plexus
 - Lies at the level of the superficial fascia.
 - Mainly supplied by musculocutaneous vessels.
 - Predominant on the torso.
- 4 Subdermal plexus
 - Receives blood from the underlying plexuses.
 - The main plexus supplying blood to the skin.
 - Represented by dermal bleeding observed in incised skin.
- 5 Dermal plexus
 - Mainly composed of arterioles.
 - Plays an important role in thermoregulation.
- 6 Subepidermal plexus
 - Contains small vessels without muscle in their walls.
 - Has a predominantly nutritive and thermoregulatory function.

Angiosomes

- An angiosome is a composite block of tissue supplied by a named artery.
- The area of skin supplied by an artery was first studied by Manchot in 1889.
- His work was expanded by Salmon in the early 1930s, and more recently by Taylor and Palmer.
- The anatomical territory of an artery is the area in which the vessel branches ramify before anastomosing with adjacent vessels.
- The dynamic territory of an artery is the area into which staining extends after intravascular infusion of fluorescein.
- The potential territory of an artery is the area that can be included in a flap if it is delayed.
- The vessels that pass between anatomical territories are called choke vessels.
 - The transverse rectus abdominis muscle (TRAM) flap illustrates the angiosome concept well.
- *Zone 1*
 - This receives musculocutaneous perforators from the deep inferior epigastric artery (DIEA) and is therefore in its anatomical territory.
- *Zones 2 and 3*
 - There is some controversy as to which of the following zones is 2 and which is 3; the numbers of these zones are interchanged in various texts.
 - The portion of skin lateral to zone 1 is in the anatomical territory of the superficial circumflex iliac artery (SCIA). Blood has to travel through a set of choke vessels to reach it from the ipsilateral DIEA.

- The portion of skin on the other side of the linea alba is in the anatomical area of the contralateral DIEA. This area is reliably perfused in a TRAM flap based on the contralateral DIEA and is therefore within its dynamic territory.
- *Zone 4*
 - This lies furthest from the pedicle and is in the anatomical territory of the contralateral SCIA.
 - Blood passing from the flap pedicle to zone 4 has to cross two sets of choke vessels.
 - This portion of the TRAM flap has the worst blood supply and for this reason it is often discarded.

Arterial characteristics

From his detailed anatomical dissections Taylor made the following observations:

- 1 Vessels usually travel with nerves.
- 2 Vessels obey the law of equilibrium—if one is small, its neighbour will tend to be large.
- 3 Vessels travel from fixed to mobile tissue.
- 4 Vessels have a fixed destination but a varied origin.
- 5 Vessel size and orientation is a product of growth.

The microcirculation

- Terminal arterioles are present in the reticular dermis and terminate as they enter the capillary network.
- The precapillary sphincter is the last part of the arterial tree containing muscle within its wall. It is under neural control and regulates the blood flow into the capillary network.
- Arteriovenous anastomoses (AVAs) connect the arterioles to the efferent veins.
- Blood flowing through AVAs bypasses the capillary bed and has a thermoregulatory rather than nutritive function.
- AVAs are of two types:
 - 1 Indirect AVAs are convoluted structures known as glomera and are densely innervated by autonomic nerves.
 - 2 Direct AVAs are much less convoluted and have a sparser autonomic supply.
- The blood supply to the skin far exceeds its nutritive requirements—much of it bypasses the capillary beds via the AVAs and has a primarily thermoregulatory function.

Control of blood flow

The muscular tone of vessels is controlled by the following factors.

Pressure of the blood within vessels (myogenic theory)

- The myogenic theory was originally described by Bayliss and states that:
 - Increased intraluminal pressure results in constriction of vessels.
 - Decreased intraluminal pressure results in their dilatation.
- This mechanism helps to keep blood flow constant and is the cause of the immediate hyperaemia observed on release of a tourniquet.

Neural innervation

- Arterioles, AVAs and precapillary sphincters are densely innervated by sympathetic fibres.
- Neural control regulates skin blood flow in the following ways.
 - Increased arteriolar tone results in a decrease of cutaneous blood flow.
 - Increased precapillary sphincter tone reduces the blood flow into the capillary networks.
 - Decreased AVA tone results in an increase in the non-nutritive blood flow bypassing the capillary bed.

Humoral factors

- Epinephrine (adrenaline) and norepinephrine (noradrenaline) cause vasoconstriction of the vessels.
- Histamine and bradykinin cause vasodilatation.
- Low oxygen saturation, high carbon dioxide saturation and acidosis also result in vasodilatation.

Temperature

Increased heat produces cutaneous vasodilatation and increased flow which predominantly bypasses the capillary beds via the AVAs.

The delay phenomenon

- Delay is any preoperative manoeuvre that results in increased flap survival.
- Historical examples include Tagliacozzi's technique for nasal reconstruction described in the 16th century.
 - This involves elevation of a bipediced flap with a length : breadth ratio of 2 : 1 (the flap can be considered as two flaps of the ratio 1 : 1).
 - Cotton lint is then placed under the flap, preventing its reattachment.
 - Two weeks later one end of the flap is detached from the arm and attached to the nose.
 - A flap of these dimensions transferred immediately, without a prior delay procedure, would have an increased chance of distal necrosis.
- A form of delay used in clinical practice today is the division of the DIEA supplying the rectus muscle, 2 weeks prior to pedicled TRAM-flap breast reconstruction.

Despite many advances in our understanding, the mechanism of delay remains incompletely understood. The following theories have been proposed to explain the delay phenomenon.

Increased axiality of blood flow

- Removal of the blood flow from the periphery of a random flap will promote the development of an axial blood supply from its base along its axis.
- Axial flaps are known to have improved survival when compared with random flaps.

Tolerance to ischaemia

- Cells become accustomed to hypoxia after the initial delay procedure.
- Less tissue necrosis therefore occurs after the second operation.

Sympathectomy vasodilatation theory

- Sympathectomy resulting from dividing the sympathetic fibres at the borders of the flap results in vasodilatation and an improved blood supply.
- But why, if sympathectomy is immediate, does the delay phenomenon only begin to appear at 48 h, and why does it take 2 weeks to reach its maximum effect?

Interflap shunting hypothesis

- This theory postulates that sympathectomy dilates the AVAs more than the precapillary sphincters, resulting in an increase in non-nutritive blood flow bypassing the capillary bed.
- A greater length of flap will survive at the second stage as there are fewer sympathetic fibres to cut and therefore there will be less of a reduction in non-nutritive flow.

Hyperadrenergic state

- Surgery results in increased tissue concentrations of vasoconstrictor substances, such as epinephrine and norepinephrine.
- After the initial delay procedure, the resultant reduction in blood supply is not sufficient to produce tissue necrosis.
- The level of vasoconstrictor substances returns to normal before the second procedure.
- The second procedure produces another rise in the concentration of vasoconstrictor substances.
- This rise is smaller than it would be if the flap were elevated without a prior delay.
- The flap is therefore less likely to undergo distal necrosis if a prior delay is performed.

Unifying theory

- This theory was described by Pearl in 1981.
- It incorporates elements of all of the above theories.

Classification of flaps

Flaps can be classified by the five 'C's':

- Circulation
- Composition
- Contiguity
- Contour
- Conditioning.

Circulation

The circulation to flaps can be further subcategorized into:

- Random
- Axial (direct; fasciocutaneous; musculocutaneous; or venous).

Random flaps

- Random flaps have no directional blood supply and are not based on any known vessel.
- These include most local flaps on the face.
- They should have a maximum length : breadth ratio of 1 : 1 in the lower extremity, as it has a poor blood supply.
- They can have a length : breadth ratio of up to 1 : 6 in the face, as it has a good blood supply.

Axial flaps

Direct

- Direct flaps contain a named artery running along the axis of the flap in the subcutaneous tissue.
- Examples include:
 - The groin flap based on the superficial external iliac vessels.
 - The deltopectoral flap based on perforating vessels of the internal mammary artery.
- Both flaps can include a random segment in their distal portions after the artery tapers out.

Fasciocutaneous

- Fasciocutaneous flaps are based on vessels running either within or near the fascia.
- Blood reaches these flaps from fasciocutaneous vessels (also called septocutaneous vessels) running from the deep arteries of the body to the fascia.
- The fasciocutaneous system predominates on the limbs and this is the location of most of these flaps.

Fasciocutaneous flaps have been classified by Cormack and Lamberty into the following types:

- *Type A*

- These flaps are dependent on multiple non-named fasciocutaneous vessels that enter the base of the flap.
- The lower-leg 'super flaps' described by Pontén are examples of type A flaps. Their dimensions vastly exceed the 1 : 1 ratios recommended for random flaps in the lower leg.

- *Type B*

- These are based on a single fasciocutaneous vessel which runs along the axis of the flap.
- Examples include the scapular and parascapular flaps, and the fasciocutaneous flaps based on perforators in the lower leg.

- *Type C*
 - These flaps are supplied by multiple small, perforating vessels which reach the flap from a deep artery running along a fascial septum between muscles.
 - Examples include the radial forearm flap (RFF) and the lateral arm flap.
- *Type D*
 - These are fasciocutaneous flaps that contain bone.
 - As these flaps are usually type C, they have recently been reclassified as 'type C flaps with bone'.
 - Examples include:
 - The RFF raised with a segment of the radius.
 - The lateral arm flap raised with a segment of the lateral supracondylar ridge of the humerus.

Musculocutaneous

- Musculocutaneous flaps are based on perforators that reach the skin through the muscle.
- The musculocutaneous system predominates on the torso and this is the location of most of these flaps.
 - Musculocutaneous flaps were classified by Mathes and Nahai in 1981.
- *Type 1*
 - These flaps are supplied by a single vascular pedicle.
 - Examples include the gastrocnemius, the tensor fascia lata (TFL) and the abductor digiti minimi (ADM).
 - These are generally good flaps for transfer, as the whole muscle is nourished by a single pedicle.
- *Type 2*
 - These flaps are supplied by a single dominant pedicle which enters the muscle near its origin or insertion point.
 - Additional smaller vascular pedicles enter the muscle belly.
 - Examples include the trapezius, temporalis and gracilis flaps.
 - These are generally good flaps for transfer, as they can be based on the single dominant pedicle.
- *Type 3*
 - These flaps are supplied by two vascular pedicles, each arising from a separate regional artery.
 - Examples include the rectus abdominis and the gluteus maximus flaps.
 - These are useful muscles for transfer, as they can be based on either pedicle.
- *Type 4*
 - These flaps are supplied by multiple segmental pedicles.
 - Examples include the sartorius, the tibialis anterior and the long flexors and extensors of the toes.
 - In practice they are seldom used for transfer, as each pedicle only supplies a small portion of muscle.
- *Type 5*
 - These flaps have one dominant vascular pedicle and secondary smaller segmental pedicles.

- Examples include the latissimus dorsi and the pectoralis major.
- These are useful flaps, as they can be based on either the dominant vascular pedicle or the secondary smaller segmental pedicles.

Venous

- These flaps are based on venous rather than arterial pedicles.
- In fact, many of the venous pedicles have very small arteries running alongside them.
- One example is the saphenous flap, which is based on the short saphenous vein and often used to reconstruct defects around the knee.

