MANAGEMENT OF DIFFICULT WOUNDS:

STASIS ULCERS AND PRESSURE SORES

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Types of Surgical Infections

- pressure sores
- leg ulcers
- chronic/acute osteomyelitis
- abscesses
- post-operative wound infections
- diabetic foot infections
- deep space infections of hands/feet
- burns
- septic thrombophlebitis
- necrotizing fasciitis
- bites and stings
Identification of Surgical Infection

quantitative cultures —> determine level of bacterial loads

qualitative cultures —> identify causative organism(s)

histologic samples —> determine depth of invasion
Ways to Decrease Bacterial Load

1. debride

2. systemic antibiotics

3. topical antimicrobials

4. prevent edema
Methods of Debridement

1. drain pus

2. debride necrotic tissue

   sharply

   lavage

   ultrasonification

   whirlpool

   dressing changes
Etiology of Cutaneous Ulcerations

Infection

↑ ↓

Ischemia
Goals of Treatment

1. remove necrotic tissue

2. decrease bacterial count

3. obtain a closed wound
Types of Leg Ulcers

I. Venous (outflow)

II. Arterial (inflow)
   A. atherosclerotic
   B. vasculitis
   C. hypertensive
   D. blood dyscrasias
Work-up of Leg Ulcers

I. Determine bacterial load.

II. Determine vascular etiology
   A. Doppler non-invasive studies
      1. arteriography or venography
   B. Vital signs to determine BP
   C. Blood work: ESR, ANA, Rheumatoid Factor
      1. Biopsy of lesion if vasculitis is suspected
   D. CBC, peripheral smear, bone marrow
Generalized Leg Ulcer Treatment

I. Work-up

II. Pre-op
   A. Elevate
   B. Decrease bacterial count
      1. Debride
      2. Topical antimicrobials
   C. Control causative factors

III. Split Thickness Skin Graft to Close

IV. Post-op
   A. Control causative factors
   B. Bed rest followed by guarded ambulation
ETIOLOGY OF PRESSURE SORES

PRESSURE

MOBILITY
SENSORY PERCEPTION
ACTIVITY

PRESSURE SORE DEVELOPMENT

TISSUE TOLERANCE

EXTRANSC FACTORS
moisture
friction
shear

INTRINSIC FACTORS
endogenous infection
denervation
edema
nutrition
age
arteriolar pressure
steroids
diabetes
atherosclerosis

Figure 1 Diagrammatic representation of conical configuration of pressure sore with base on bony prominence

Figure 2 Pressure distribution when weight supported largely on posterior thighs (A) and increase in pressure when feet supported and weight shifted posteriorly onto ischial tuberosities (B)
ETIOLOGY OF PRESSURE SORES (cont)

Figure 3 Canine data for time-pressure relationship of pressure ulceration.

CLASSIFICATION OF PRESSURE SORES

**Stage I**
- Precursor Phase
- Redness

**Stage II**
- Excoriation
- Vesiculation or Skin Breakdown

**Stage III**
- Full Thickness Loss
- Serosanguinous Drainage

**Stage IV**
- Full Thickness Loss
- Invasion of Deeper Tissues
PRE-OPERATIVE EVALUATION

Pressure Sore
Location
a. depth, volume
b. involvement of adjacent structures
   1) bone
   2) joint
   3) sinus
Quality
a. vascularity
b. presence of scarring
c. extent of infection
   1) cellulitis
   2) heavy bacterial count
      - identification/sensitivity of bacteria
   3) necrotic debris
Presence and quality of adjacent tissue

Nutritional Status
Cachexia
Anemia

Spasticity
Spasms
Fixed joint contractures

Distant Infection
Urinary
Pulmonary
Other

General Status
Neurologic/Psychiatric
a. coma
b. disorientation
c. schizophrenia/depression
d. social support systems
Chronic disease
a. cardiac
b. pulmonary
c. oncologic
d. other
Risk Assessment
a. Norton Scale
b. Braden Scale

PRE-OPERATIVE CARE

Pressure sore
Infection
a. debride necrotic tissue
   1) skin
   2) subcutaneous tissue
   3) muscle
   4) bone
b. drain pus
   1) subcutaneous
   2) joint
c. treat local infection
   1) skin (cellulitis)
   2) bone (osteomyelitis)
d. obtain bacterial balance
   1) assess number, type and sensitivity of bacteria
   2) treat viable tissue with topical antimicrobials
Contiguous structures
a. bone involvement
   1) heterotopic bone
   2) osteomyelitis vs parosteitis
      i) x-ray
      ii) biopsy
b. joint involvement
   1) x-ray
   2) direct exam, palpation
   3) sinogram
   4) CT scan
c. visceral involvement
   1) urethra
   2) rectum
Pressure disbursement
a. pads
b. mattresses
c. beds

Nutritional Status
Obtain positive nitrogen balance
Correct anemia
Reverse vitamin deficiencies