Venous flaps have been classified by Thatte and Thatte as follows:

- *Type 1*
 - These flaps are supplied by a single venous pedicle.
- *Type 2*
 - These are venous flow-through flaps and are supplied by a vein which enters one side of the flap and exits from the other.
- *Type 3*
 - These are arterialized venous flaps.

Venous flaps tend to become very congested post-operatively and have not been universally accepted.

Composition

Flaps can be classified by their composition, as:

- Cutaneous
- Fasciocutaneous
- Fascial
- Musculocutaneous
- Muscle only
- Osseocutaneous
- Osseous.

Contiguity

Flaps can be classified by their source, as:

- Local flaps
 - These are composed of tissue adjacent to the defect.
- Regional flaps
 - These are composed of tissue from the same region of the body as the defect, e.g. head and neck, upper limb.
- Distant flaps
 - Pedicled distant flaps are from a distant part of the body to which they remain attached.
 - Free flaps are completely detached from the body and anastomosed to recipient vessels close to the defect.

Contour

Flaps can be classified by the method in which they are transferred into the defect. Methods of transferring flaps include the following.

Advancement

The following methods can be used to facilitate advancement of a flap into a defect.

- Stretching of the flap
- Excision of Burow's triangles at its base
- V-Y advancement
- Z-plasty at its base
- A combination of the above.

Transposition

• The flap is moved into a defect from an adjacent position, leaving a defect which must be closed by another method.

Rotation

- The flap is rotated into the defect.
- Classically, rotation flaps are of sufficient dimensions to permit closure of the donor defect.
- In reality, many flaps have elements of transposition and rotation and may be best described as pivot flaps.

Interpolation

• These flaps are moved into a defect either under or above an intervening bridge of tissue.

Crane principle

- This technique aims to transform an ungraftable bed into one that will accept a skin graft.
- At the first stage a flap is placed into the defect.
- After a sufficient time period to allow vascular ingrowth into the flap from the recipient site, the superficial portion of flap is replaced in its original position. This leaves a segment of subcutaneous tissue in the defect, which can now accept a skin graft.

Conditioning

- 'Delay' is any preoperative manoeuvre which will result in increased flap survival.
- Traditionally delay has been used to increase the survival of flaps prior to surgery.
- The mechanism of delay is discussed in more detail in 'The blood supply to the skin' (p. 7).

Geometry of local flaps**Orientation of elective incisions**

- In the 19th century, Langer showed that circular awl wounds produced elliptical defects in cadaver skin.
- He believed that this occurred because the skin tension along the longitudinal axis of the ellipse exceeded that along the transverse axis.

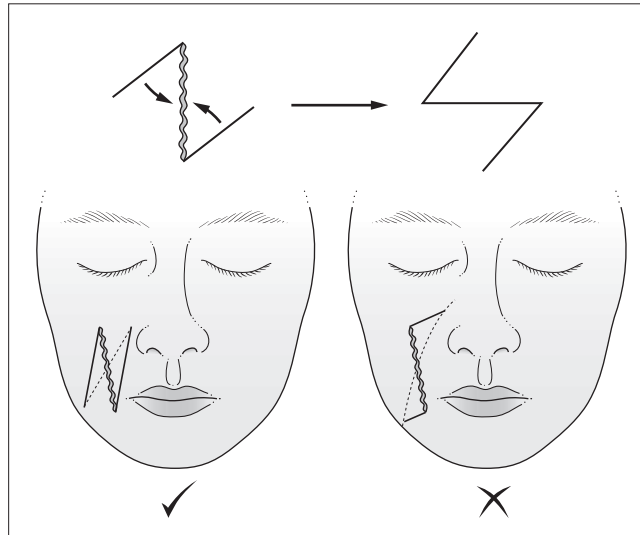
- Borges has provided over 36 descriptive terms for skin lines. These include:
 - Relaxed skin tension lines (RSTLs)—these are parallel to the natural skin wrinkles (rhytids) and tend to be perpendicular to the fibres of the underlying muscle.
 - Lines of maximum extensibility (LMEs)—these lie perpendicular to the RSTLs and parallel to the fibres of the underlying muscle.
- The best orientation of an incision can be judged by a number of methods, including:
 - Knowledge of the direction of pull of the underlying muscle.
 - Ascertaining whether the incision is parallel to any rhytids or RSTLs.
 - Ascertaining whether the incision is perpendicular to the LMEs.
 - Ascertaining whether the incision is parallel to the direction of hair growth.
 - ‘The pinch test’—if the skin is pinched transversely it will form a transverse fold without distortion if it is orientated correctly; if a sigmoid-shaped fold forms it is orientated incorrectly.

Plasty techniques

Z-plasty

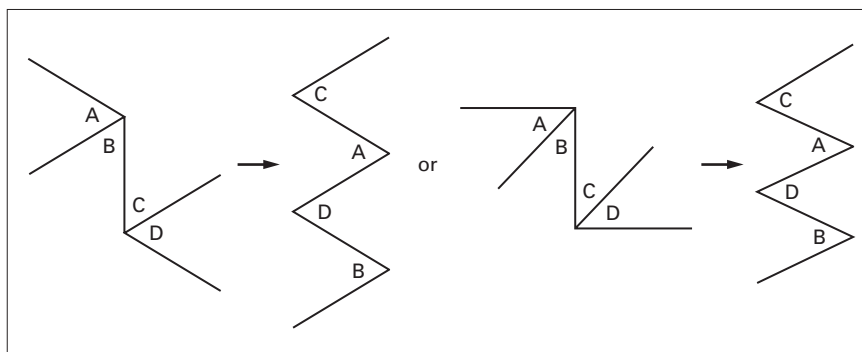
- This technique involves the transposition of two triangular-shaped flaps.
- A Z-plasty can be used to:
 - Increase the length of an area of tissue or a scar
 - Break up a straight-line scar
 - Realign a scar.
- The degree of elongation of the longitudinal axis of the Z-plasty is directly related to the angles of its constituent flaps.
 - 30° → 25% elongation
 - 45° → 50% elongation
 - 60° → 75% elongation
 - 75° → 100% elongation
 - 90° → 125% elongation.
- The amount of elongation obtained for each flap angle can be worked out by starting at 30° and 25% and adding 15° and 25% to each of the figures.
- Gains in tissue length are only estimates and depend on local tissue elasticity and tension.
- Flaps of 60° angulation are most commonly used clinically as they provide sufficient lengthening without undue tension.
- The angles of the two flaps do not need to be equal and can be designed to suit local tissue requirements.
- All three limbs should be of the same length.
- The following steps should be taken when designing a Z-plasty to realign a scar.
 - 1 Mark the desired direction of the scar.
 - 2 Draw the central limb of the Z-plasty along the original scar.
 - 3 Draw the lateral limbs of the Z-plasty from the ends of the central limb to a line along the desired direction of the scar.
 - 4 Two patterns will be available, one with a wide angle at the apex of the flaps, the other with a narrow angle.

- 5 Select the pattern with the narrower angle as these flaps transpose better than those with a wider angle.



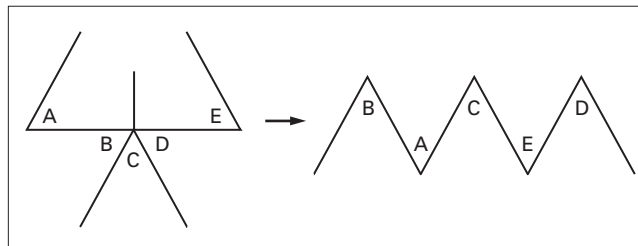
The four-flap plasty

- This technique is used to elongate an area of tissue.
- It is, in effect, two interdependent Z-plasties.
- It can be designed with different angles.
- The two outer flaps become the inner flaps after transposition.
- The two inner flaps become the outer flaps after transposition.
- The flaps, which are originally in an 'ABCD' configuration, end as 'CADB' (CADBury).



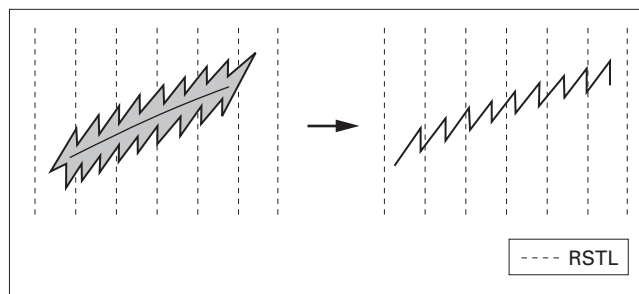
The five-flap plasty

- Because of its appearance this technique is also called a jumping-man flap.
- It is used to elongate tissue and is often utilized clinically to release first web space contractures and epicanthal folds.
- It is, in effect, two opposing Z-plasties with a V-Y advancement in the centre.
- The flaps, which are originally in an ‘ABCDE’ configuration, end as ‘BACED’.



The W-plasty

- This technique is used to break up the line of a scar and improve its aesthetics.
- Unlike the Z-plasty and the four- and five-flap plasties, it does not lengthen tissue.
- If possible, one of the limbs of the W-plasty should lie parallel to the RSTLs so that half of the resultant scar will lie parallel to them.
- This technique involves discarding normal tissue, which may be a disadvantage in certain areas.



Local flaps

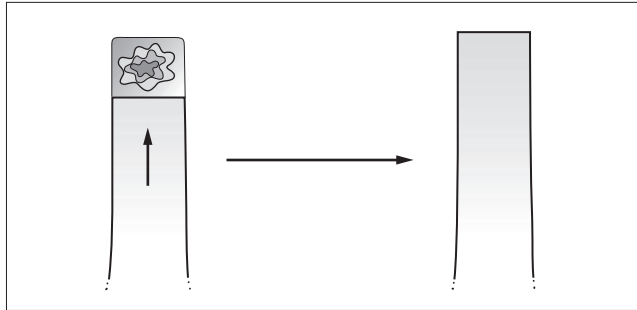
Local flaps may be:

- Advancement flaps (simple; modified; V-Y; or bipediced).
- Pivot flaps (transposition; interpolation; rotation ; or bilobed).

Advancement flaps

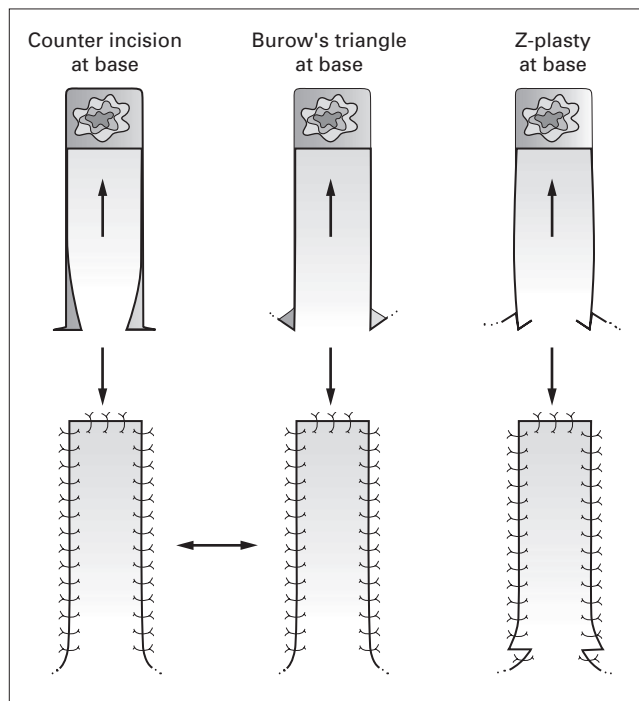
Simple

Simple advancement flaps rely on skin elasticity.

***Modified***

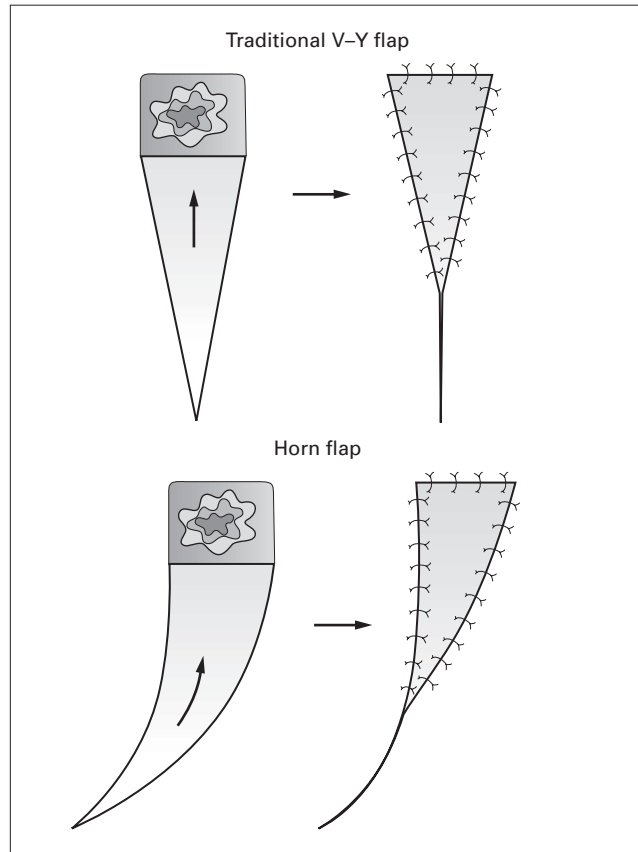
Modified advancement flaps incorporate one of the following techniques at the base of the flap to increase tissue advancement.

- A counter incision
- A Burow's triangle
- A Z-plasty.

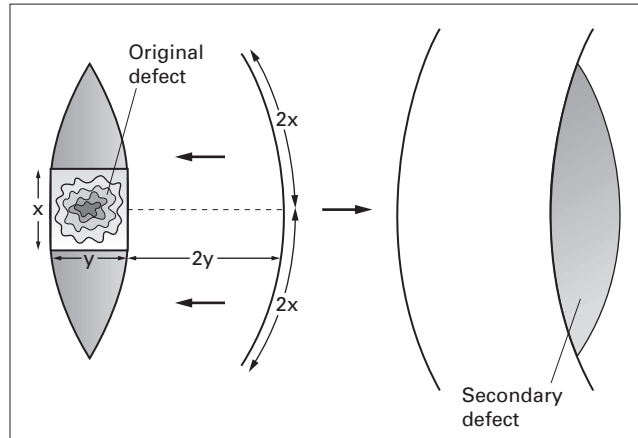


V-Y

- These flaps are incised along each of their cutaneous borders.
- The blood supply to these flaps arises from the deep tissue and passes to the flap through a subcutaneous pedicle.
- Horn flaps and oblique V-Y flaps are modifications of the original V-Y flap.

***Bipedicled***

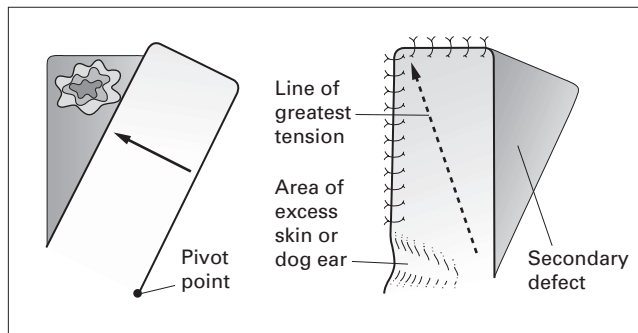
- These flaps receive a blood supply from both ends.
- They are less prone to necrosis than flaps of similar dimensions, which are only attached at one end.
- A commonly used bipedicled flap is the von Langenbeck mucoperiosteal flap, used to repair cleft palates.
- Bipedicled flaps should be designed with their limbs curved parallel to the circumference of the defect.
- This design permits flap transposition with less tension.



Pivot flaps

Transposition flaps

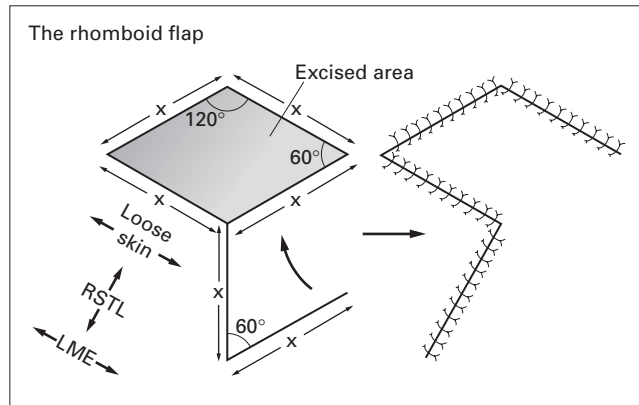
These flaps are transposed into the defect, leaving a donor site which is closed by some other means (often a skin graft).



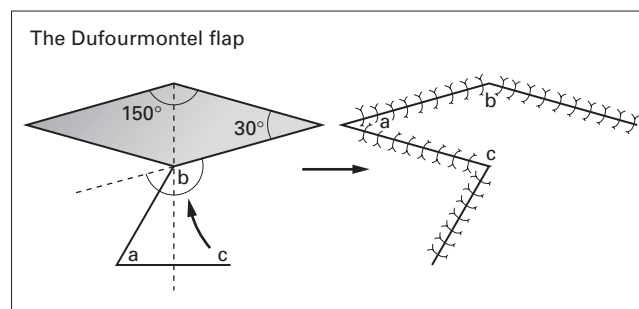
Transposition flaps with direct closure of donor site

- These include the rhomboid flap (Limberg flap) and the Dufourmontel flap.
- These flaps are similar in concept but vary in geometry.
- Both flaps should be designed so as to leave the donor site scar lying parallel to the RSTLs.

The rhomboid flap

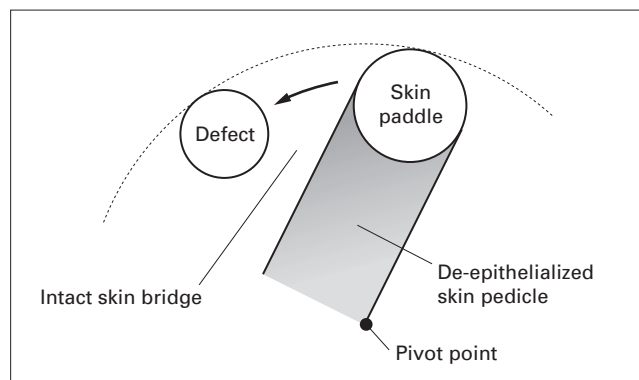


The Dufourmontel flap



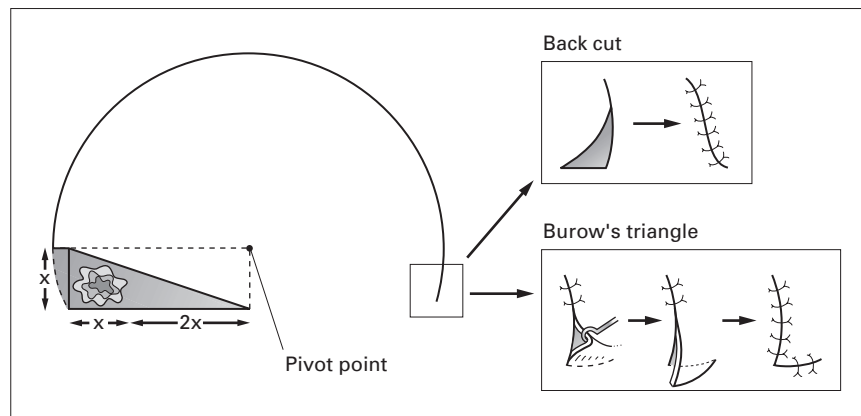
Interpolation flaps

- These flaps are raised from local, but not adjacent, skin.
- The pedicle must therefore be passed either over or under an intervening skin bridge.

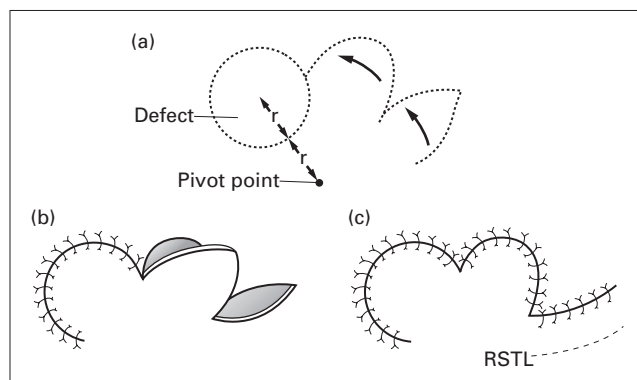


Rotation flaps

- These large flaps rotate tissue into the defect.
- Tissue redistribution usually permits direct closure of the donor site.
- The flap circumference should be 5–8 times the width of the defect.
- Clinically, these flaps are often used on the scalp.
- The back cut at the base of the flap can be directed either towards or away from the defect.

***The bilobed flap***

- Many varied designs of this flap have been described.
- It consists of two transposition flaps.
- The first flap is transposed into the original defect.
- The second flap is transposed into the secondary defect at the original site of the first flap.
- The tertiary defect at the original site of the second flap should be small enough to close directly.
- The flap should ideally be designed so that this suture line lies parallel to the RSTLs.



Wound healing and skin grafts

Wound healing can occur by the following methods.

- Healing by primary intention
 - The skin edges are directly opposed.
 - Healing is normally good with minimal scar formation.
- Healing by secondary intention
 - The wound is left open to heal by a combination of contraction and epithelialization.
 - Increased inflammation and proliferation occur in these wounds when compared with those that heal by primary intention.
- Healing by tertiary intention
 - This occurs in wounds that are initially left open, then closed as a secondary procedure.

Phases of wound healing

Wound healing consists of four phases: (i) haemostasis; (ii) inflammation; (iii) proliferation; and (iv) remodelling.

Haemostasis

- The vessels vasoconstrict immediately after division.
- A platelet plug is then formed.
- The platelets degranulate; platelet-derived growth factor (PDGF) and thromboxanes stimulate the conversion of fibrinogen to fibrin. This stimulates propagation of the thrombus.
- The thrombus is initially pale when it contains platelets alone (white thrombus).
- As red blood cells are trapped within it the thrombus becomes darker (red thrombus).