Spasticity
Oral medication
Peripheral neurectomy
Central rhizotomy
Release of Fixed Contractures

Distant Infection
Treat UTI/remove stones

General Status
Plan discharge/rehabilitation
POST-OPERATIVE CARE

Local wound care
1. dressings
2. drains
   type
duration
3. avoid pressure
4. control spasms
5. suture removal

Systemic Care
1. Antibiotics
   choice
duration

Post-op mobilization
1. timing
2. limitations

Education
1. transfer techniques
2. pressure avoidance
3. inspection
4. bowel toilet - self disimpaction

<table>
<thead>
<tr>
<th>COMPLICATIONS</th>
<th>PRESSURE SORE RECURRENT RATES</th>
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<tbody>
<tr>
<td>SEROMA</td>
<td>1964</td>
</tr>
<tr>
<td>HEMATOMA</td>
<td>DANSEREAU</td>
</tr>
<tr>
<td>2000 PTS</td>
<td></td>
</tr>
<tr>
<td>INFECTION</td>
<td></td>
</tr>
<tr>
<td>WOUND DEHISCENCE</td>
<td>ISCHIAL</td>
</tr>
<tr>
<td>RECURRENT</td>
<td>15%</td>
</tr>
</tbody>
</table>

TROCHANTER
14%   | 7.5%  | 38%   |
INTRA-OPERATIVE CARE

Pressure Sore
Bursa
  stain with methylene blue
  excise wound margin
  excise bursa
  excise all sinus tracts
Bony Prominence
  osteotomize
  rongeuer

Reconstruction
Flap Choices
  avoid "burning bridges"
    (see below)
Flap Closure
  dead space
  drains
  sutures

Management Options: ISCHIAL Pressure Sores
Nonsurgical
Primary Closure
Split-thickness skin graft
Skin flaps
  Random
    Posterior thigh flap
  Axial
    Gluteal thigh flap
Muscle flaps
  Gluteus maximus myoplasty
Myocutaneous flaps
  gluteus maximus MC flap
  tensor fascia lata MC flap
  hamstring V-Y advancement MC
Sensory flaps
  tensor fascia lata innervated or reinnervated flap

Management Options: SACRAL Pressure Sores
Nonsurgical
Primary Closure
Split-thickness skin graft
Skin flaps
  Random
    Buttock rotation flap
    Transverse lumbosacral
  Axial
    Gluteal thigh flap
Muscle flaps
  gluteus maximus myoplasty
Myocutaneous flaps
  gluteus maximus MC flap
  Rectus femoris MC flap
Sensory flaps
  Intercostal neurovascular flap

Management Options: TROCHANTERIC Pressure Sores
Nonsurgical
Primary Closure
Split-thickness skin graft
Skin flaps
  Random
    Anteriorly based thigh
    Bipedicle flap
  Axial
    Gluteal thigh flap
Muscle flaps
  Vastus lateralis myoplasty
Myocutaneous flaps
  gluteus maximus MC flap
  tensor fascia lata MC flap
  vastus lateralis MC flap
Sensory flaps
  tensor fascia lata innervated or reinnervated flap
REFERENCES


11. Lister, J. On a new method of treating compound fracture, abscess, etc., with observation on the conditions of suppuration, Lancet, 1, 326, 1867.


WOUND HEALING

I OVERVIEW:

There are 3 basic components to wound healing. Each are considered separately, but not mutually exclusive. They are overlapping at points and are better thought of as a continuum of ongoing processes. They are:

1. Inflammation: including coagulation, and the activation of humoral and cellular factors.
2. Fibroplasia: including angiogenesis, wound contracture and reepithelialization
3. Maturation: this is the final phase of indeterminate duration. It is a balance of collagen synthesis and degradation.

II INFLAMMATION:

An initiating event (trauma etc.,) in which there is a disturbance in the blood vessel endothelium which exposes the blood to the subendothelium parenchyma and collagen. The entire sequence of events can be divided into 4 basic components which include:

1. Vascular and Platelet Response
2. Neutrophil Response
3. Monocyte-Macrophage Migration
4. Formation of the Wound Matrix

A. The Vascular and Platelet Response:

1. The Vascular Response is biphasic: a) vasoconstriction for hemostasis mediated by thromboxane (pil), epineph, and serotonin
   b) vasodilation mostly mediated by histamine release from mast cells, plts, and basophills. The concept here is to increase delivery of required substrates. There will be an increase in vasc permeability, secondary to the widening of the cell junctions to cause edema and from a direct effect of neutrophils on the endothel cells.