Inflammation

- This phase occurs in the first 2–3 days after injury.
- Its stimulus may be:
 - Physical injury
 - Antigen–antibody reaction
 - Infection.
- The thrombus releases growth factors such as PDGF.
- Endothelial cells swell, allowing the egress of polymorphonuclear lymphocytes (polymorphs or PMNs) and mononuclear cells (monocytes and macrophages) into the surrounding tissue.

Proliferation

- This phase begins on the 2nd or 3rd day following injury and lasts for 2–4 weeks.
- Macrophages within the tissue release growth factors which are chemoattractant to fibroblasts.
- Fibroblasts which are usually located in perivascular tissue migrate along networks of fibrin fibres into the wound.

- The fibroblasts secrete GAGs and produce collagen and elastin.
- GAGs consist of a protein core surrounded by disaccharide units.
- When hydrated, GAGs become ground substance.

Remodelling

- This phase begins 2–4 weeks after injury, as the proliferative phase subsides.
- During the remodelling phase there is no net increase in collagen (state of collagen homeostasis).
- The extensive capillary network produced in the proliferative phase begins to involute.
- The collagen fibres, which are initially laid down in a haphazard manner, become arranged in a more organized manner.

Function of the macrophage in wound healing

- Macrophages are derived from mononuclear leucocytes.
- They debride tissue and remove micro-organisms.
- They co-ordinate the activity of fibroblasts by releasing growth factors.
- These include interleukin 1 (IL-1), tumour necrosis factor alpha (TNF-alpha) and transforming growth factor beta (TGF-beta).
- Macrophages are essential for normal wound healing.
- Wounds depleted of macrophages heal slowly.

Epithelial repair

This process, whereby epithelial continuity is re-established across a wound, consists of the following four phases.

Mobilization

- 1 Epithelial cells at the wound edges enlarge and flatten.
- 2 They detach from the neighbouring cells and the basement membrane.
- 3 They then move away from adjoining cells.

Migration

- 1 Decreased contact inhibition promotes cell migration.
- 2 The cells migrate across the wound until they meet those from the opposite wound edge.
- 3 At this point, contact inhibition is reinstated and migration ceases.

Mitosis

Epithelial cells begin to proliferate once they have covered the surface of the wound.

Cellular differentiation

- 1 The normal structure of stratified squamous epithelium is re-established.
- 2 The cells differentiate and the layered structure of stratified squamous epithelium is reconstituted.

Collagen

- Collagen constitutes approximately 30% of the total body protein.
- Collagen is formed by the hydroxylation of the aminoacids lysine and proline.
- Procollagen is initially formed within the cell.
- Procollagen is transformed into tropocollagen after it is excreted from the cell.
- Fully formed collagen has a complex structure.
 - It consists of three polypeptide chains wound in a left-handed helix.
 - These three chains are further wound in a right-handed coil to form the basic tropocollagen unit.
- Collagen formation is inhibited by colchicine, penicillamide, steroids, vitamin C and iron deficiency.
- There are at least five types of collagen. Each type of collagen shares the same basic structure but differs in the relative composition of hydroxylysine and hydroxyproline and in the degree of cross-linking between chains.
 - *Type 1*: predominant in mature skin, bone and tendon.
 - *Type 2*: present in hyaline cartilage and the cornea.
 - *Type 3*: present in healing tissue, particularly in fetal wounds.
 - *Type 4*: predominant constituent of basement membranes.
 - *Type 5*: similar to type 4 and also found in the basement membrane.
- The ratio of type 1 collagen : type 3 collagen in normal skin is 5 : 1.
- Hypertrophic and immature scars contain a ratio of 2 : 1 or less.
- 90% of the total body collagen is type 1.

The myofibroblast

- This cell was first identified by Gabbiani in 1971.
- It resembles a fibroblast but differs in that it contains cytoplasmic filaments of α -smooth muscle actin.
- α -smooth muscle actin is also found in smooth muscle.
- The muscle fibres within the fibroblast are thought to be responsible for wound contraction.
- The number of myofibroblasts within a wound is proportional to its contraction.
- Increased numbers of myofibroblasts have been found in the fascia in patients with Dupuytren's disease.
- They are thought to be responsible for the abnormal contraction of this tissue.

TGF- β

- This growth factor is secreted by macrophages. It is believed to play a central role in wound healing and has a number of effects including:
 - Chemoattraction of fibroblasts and macrophages
 - Induction of angiogenesis
 - Stimulation of extracellular matrix deposition.
- Three isoforms of TGF- β have been identified.
 - Types 1 and 2 promote wound healing and scarring.
 - Type 3 decreases wound healing and scarring and in the future may have a role as an anticarring agent.

- TGF- β is not present in fetal wounds and this may be one of the factors responsible for the decreased inflammation and improved scarring observed in this tissue.

Factors affecting healing

Factors affecting wound healing may be: (i) systemic (congenital or acquired); or (ii) local.

Systemic factors: congenital

Pseudoxanthoma elasticum

- This is an autosomal recessive condition.
- It is characterized by increased collagen degradation.
- The skin is pebbled and extremely lax.

Ehlers–Danlos syndrome

- This is a heterogeneous collection of connective tissue disorders.
- It results from defects in the synthesis, structure or cross-linking of collagen.
- Clinical features include:
 - Hypermobility fingers
 - Hyperextensible skin
 - Fragile connective tissues.
- Surgery should be avoided if possible in these patients as wound healing is poor.

Cutis laxa

- This condition presents in the neonatal period.
- The skin is abnormally lax.
- Typically the patient has coarsely textured, drooping skin.

Progeria

- This condition is characterized by premature ageing.
- Clinical features of the condition include:
 - Growth retardation
 - Baldness
 - Atherosclerosis.

Werner syndrome

- This is an autosomal recessive condition.
- Skin changes are similar to scleroderma.
- Elective surgery should be avoided whenever possible as healing is poor.

Epidermolysis bullosa

- This is a heterogeneous collection of separate conditions.
- The skin is very susceptible to mechanical stress.
- Blistering may occur after minor trauma (Nikolsky sign).

- The most severe subtype, dermolytic bullous dermatitis (DBD), results in hand fibrosis and syndactyly.

Systemic factors: acquired

Nutrition

- Vitamin A deficiency delays wound healing.
- Vitamin C is required for collagen synthesis.
- Vitamin E acts as a membrane stabilizer; deficiency may inhibit healing.
- Zinc is a constituent of many enzymes; administration accelerates healing in deficient states.
- Albumin is an indicator of malnutrition; low levels are associated with poor healing.

Pharmacological

- Steroids decrease inflammation and subsequent wound healing.
- Non-steroidal anti-inflammatory drugs (NSAIDs) decrease collagen synthesis.

Endocrine abnormalities

- Diabetics often have delayed wound healing.
- Recent evidence suggests neuropathy rather than small vessel occlusive disease may be responsible for the delayed healing (see 'Leg ulcers', p. 244).

Age

- The rate of cell multiplication decreases with age.
- All stages of wound healing are more protracted in the elderly.
- Healed wounds have decreased tensile strength in the elderly.

Smoking

- Nicotine is a sympathetic stimulant which causes vasoconstriction and consequently decreases tissue perfusion.
- Carbon dioxide, contained in cigarette smoke, shifts the oxygen dissociation curve and reduces tissue oxygenation.

Local factors

Infection

- Subclinical wound infection can impair wound healing.
- Wounds with over 10^5 organisms per gram of tissue are considered infected and are unlikely to heal without further treatment.

Radiation

- Radiation causes endothelial cell, capillary and arteriole damage.
- Irradiated fibroblasts secrete less collagen and extracellular matrix.
- Lymphatics are also damaged, resulting in oedema and an increased risk of infection.

Blood supply

- Decreased tissue perfusion results in decreased wound oxygenation.
- Fibroblasts are oxygen-sensitive and their function is reduced in hypoxic tissue.
- Reduced oxygen delivery to the tissues can result from decreases in:
 - Inspired oxygen concentration
 - Oxygen transfer to haemoglobin
 - Haemoglobin concentration
 - Tissue perfusion.
- Decreased oxygen delivery to the tissue reduces:
 - Collagen formation
 - Extracellular matrix deposition
 - Angiogenesis
 - Epithelialization.
- Hyperbaric oxygen treatment increases the inspired oxygen concentration but its effectiveness relies on good tissue perfusion.

Trauma

The delicate neoepidermis of healing wounds is disrupted by trauma.

Neural supply

- There is some evidence that wounds in denervated tissue heal slowly.
- This may contribute to the delayed wound healing observed in some pressure sores, and in patients with diabetes and leprosy.

Fetal wound healing

- Tissue healing during the first 3 months of fetal life occurs by regeneration rather than by scarring.
- Regenerative healing is characterized by the absence of scarring.
- Regenerative wound healing differs from normal adult healing in the following ways.
 - Inflammation is reduced.
 - Epithelialization is more rapid.
 - Angiogenesis is reduced.
 - Collagen deposition is rapid, not excessive and organized.
 - More type 3 rather than type 1 collagen is laid down.
 - The wound contains a greater proportion of water and hyaluronic acid.
- The lack of TGF- β in fetal wounds may be responsible for some of these differences.

Skin grafts

- Skin grafts are either full or split thickness.
- Split-skin grafts contain a variable amount of dermis and are usually harvested from the thigh or buttock.
- Full-thickness skin grafts contain the entire dermis and are usually harvested from areas with sufficient tissue laxity to permit direct closure of the donor defect.

- Primary contraction is the immediate recoil observed in freshly harvested skin.
- Secondary contraction occurs after the graft is applied to its bed.
- The thinner the graft, the greater the degree of secondary contraction.

Mechanisms

Skin grafts heal in four phases.

Adherence

- Fibrin bonds form immediately on applying a skin graft to a suitable recipient bed.

Serum imbibition

- Skin grafts swell in the first 2–4 days after application.
- This increase in volume results from absorption of fluid (serum imbibition).
- The nutritive value of serum imbibition in maintaining graft viability is debated.

Revascularization

- Vessel ingrowth into skin grafts begins on about the 4th day.
- The mechanism of revascularization is uncertain and may be via:
 - Inosculation—direct anastomosis between the vessels within the graft and those in the recipient tissue.
 - Revascularization—new vessel ingrowth from the recipient tissue along the vascular channels of the graft.
 - Neovascularization—new vessel ingrowth from the recipient tissue along new channels in the graft.

Remodelling

This is the process whereby the histological architecture of the graft returns to that of normal skin.

Reasons for graft failure

Skin grafts fail for the following reasons.

Haematoma

- This is the most common cause of graft failure.
- The risk of haematoma formation is minimized by:
 - Meticulous haemostasis
 - The use of a meshed skin graft which allows blood to escape
 - The application of a pressure dressing.

Infection

- Generally, skin grafts will not take if the bacterial count of the donor site exceeds 10^5 organisms per gram.
- Some organisms such as the beta haemolytic streptococcus can destroy grafts when present in much fewer numbers.

Seroma

Any collection of fluid under the graft reduces the likelihood of its taking successfully.

Shear

- This is a lateral force placed on a graft.
- It results in the disruption of the delicate connections between the graft and its bed and consequently reduces the likelihood of successful graft take.

Inappropriate bed

- Skin grafts will not survive on cartilage, tendon and endochondral bone denuded of periosteum.
- Membranous bone, found in some areas of the skull, will accept a skin graft.
- Grafts on previously irradiated tissue are prone to failure.

Technical error

- An assortment of technical errors can result in graft failure.
- Examples include placing the graft upside down or allowing it to dry out before application.

Bone healing and bone grafts

- All bones are derived from mesenchyme.
 - All are composed of an organic matrix (osteoid) which is mineralized by the calcium salt hydroxyapatite.
- Bones are formed by one of two different mechanisms: (i) intramembranous ossification; or (ii) endochondral ossification.

Intramembranous ossification

- Bones formed by intramembranous ossification include the flat bones of the face, calvarium and ribs.
- Intramembranous ossification occurs by direct deposition of bone within a vascularized membranous template.

Endochondral ossification

- Endochondral bones develop from a cartilage precursor.
- Bones formed by endochondral ossification include all the long bones and the iliac crest.

Bone structure

- All bones have an outer cortical layer and an inner cancellous layer.
- The cancellous portion of membranous bone is found within the diploic space.
- Cancellous bone consists of loosely woven trabeculae made up of organic and inorganic bone.

- Cortical bone consists of:
 - Multiple bone units (osteons), which are composed of a central longitudinal canal (haversian canal) that contains a central blood vessel.
 - The osteons are interconnected by transverse nutrient canals (Volkmann canals).
 - Bone is laid down in concentric layers around each haversian canal.
 - Osteocytes are scattered throughout the osteons.

Blood supply to bone

Blood reaches bone by one of the following routes:

- 1 Periosteal vessels at the sites of muscle attachments
- 2 Apophyseal vessels at the sites of tendon and ligament attachment
- 3 Nutrient arteries supplying the medullary cavity
- 4 Epiphyseal vessels supplying the growth plates.

Bone healing

The phases of bone healing are similar to those of wound healing.

- 1 Haematoma formation
- 2 Inflammation
- 3 Cellular proliferation
 - Periosteal proliferation occurs on the outer aspect of the cortex.
 - Endosteal proliferation occurs on the inner aspect of the cortex.
- 4 Callus formation
 - Callus consists of immature woven bone composed of osteoid laid down by osteoblasts.
 - This osteoid is mineralized with hydroxyapatite.
- 5 Remodelling
 - The cortical structure and medullary cavity are restored.

Primary healing

- This occurs if bone is rigidly fixed with direct apposition of the bone ends.
- Primary bone healing is characterized by restoration of the normal bone structure.
- The inflammatory and proliferative phases of bone healing do not occur.
- Callus is not formed.

Secondary healing

- This occurs if the fragments are not rigidly fixed, or if a gap exists between the bone ends.

Complications of fractures

These include:

- Delayed union
- Non-union
- Mal-union
- Infection

- Avascular necrosis (AVN)
- Shortening
- Damage to adjacent structures.

Bone graft healing

Bone grafts heal by the following mechanisms.

Incorporation

- This is adherence of the graft to the host tissue.
- Incorporation is maximized in immobilized, well-vascularized tissue.

Osseointegration

- The bone graft acts as a scaffold along which vessels and osteoprogenitor cells travel.
- Old bone is absorbed as new is deposited.
- This process is also known as creeping substitution.

Osseoinduction

- This is the differentiation of mesenchymal cells within the local tissue into osteocytes.
- Osteoclasts, osteoblasts and osteocytes within the bone graft are not capable of mitosis.
- The increased numbers of these cells within the bone graft are derived from the mesenchymal tissue of the recipient site.
- Osseoinduction is controlled by bone morphogenic proteins (BMPs).

Osteogenesis

- This is the formation of new bone by surviving cells within the bone graft.
- It is the predominant mechanism by which new bone is formed in vascularized bone grafts.
- Osteogenesis does not occur to a significant degree in non-vascularized bone grafts.

Survival of bone grafts

Factors influencing the survival of bone grafts can be divided into three groups: (i) systemic factors; (ii) intrinsic graft factors; and (iii) factors relating to the placement of the graft.

Systemic factors

These are similar to those affecting wound healing and include:

- Age
- Nutrition
- Immunosuppression
- Drugs
- Diabetes
- Obesity.

Intrinsic graft factors

- Bone grafts with intact periosteum undergo less absorption than those stripped of this covering.
- Membranous bone undergoes less absorption than endochondral bone when used as an onlay graft in the facial skeleton.

Graft placement factors*Orthotopic or heterotopic placement*

- Orthotopic—graft is placed into a position normally occupied by bone.
- Heterotopic—graft is placed into a position not normally occupied by bone.
- Grafts placed into an orthotopic position are less prone to absorption.

Quality of the recipient bed

- Radiotherapy, scarring and infection adversely affect graft survival.

Graft fixation

- Rigidly fixed grafts survive better than those that are mobile.

Site of graft placement

- Grafts survive better in areas in which bone is normally laid down (depository sites).
- These sites include areas such as the zygoma and mandible in the child.

Nerve healing and nerve grafts**Nerve anatomy and function**

- Nerve cells (neurons) consist of a cell body from which nerve fibres project.
- Efferent nerve fibres are called axons.
- Afferent nerve fibres are called dendrites.
- The endoneurium surrounds individual nerve fibres or axons.
- The perineurium surrounds groups of nerve fibres (fascicles).
- The epineurium surrounds a group of fascicles to form a peripheral somatic nerve.
- Schwann cells produce a multilaminated myelin sheath in myelinated nerves.
- Unmyelinated nerves are surrounded by a double layer of basement membrane.
- In myelinated nerves, adjacent Schwann cells abut at the nodes of Ranvier.
- Nerve conduction involves the passage of an action potential along a nerve.
- In myelinated nerves, this is via saltatory conduction between adjacent nodes of Ranvier.

Nerve fibres are subdivided into the following groups.

- *Group A*
 - Group A-alpha fibres conduct motor and proprioceptive impulses.
 - Group A-beta fibres transmit pressure and proprioceptive impulses.
 - Group A-gamma fibres conduct motor impulses to the muscle spindles.
 - Group A-delta fibres transmit touch, pain and temperature impulses.

- *Group B*
 - These fibres are found in myelinated, preganglionic autonomic nerves.
- *Group C*
 - These fibres are found in myelinated, postganglionic autonomic nerves.

Medical Research Council grading of nerve function

The MRC have recommended the following grading of nerve function.

Motor function		Sensory function	
M0	No contraction	S0	No sensation
M1	Flicker	S1	Pain sensation
M2	Movement with gravity eliminated	S2	Pain and some touch sensation, possible hypersensitivity
M3	Movement against gravity	S3	Pain and touch with over-reaction
M4	Movement against gravity and resistance	S3+	Some 2-point discrimination
M5	Normal	S4	Normal

Injury

- After transection of a nerve, traumatic degeneration occurs proximally as far as the last node of Ranvier.
- Distally, nerves undergo wallerian degeneration.
- This process was described by Waller in 1850 and consists of:
 - Degeneration of axons and myelin which are then phagocytosed by macrophages and Schwann cells.
 - Collapsed columns of nerve cells develop a bandlike appearance on electron microscopy; these are known as the bands of Buengner.
- Neurotropism is selective, directional growth of nerve fibres towards their appropriate receptors.
- It is mediated by nerve growth factors and consists of the following stages.
 - 1 The proximal nerve stump sprouts many new fibres.
 - 2 Fibres growing in an inappropriate direction atrophy.
 - 3 Those growing in the correct direction survive and grow.
- Neurotropism is non-selective, non-directional growth of nerve fibres.
- Factors which mediate neurotropism include growth factors, extracellular matrix components and hormones.

Classification of nerve injury

- The degree of nerve injury has been classified by both Seddon and Sunderland.
- Seddon classified nerve damage into three groups:
 - 1 Neurapraxia
 - 2 Axonotmesis
 - 3 Neurotmesis.
- Sunderland expanded this classification to five groups.

- **First-degree injury**
 - The axon remains in continuity although conduction is impaired.
 - Recovery should be complete.
- **Second-degree injury**
 - Axonal injury occurs and the segment of nerve distal to the site of damage undergoes wallerian degeneration.
 - All connective tissue layers remain intact and recovery should be good.
- **Third-degree injury**
 - The axon and endoneurium are divided.
 - The perineurium and epineurium remain intact.
 - Recovery should be reasonable.
- **Fourth-degree injury**
 - Complete division of all intraneural structures occurs.
 - The epineurium remains intact.
 - Recovery of some function is expected.
 - This injury may result in neuroma-in-continuity.
- **Fifth-degree injury**
 - The nerve trunk is completely divided.

A sixth-degree injury is added by some to the classification, although it was not described by Sunderland.

 - This stage consists of a mixed pattern of nerve injury with segmental damage.
 - Seddon's classification of neurapraxia equates to a Sunderland first-degree injury.
 - Axonotmesis equates to a second-, third- or fourth-degree injury.
 - Neurotmesis equates to a fifth-degree injury.

Nerve repair

- Nerve repair should be performed by direct approximation of the divided stumps whenever possible.
- The ends of the nerve should be trimmed and an epineural repair performed with fine sutures, under magnification.
- Attempts should be made to correctly align the fascicles of the nerve trunks.
- The repair should not be under undue tension.
- Some authorities maintain that primary repair should only be performed in cases in which a single 8/0 suture is strong enough to oppose the divided nerve ends.

Fascicular identification

The following methods can be used to aid fascicular matching during nerve repair.

Matching of anatomical structures during repair

Anatomical guides to the correct orientation of the nerve stumps include:

- The size and orientation of the fascicles
- The distribution of the vessels on the surface of the nerve.

Electrical stimulation

- Motor nerves respond to electrical stimulation for approximately 72 h following division.
- Electrical stimulation of the distal nerve stump during this period can be used to differentiate motor from sensory fibres.
- Awake stimulation of the nerves can be used to differentiate motor from sensory fibres in the proximal nerve stump.
- Electrical stimulation of sensory fibres produces sharp pain.
- Similar stimulation of motor fibres is felt as a dull ache.

Knowledge of internal nerve topography

- The fascicular layout of many nerves is known and can be used to aid accurate repair.
- Ulnar-nerve motor fascicles lie centrally between the volar sensory branches coming from the palm and the dorsal sensory branches coming from the dorsum of the hand.

Nerve grafts

- Nerve grafts are required if primary nerve repair is not possible without undue tension.
- If the divided nerve is large, multiple cables of a smaller donor nerve may be required to bridge the defect.
- It may be possible to reduce the tension across the repair by mobilizing the nerve stumps proximally or distally.
- Methods by which extra nerve length can be obtained by proximal dissection include:
 - Transposition of the ulnar nerve at the elbow.
 - Intratemporal dissection of the facial nerve.
- Materials used to bridge nerve gaps are either autologous or synthetic.
- Of these, autologous nerve is the best material for bridging nerve gaps at present.

Composition

- Autologous tissues that can be used as nerve grafts include:
 - Fresh nerve
 - Freeze-thawed muscle
 - Segments of vein.
- Synthetic nerve grafts composed of fibronectin mats impregnated with growth factors may be available in the future.

Autologous grafts

The following nerves can be used as autologous grafts.

Sural nerve

- This nerve passes behind the lateral malleolus.
- Proximally it divides into the medial sural nerve and the peroneal communicating branch.

- Graft lengths of up to 30–40 cm are available in the adult.
- Endoscopic harvesting has been reported; this produces less scarring.

Lateral antebrachial cutaneous nerve

- This nerve lies adjacent to the cephalic vein alongside the ulnar border of the brachioradialis.
- Graft lengths of up to 8 cm in length are available.
- Removal of this nerve results in only a limited loss of sensation due to cutaneous sensory overlap.

Medial antebrachial cutaneous nerve

- This is located in the groove between triceps and biceps, alongside the basilic vein.
- Distally, it divides into anterior and posterior branches.
- Graft lengths of up to 20 cm are available.

The terminal branch of the posterior interosseous nerve

- This nerve is useful for bridging small defects in small diameter nerves.
- It is located in the radial side of the base of the fourth extensor compartment at the wrist.
- Only a relatively short length of nerve graft is available.

Principles

The following principles are universal to all nerve grafts.

- Both nerve ends should be trimmed back to healthy tissue.
- The graft should be placed in a healthy vascular bed.
- Tension on the graft should be avoided.
- The level of repair should be staggered between the separate cables.
- Wherever possible, the cables should be separated from one another as they bridge the defect.

Tendon healing

Anatomy

- Tendons are composed of dense, metabolically-active connective tissue.
- Within their substance, collagen bundles are arranged in a regular spiraling fashion.
- The collagen is predominantly type 3 with a small amount of type 1.
- Tendons contain few cells; those that are present include:
 - Tenocytes
 - Synovial cells
 - Fibroblasts.
- Endotendon surrounds tendons whilst they lie within synovial sheaths.
- Paratendon is a loose adventitial layer that surrounds tendons outside synovial sheaths.

- Verdan described five zones of flexor tendon injury.
 - *Zone 1*: distal to the insertion of flexor digitorum superficialis (FDS).
 - *Zone 2*: between the proximal end of the flexor sheath and the insertion of FDS.
 - *Zone 3*: between the distal edge of the flexor retinaculum and the proximal end of the flexor sheath.
 - *Zone 4*: under the flexor retinaculum.
 - *Zone 5*: proximal to the flexor retinaculum.
- *Zone 2* was described as ‘no man’s land’ by Bunnell because of the poor results of flexor tendon repair at this site.
- Tendon repair in this area is complicated by the fact that the superficial and deep flexors are in close approximation within a tight sheath.
- Extensor tendons are subdivided into eight zones.
 - *Zone 1*: over the distal interphalangeal joint (DIPJ).
 - *Zone 2*: between the proximal interphalangeal joint (PIPJ) and the DIPJ.
 - *Zone 3*: over the PIPJ.
 - *Zone 4*: between the metacarpophalangeal joint (MCPJ) and the PIPJ.
 - *Zone 5*: over the MCPJ.
 - *Zone 6*: between the MCPJ and the extensor retinaculum.
 - *Zone 7*: under the extensor retinaculum.
 - *Zone 8*: between the extensor retinaculum and the musculotendinous junction.
- The odd-numbered zones are located over the joints.
- The first five zones are in the finger.

Mechanisms of tendon healing

Extrinsic healing

- Extrinsic healing is dependent on fibrous attachments forming between the tendon sheath and the underlying tendon.
- Historically this was believed to be the sole mechanism by which tendons healed.
- This led to the development of post-operative protocols which immobilized the tendons in the mistaken belief that this maximized tendon repair.

Intrinsic healing

- Intrinsic tendon healing is dependent on:
 - Bloodflow through the long and short vinculae.
 - Diffusion from the synovial fluid.
- Lunborg showed that tendons heal when wrapped in a semipermeable membrane and placed in the knee joint of a rabbit.
- Enclosing the tendons in semipermeable membrane stimulates intrinsic healing as it permits the passage of nutrients but not cells.
- Awareness of the ability of tendons to heal by intrinsic mechanisms has led to the development of post-operative protocols which include early mobilization.

Phases of tendon healing

These are similar to those of wound healing.

Inflammation

- This occurs in the first 2–3 days following tendon injury.
- Inflammatory cells infiltrate the wound.
- These cells secrete growth factors which attract fibroblasts.

Proliferation

- This starts 2–3 days after tendon injury and lasts approximately 3 weeks.
- Fibroblasts are responsible for tissue proliferation.
- They manufacture and secrete collagen and GAGs.
- Collagen is initially arranged randomly, consequently the tendon lacks tensile strength.

Remodelling

- This begins approximately 3 weeks following tendon injury.
- It is characterized by collagen homeostasis (the net amount of collagen in the wound remains stable).
- The structure of the tendon differentiates into an organized structure.
- Early motion of the tendon limits the formation of fibrous attachments between itself and the tendon sheath.
- Early motion promotes intrinsic healing at the expense of extrinsic healing.
- Mobilized tendons are stronger than immobilized tendons.

Techniques of repair

Many methods of tendon repair have been described. The following principles apply to most techniques.

- The number and size of the incisions in the flexor sheath should be minimized.
- The A2 and A4 pulleys should be preserved wherever possible.
- Any incision in the sheath should be made between the annular pulleys.
- The tendon ends should be touched as little as possible to protect their delicate covering and reduce the risk of adhesion formation.
- The epitendinous suture in the posterior wall is usually performed first to correctly align the tendon.
- This suture should be inverting and is generally continuous.
- Many designs of core suture have been described, amongst the more commonly used are the:
 - Bunnell stitch
 - Kessler stitch
 - Modified Kessler stitch.
- These suture patterns are usually self locking.
- Two or four strands of core suture are usually used to bridge the gap between the tendons.
- The tendon sheath should be reconstructed when possible but may be left unrepaired in part, if it involves compromising tendon glide.
- In tendon grafts and transfers, the extra length of available tendon allows the ends to be woven into each other, rather than be repaired end-to-end.

- Tendon weaves are more secure than end-to-end repairs.
- The technique most commonly used was described by Pulvertaft and is known as the Pulvertaft weave.
- In this technique the tendons are woven together by passing their ends through three or four longitudinal slits in the body of the other tendon.

Rehabilitation following repair of flexor tendons

- Until relatively recently, tendons were immobilized post-operatively.
- There is now a trend towards earlier mobilization.
 - The post-operative rehabilitation regimens may consist of the following.

Immobilization

Immobilization is used mainly in children and adults considered unsuitable for early mobilization.

Early passive mobilization

- This involves regular passive motion of the joints.
- No active movement is permitted.

Early active extension with passive flexion

- This regimen was advocated by Kleinert *et al.*
- A dorsal splint protects against hyperextension.
- Finger flexion is maintained by rubber-band traction.
- The rubber bands are attached to the fingernail and the volar aspect of the splint.
- Active extension can occur against the elastic recoil of the bands.
- Passive flexion occurs by the elastic recoil of the bands.

Early active mobilization

- The 'Belfast' regimen is widely used.
- This involves the fitting of a dorsal splint which leaves the fingers free to flex.
- The splint should hold the wrist between neutral and 30° of flexion.
- It should limit MCP extension to 70° of flexion.
- It should limit hyperextension of the interphalangeal joints (IPJs) beyond the neutral position.
- The fingers are left free on their volar surfaces.
- Active mobilization is started in the early post-operative period. This consists of the following three elements.

Passive flexion

This mobilizes the joints and prevents their contraction.

Passive flexion and hold

- This produces an isometric force on the proximal muscle bellies.
- This helps to maintain their function.

Active flexion

- This results in tendon glide within the flexor sheath.
- It limits the formation of fibrous attachments and increases the rate of intrinsic healing.
- The strength of the tendon repair is increased by early active flexion.

Transplantation

- Transplantation is the movement of tissue from one body location to another.
- Orthotopic transfers are transplants into an anatomically similar site.
- Heterotopic transfers are transplants into an anatomically different site.

The following types of transplantation are available.

Autografts

- This is transplantation of tissue from one location to another within the same individual.
- It includes all flaps and grafts.
- Flaps carry with them some intrinsic blood supply; grafts do not.

Isografts

This is transplantation of tissue between genetically identical individuals.

Allografts

- These are also called homografts.
- This is transplantation between different individuals of the same species.

Xenografts

- These were previously called heterografts.
- This is transplantation between individuals of differing species.

Transplant immunology

History

- Gibson and Medawar did much of the pioneering work on transplant immunology in the 1940s and 1950s.
- They described the second set phenomenon, which they defined as ‘the accelerated rejection of allogenic tissue due to the presence of humoral antibodies from prior exposure to the same allogenic source’.
- The first set reaction occurs when a skin allograft is applied to an individual for the first time.
- The first set reaction is characterized by the following stages.
 - 1** During the first 1–3 days, allografts behave in a similar fashion to autografts in that they develop dilated capillaries with no blood flow.
 - 2** Between 4 and 7 days, the grafts are infiltrated by leucocytes and thrombi, and punctate haemorrhages appear within their vessels.

3 Between 7 and 8 days, blood flow ceases and the skin graft undergoes necrosis.

- The second set reaction occurs in patients who have been previously grafted with the same allograft material.
- The second set reaction is characterized by the following stages.
 - 1** Immediate hyperacute rejection.
 - 2** The graft never undergoes any revascularization and has been termed a 'white graft'.

Immunology

- Rejection occurs when the host immune system recognizes foreign antigens.
- Foreign antigens are from the major histocompatibility complex (MHC).
- In humans these are known as human leucocyte antigens (HLAs).
- HLAs are six closely linked genes on the short arm of chromosome 6 and are divided into two classes.
 - *Class 1*: includes HLAs A, B and C which are found on all nucleated cells and platelets.
 - *Class 2*: includes HLAs DR, DQ and DP which are found on monocytes, macrophages and both B and T lymphocytes.
- HLAs, A, B and DR are the most important mediators of tissue rejection.
 - Antigen-presenting cells (APCs), such as macrophages, pick up HLAs from allograft tissue and present them to the host immune system.
 - APCs can be of:
 - Donor origin (known as direct presentation)
 - Host origin (known as indirect presentation).
- The host immune system reacts by:
 - Increasing production of IL-1 and IL-2.
 - This causes a rapid clonal expansion in the numbers of T and B lymphocytes within lymphoid tissue.
- Graft destruction is produced in the following ways:
 - 1** Direct destruction
 - This is mediated by the cellular system.
 - CD4 and CD8 cytotoxic T cells cause damage to the graft.
 - 2** Indirect destruction
 - This is mediated by the humoral system.
 - Stimulated B lymphocytes produce an antibody that binds with the antigen and stimulates tissue destruction via the complement system.

Xenografts

- In transplants between species, natural antibodies often exist without prior sensitization.
- If natural antibodies are present, hyperacute rejection results, occurs secondary to complement activation.
- Concordant transplantation occurs when natural antibodies between species are not present, e.g. primate to human.

- Discordant transplantation occurs when natural antibodies are present, e.g. pig to human.

Immunosuppression

Immunosuppressive techniques can be subdivided into non-specific and specific modalities. Non-specific techniques of immunosuppression include the following.

Radiation

- Whole-body radiation removes mature lymphocytes.
- This technique is not used in humans.
- Localized lymphoid-tissue irradiation is more specifically targeted.
- Graft irradiation aims to try and reduce its antigenicity.

Drugs

- Steroids have an anti-inflammatory and immunosuppressive action.
- Azathioprine downgrades the lymphocyte-activation cascade.
- Cyclosporin is a fungus derivative, isolated in 1976.
- Cyclosporin inhibits the production of IL-2.

Biological agents

- Anti-lymphocyte serum is made by injecting another species with lymphoid tissue from the recipient.
- The anti-lymphocyte antigens produced are powerful suppressers of T-cell activity.

One specific technique of immunosuppression is the administration of monoclonal anti-T-lymphocyte antibodies. In the future, monoclonal antibodies may be available to down-regulate specific parts of the immune response.

Alloplastic implantation

The ideal implant should be:

- 1 Non-allergenic, causing a minimal soft tissue reaction.
- 2 Strong and fatigue resistant.
- 3 Resistant to reabsorption, corrosion or deformation.
- 4 Non-supportive of growth of micro-organisms.
- 5 Radiolucent.
- 6 Cheap.
- 7 Readily available.

Classification

Implants may be classified into:

- Liquids (silicone, collagen preparations, hyaluronic acid preparations)
- Solids (metals, polymers, ceramics).

Liquids

Silicone

- Silicon is an element.
- Silica is silicone oxide and is the main constituent of sand.
- Silicone consists of interlinked silicon and oxygen molecules with methyl, vinyl or phenol side groups.
- Short polymer chains produce a viscous liquid.
- Long polymer chains produce a firmer, cohesive gel.
- Cross-linking of the chains produces solid silicone.
- Silicon is biologically inert but elicits a mild foreign-body reaction with subsequent capsule formation.
- Synovitis can occur when silicone prostheses are used in joint arthroplasty.
- Bioplastique consists of textured silicone-rubber microparticles mixed with water in a hydrogel carrier.

There has been much debate as to whether silicone implantation is associated with an increased risk of developing connective tissue diseases.

- Extensive reviews of the safety of silicone have been performed:
 - In the USA by the Institute of Medicine (IOM) of the National Academy of Science
 - In the United Kingdom by the Independent Review Group.
- Both of these reviews concluded that there was no evidence that silicone implants were responsible for any major diseases.
- The findings of these groups are discussed in more detail in 'Plastic surgery of the breast and chest wall. Breast augmentation', see pp. 177–8.

Collagen preparations

Zyderm 1

- This is made from sterilized, fibrillar bovine collagen.
- It is composed of 95% type 1 collagen and 5% type 3 collagen.
- The collagen concentration is 35 mg/mL.
- It is administered via injection and is used for treating fine, superficial wrinkles.

Zyderm 2

- This has a similar collagen composition to *Zyderm 1*.
- The collagen concentration is higher, at 65 mg/mL.
- It is used to treat coarser wrinkles.
- Absorption of the water carrier from both *Zyderm 1* and *Zyderm 2* reduces their injected volume by approximately 30%.
- Soft-tissue defects should therefore be overcorrected initially.

Zyplast

- This is formed by cross-linking the collagen with glutaraldehyde.
- It is firmer than either *Zyderm 1* or *Zyderm 2*.

- It is used to treat deep dermal defects and coarse rhytids.
- Little reabsorption occurs 50 overcorrection is not recommended.

Hyaluronic acid preparations

- A number of preparations, such as Restylane and Perlane, composed of synthetically manufactured hyaluronic acid are now available.
- Average absorption rates are 20%–50% of the original volume by 6 months.
- These preparations are typically injected superficially, to treat wrinkles or increase lip definition.

Solids

Metals

Stainless steel

- Stainless steel is an alloy of iron, chromium and nickel.
- It has a relatively high incidence of corrosion and implant failure.
- Galvanic currents set up between screws and the plates can result in corrosion.

Vitalium

- Vitalium is an alloy of chromium, cobalt and molybdenum.
- It has a higher tensile strength than either stainless steel or titanium.

Titanium

- Titanium is a pure material and not an alloy.
- It is more malleable and less prone to corrosion than either stainless steel or vitalium.
- In addition, it is less likely to produce an artefact on MRI or CT scanning.

Gold

- Gold is resistant to corrosion but has a low tensile strength.
- It is used primarily as an upper-eyelid weight to facilitate eye closing in facial palsy.

Polymers

Polyurethane

- This polymer induces an intense foreign-body reaction followed by tissue adhesion.
- Breast implants covered with polyurethane foam have a low rate of capsular contracture.
- Breakdown products of polyurethane include toluene-diamine dimers.
- Concern over the risk of carcinogenesis from the build-up of these dimers has resulted in withdrawal of these breast implants.

Fluorocarbons

- Bonding between fluorine and carbon results in an extremely stable biomaterial.
- No human enzyme can break the bond between the two substances.

Proplast 1

- This is a black composite of Teflon and carbon.
- It is used for facial bony augmentation.

Proplast 2

- This is a white composite of Teflon and aluminium oxide.
- It is used for more superficial augmentation.
- A high rate of complications (infection, extrusion, etc.) with proplast temporomandibular joint (TMJ) implants resulted in its withdrawal from the market in the USA.

Goretex

- This is a sheet of expanded polytetrafluoroethylene (PTFE).
- It is soft and very strong.
- PTFE has been used as a vascular prosthesis since 1975.
- Goretex has been approved for facial implantation in the USA since 1994.

Polyethylene

- This material has a simple carbon chain structure and, unlike the fluorocarbons, does not contain fluorine.
- It is available in three grades:
 - 1 Low density
 - 2 High density
 - 3 Ultra-high molecular weight.
- Medpor is high-density, porous polyethylene.
- It is commonly used for augmenting the facial skeleton.
- It elicits very little foreign-body reaction.
- Some soft tissue ingrowth does occur—this acts to stabilize the implant.
- Medpor implants are available in a variety of preformed shapes.
- Ultra-high molecular weight polyethylene is used in the fabrication of load-bearing orthopaedic implants.

Polypropylene

- Polypropylenes have a similar structure to polyethylenes.
- They differ by containing a methyl group instead of a hydrogen atom in each unit of the polymer chain.
- Marlex polypropylene mesh has high tensile strength and allows early tissue ingrowth.

Methylmethacrylate

- This is a self-curing acrylic resin.
- It is used for:
 - Securing artificial joint components
 - Craniofacial bone augmentation
 - Fabrication of gentamicin-impregnated beads.
- It is available in two forms:
 - 1 As a paste that dries, forming a solid block
 - 2 As preformed implants.
- Methylmethacrylate elicits an exothermic reaction during drying.
- When used for calvarial remodelling, it is important to cool the methylmethacrylate to avoid soft-tissue burn.

Cyanoacrylate

- This is the main constituent of superglue.
- It is a strong, biodegradable tissue adhesive.
- Clinically, it is used for:
 - Opposing skin edges
 - Securing skin grafts
 - Securing nails to their underlying beds.
- It is particularly useful for repairing simple lacerations in children, as it avoids the pain associated with suturing.

Ceramics***Hydroxyapatite***

- This is the major inorganic constituent of bone.
- It is produced by corals and is available in block, granule or cement form.
- Hydroxyapatite is osseoconductive, allowing creeping substitution.
- It has no osseoinductive or osteogenic properties.
- BoneSource is hydroxyapatite cement.
- When mixed with water and a drying agent, this material forms a paste which rapidly hardens.
- Clinically it is used for:
 - Inlay calvarial remodelling
 - Onlay calvarial remodelling
 - Augmentation of the facial skeleton.
- Inlay calvarial remodelling is the replacement of the full thickness of the skull.
- Onlay calvarial remodelling is the replacement of a portion of the outer thickness of the skull.

Other ceramics

Other alloplastic ceramics include:

- Calcium sulfate (plaster of Paris)
- Calcium phosphate.

Wound dressings

There is little concrete evidence that any one dressing is better than another. The ideal wound dressing should:

- 1 Protect the wound physically
- 2 Be non-irritant
- 3 Remove necrotic material
- 4 Promote epithelialization
- 5 Promote granulation
- 6 Be cheap and readily available.

Classification

Wound dressings can be broadly classified into the following groups.

Low-adherent dressings

- Melolin is gauze with polyethylene backing.
- Inadine is a rayon mesh impregnated with povidone-iodine.
- Paraffin gauze-based dressings include:
 - Jelonet
 - Bactigras (paraffin gauze impregnated with chlorhexidine).

Semipermeable films

- Semipermeable films are:
 - Permeable to gases and vapour
 - Impermeable to liquids and bacteria.
- Omniderm is a polyurethane film without an adhesive backing.
- Opsite and Tegaderm are polyurethane films with adhesive backing.

Hydrogels

- Hydrogels are composed of a starch-polymer matrix which swells to absorb moisture.
- They promote autolysis of necrotic material and are principally used to debride wounds.

Hydrocolloids

- This dressing is composed of a hydrocolloid matrix backed with adhesive.
- It physically protects the wound while absorbing fluid and maintaining a moist environment.
- Examples include:
 - Granuflex
 - Duoderm.

Alginates

- These substances are derived from seaweed.
- They contain calcium which activates the clotting cascade when exchanged with sodium within the wound.

- They are very absorbent and become gelatinous upon absorbing moisture.
- Examples include:
 - Sorbisan
 - Kaltostat.

Synthetic foams

- These foams are usually used in concave wounds.
- They conform to the cavity, obliterating dead space.
- They are suitable for heavily exudating wounds.
- An example of this type of dressing is Lyofoam.

Vacuum-assisted wound closure

- It has recently been discovered that the application of suction to a wound speeds its healing.
- The mechanism by which this occurs is uncertain.
- Possible mechanisms include:
 - A direct suction effect on the wound edges and base, pulling the wound inwards.
 - An increase in the rate of angiogenesis and the formation of granulation tissue.
 - A reduction in the concentration of tissue metalloproteinases.
 - A decrease in the bacterial contamination of the wound.
 - A decrease in the interstitial fluid content of the wound.
- Suction is applied to the wound in the following manner.
 - 1 The wound is covered with a non-adherent, sponge dressing containing the end of a suction tube.
 - 2 The wound is then sealed with a semipermeable, adhesive film.
 - 3 Intermittent or continuous suction is then applied to the wound from a specifically designed machine.
- Suction pressures are usually set at approximately 120 mmHg for acute wounds and 50–70 mmHg for chronic wounds.

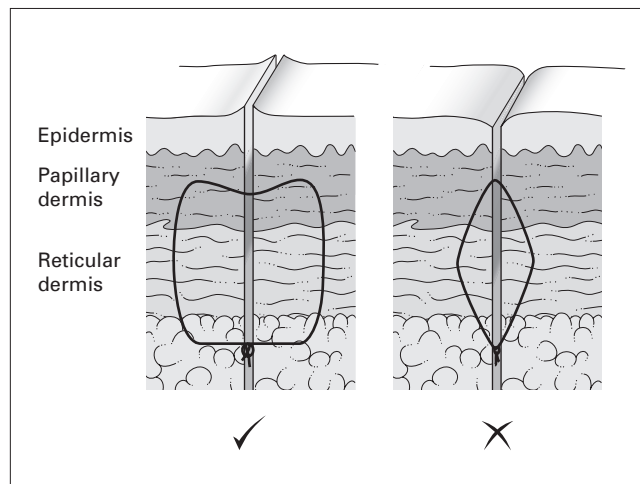
Sutures and suturing

Suturing

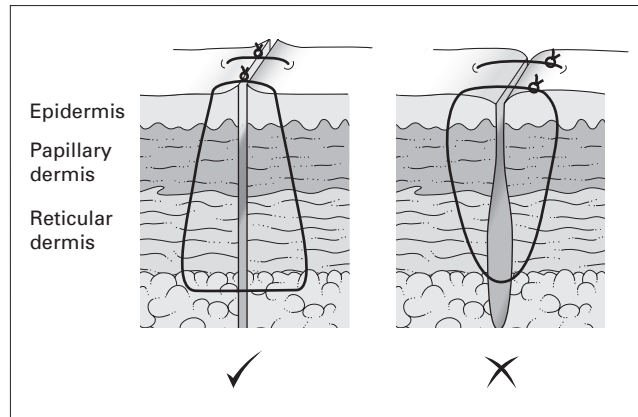
- The skin edges should always be everted when suturing is complete.
- This results in:
 - Better dermal apposition
 - Improved healing
 - A finer final scar.
- Most wounds are closed by first opposing the skin edges with a dermal suture.
- This reduces the tension on the subsequent cutaneous suture and helps to limit stretching of the wound.

Dermal suture

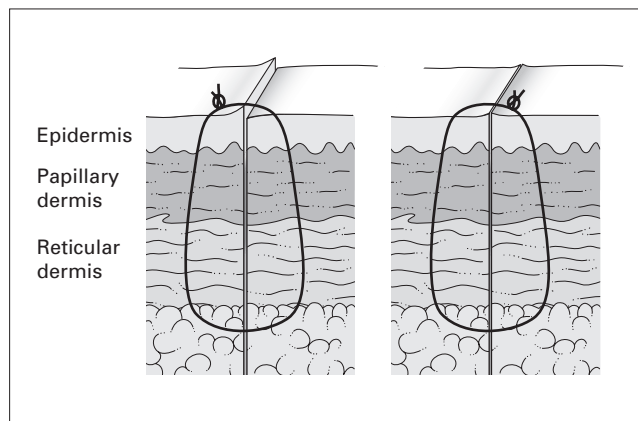
- The dermal suture should enter the deep reticular dermis on the incised edge of the wound.
- It should then pass superficially into the papillary dermis.
- The knot should be tied deeply to prevent subsequent exposure of the suture.
- This method of suture placement produces good apposition and eversion of the skin edges.
- If one side of the wound is longer than the other, the suture should be passed more superficially on the long side and deeper on the short side.
- Passing the suture in this way tends to gather up the longer side, allowing neater wound closure.

**Cutaneous suture**

- The aim of this suture is to accurately appose and evert the skin edges.
- The following may be helpful in achieving this.
 - When viewed in a cross-section, the suture passage should be triangular-shaped with its base located deeply—this will evert the wound edges.
 - A triangular-shaped suture passage with the base located superficially tends to invert the wound edges.



- If one of the wound edges lies lower than the other, the suture should be passed through the cut edge of the skin low on that side ('low-on-the-low').
- If one of the wound edges lies higher than the other, the suture should be passed through the dermis high on that side ('high-on-the-high').
- Passing the suture in this way acts to flatten out any vertical step between the wound edges and ensures that the sides are on a level plane.
- Fine adjustments can be made by changing the side on which the knot lies (the knot will tend to raise the side on which it lies).



Intradermal skin suturing

- This technique is often incorrectly called subcuticular suturing.
- The suture passes through the dermis, not under the skin.
- The suture should enter deeply from deep in the reticular dermis on the incised skin edge.
- It should then pass more superficially into the papillary dermis at a level just deep enough to avoid puckering of the skin.

- This results in:
 - Eversion of the skin edges
 - Burying of the knot deeply so that it is unlikely to protrude through the skin, forming a stitch abscess.
- Sutures that retain their strength for a significant amount of time, such as a polydioxanone suture (PDS), should be used in areas prone to scar stretching, such as the back.
- Sutures that elicit a minimal tissue reaction, such as monocril, should be used in the face.

Suture materials

Sutures are either: (i) absorbable or non-absorbable; (ii) synthetic or natural; or (iii) braided or monofilament.

Absorbable sutures

Catgut

- Catgut is derived from the submucosal layer of sheep intestine.
- It elicits a significant inflammatory response.
- Its absorption is unpredictable.
- It loses its strength by 8–9 days.
- It is absorbed by 1 month.
- A decreased rate of absorption occurs if the suture is chromatinized (chromic catgut).
- Clinically catgut is usually used as:
 - A mucosal suture
 - A dermal suture in the face
 - A skin suture in children.

Polyglycolic acid

- Dexon is a synthetic suture composed of polyglycolic acid.
- It is degraded by hydrolyzation.
- It loses its strength by 21 days and is absorbed by 90 days.

Polyglactin 910

- Vicryl is a braided synthetic suture composed of polyglactin 910.
- It loses its strength by 21 days and is absorbed by 90 days.
- Its braided nature may make it more prone to bacterial colonization than monofilament alternatives.
- It may provoke a significant inflammatory reaction and some recommend that it is not used as a dermal suture in the face.

Poliglecaprone 25

- Monocril is a monofilament synthetic suture composed of poliglecaprone 25.
- It has similar absorption characteristics to vicryl.
- Its monofilament composition may make it less prone to bacterial colonization.

Polydioxanone

- PDS is a monofilament synthetic suture composed of polydioxone.
- It is absorbed more slowly than either vicryl, monocryl or dextron.
- It loses its strength by 3 months and is absorbed by 6 months.
- It is primarily used as a dermal suture in areas prone to developing stretched scars.

Non-absorbable sutures

- Non-absorbable sutures are generally used as:
 - Cutaneous stitches which will need to be removed
 - Deep stitches to provide permanent tissue fixation.
- Non-absorbable sutures may be natural or synthetic.

Natural

- Silk
- Cotton.

Synthetic

- Polyamide
 - Nylon
 - So-named because it was developed jointly in New York and LONDON.
- Polypropylene
 - Prolene.
- Stainless steel.

Tissue expansion

- Tissue expansion, by techniques such as neck lengthening, has been practised since ancient times.
- More recently, in 1957, Neuman described tissue expansion for therapeutic purposes.
- Since then, it has been popularized by authors such as Radovan.

Mechanisms

- Approximately 70% of tissue gain is due to stretch and 30% due to growth.
- As tissue stretches, it relaxes, and less force is required to keep it stretched—this is known as stress relaxation.
- Tissue creep is the time-dependent plastic deformation of any material in response to constant stress.
- Tissue creep occurs because of disruption of elastin fibres.
- If a plastic bag is stretched, it stays in a stretched state—this is tissue creep.
- The initial force required to stretch a plastic bag is greater than that needed to maintain it stretched—this is stress relaxation.

Changes

Tissue-expanded skin is characterized by the following changes.

The epidermis

The thickness of the epidermis usually increases but can remain the same as in unexpanded skin.

The dermis

- The thickness of the dermis decreases as the skin is expanded.
- The collagen fibres within the dermis realign along the lines of tension during expansion.

The mitotic rate of the skin

The mitotic rate of skin increases with the application of traction.

The skin appendages and nerves

- These become increasingly separated from one another during expansion.
- Hair density is therefore reduced in expanded skin.

The subcutaneous tissue, muscle and bone

Pressure effects exerted by the expander may lead to localized atrophy of the surrounding tissue.

Microscopic appearance of the expander capsule

Paysk has described four zones within the capsule surrounding an expander.

- 1 The inner zone is a fibrin layer containing macrophages.
- 2 The central zone contains elongated fibroblasts and myofibroblasts.
- 3 The transitional zone is composed of loose collagen fibers.
- 4 The outer zone contains blood vessels and collagen.

Advantages

Advantages of tissue expansion include the following.

- Reconstruction with tissue of a similar colour and texture to that of the donor defect
- Reconstruction with sensate skin containing skin appendages
- Limited donor-site deformity.

Insertion and placement of expanders

Tissue expanders can be inserted through a wide variety of incisions.

- These may be local or remote.
- Expander insertion through a remote, radially orientated incision is associated with the lowest complication rate.
- Expanders can be placed below or above the fascia.
- Subcutaneous placement is usually preferred in the face and trunk.
- Subfascial placement is usually preferred in the forehead and scalp.

Contraindications

Ideally, tissue expanders should not be inserted:

- In the vicinity of an immature scar
- In the presence of infection
- In irradiated tissue
- Under skin grafts.

Design of expanders

Tissue expanders are essentially expandable, saline-filled bags. They differ from one another in the following ways.

Shape

- Oval
- Rectangular
- Round
- Square
- Crescentic (croissant-shaped)
 - Croissant-shaped expanders may result in shorter donor defects.
 - This is because expansion principally occurs over the central portion of the expander.

Size

- Base dimensions
- Projection when inflated.

Location of the port

- Integrated ports form part of the shell of the expander.
- Remote ports are attached to the expander by a filling tube.
- Remote ports can be placed subcutaneously or externally.

Envelope composition

- The shell of an expander can have a smooth or textured surface.
- The shell is usually of a uniform thickness and compliance.
- Variations in shell thickness and compliance can be used to produce preferential expansion in a certain direction or directions.
- Expanders may or may not have a stiff backing bonded onto their shell.

Timing and length of expansion

Tissue expansion can be performed by the following methods.

Intra-operative expansion

Examples of this method of tissue expansion include:

- Sustained traction applied to the tissue by skin hooks or other instruments
- Tissue expansion with a Foley catheter
- Sureclosure devices.

Rapid expansion

- The rationale behind this technique is that most tissue creep and growth occurs in the first 2 days following expansion.
- Some authorities therefore recommend inflation of the expander every 2–3 days.

Conventional expansion

- Most tissue expanders are inflated weekly.
- This allows sufficient time for the tissues to stabilize between expansions.
- Expansion is stopped when the amount of tissue gained is sufficient to permit adequate reconstruction. This can be estimated by:
 - Recording the dimensions of the tissue over the expander from fixed points before it is inflated.
 - Comparing these measurements to the dimensions of the tissue over the expander when it is inflated.
 - Comparing the tissue gain to the dimensions of the defect.

Complications

- The complications of tissue expansion include:
 - Haematoma
 - Infection
 - Exposure of the expander
 - Extrusion of the expander
 - Pain
 - Neurapraxia
 - Pressure effects on surrounding tissue.
- Minor complications are those that do not result in the termination of the procedure.
- Major complications are those that do result in the termination of the procedure.

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