2. The Coagulation Response: There is a chain of events that are initiated with the vascular disruption and incr permeability that result in plasma and plt extravasation to come in contact with the collagen and ground substance. This attracts/activates inflammatory cells (neutro & mono). This entire portion can also be subdivided into the a) coag & kinin cascades, b) arachidonic acid metabolites, c)complement cascade, and d) growth factors.

   a) Coag & Kinin Cascades: 2 cascades intrinsic and extrinsic both serve a hemostatic and inflammatory function. The intrinsic being activated by the Hageman factor and the extrinsic being activated by tissue factors including thromboplastin, endoth cells, active neut and mono etc.

   b) Arachidonic Acid Metabolites: a milieu of cytokines. Numerous stimuli including direct injury, CSa activate cellular phospholipases

   >>> AA
TABLE 4-1. ROLE OF PLATELET PRODUCTS IN WOUNDS

<table>
<thead>
<tr>
<th>Function</th>
<th>Mediator</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Vasoconstriction</td>
<td>Thromboxane A2</td>
<td>Arachidonic acid</td>
</tr>
<tr>
<td></td>
<td>Serotonin</td>
<td>Dense bodies</td>
</tr>
<tr>
<td></td>
<td>Epinephrine</td>
<td>Dense bodies</td>
</tr>
<tr>
<td>Vasodilation</td>
<td>Histamine</td>
<td>Dense bodies</td>
</tr>
<tr>
<td>Aggregation</td>
<td>Thromboxane A2</td>
<td>Arachidonic acid</td>
</tr>
<tr>
<td>Activates intrinsic</td>
<td>Platelet factor</td>
<td>Dense bodies</td>
</tr>
<tr>
<td>coagulation cascade</td>
<td></td>
<td>Dense bodies</td>
</tr>
<tr>
<td>Leukotriene</td>
<td>Platelet factor</td>
<td>Dense bodies</td>
</tr>
<tr>
<td>Chemotaxis</td>
<td></td>
<td>a-granules</td>
</tr>
<tr>
<td>Fibroblast proliferation</td>
<td>Platelet-derived</td>
<td>Dense bodies</td>
</tr>
<tr>
<td></td>
<td>growth factor (PDGF)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Serotonin</td>
<td>Dense bodies</td>
</tr>
<tr>
<td>Collagen synthesis</td>
<td></td>
<td>Dense bodies</td>
</tr>
</tbody>
</table>


FIGURE 5.4. Biological effects of C3a and C5a des Arg. C3a causes (1) smooth muscle contraction, (2) mast cell degranulation, (3) neutrophil activation, and (4) margination and chemotaxis of neutrophils. Smooth muscle is further affected by histamine and leukotrienes released following mast cell degranulation or activation. Loss of the C-terminal arginine residue, following cleavage by carboxypeptidase B, produces C5a des Arg, which possesses weak cell-activating properties. (Reprinted from Rook, L., Brostoff, J., and Male, D.: Immunology. St. Louis, C.V. Mosby Co., Fig. 15.29, p. 1311, 1989.)
c) Complement Cascade: Initiated by variable factors for the production of two powerful anaphylatoxins; C5α & C3α. **FACT:** C5a is 100 - 1000X more potent than C3a (its more abundant). **FACT:** both degranulate mast cells, release histamine and C5α is a potent vasodilator. **FACT:** C5α is the most important chemotactic substance for neutrophil migration, aggreg & adherence.

d) Growth Factors: exact role not known. PDGF from pils, activated endothelial cells and monocytes seems to be most important in inflammat phase. It is mitogenic & chemotactic for mesenchymal cells via receptors on fibroblasts, endothelial, and chondroblasts. **stimulated the elaboration of ground matrix and collagen in the healing wound.

**B Neutrophils:** The first nucleated cell to arrive in the extravascular space. It is not necessary for wound healing( there will be a higher incidence of infection if it is depleted). They are activated by LPS, O2 radicals, lysosomal enzymes and are removed by the monocytes. There are include:

**TABLE 4-2. NEUTROPHIL PRODUCTS WITH A ROLE IN INFLAMMATION**

1. Free radicals: damage to endothelium, increase in vascular permeability, production of chemotactic lipids from arachidonic acid.
2. Cyclooxygenase products of arachidonic acid: platelet aggregation, contraction of vascular smooth muscle.
3. Lipo-oxygenase products of arachidonic acid: leukotriene chemotaxis, increased vascular permeability.

**C Monocyte-Macrophage Migration:** It replaces the neutro as the dominant cell in the wound by the 3rd day. It is essential for normal wound healing - it regulates the proliferative phase. Chemotactic factors include collagen fibronectin, elastin, C5α, & thrombin. Its role includes the removal of microbes and cellular debris, regulate matrix remodeling by cytokines (MDGF), a has a role in angiogenesis by the release of TGF-B.

**TABLE 4-3. MACROPHAGE PRODUCTS MEDIATING INFLAMMATION AND REPAIR**

1. Neutral proteases: plasminogen activator, collagenase, and elastase.
2. Complement factors
3. Reactive oxygen metabolites
4. Growth-promoting factors for fibroblasts and microvessels.
5. Arachidonic acid metabolites with vasoactive and chemotactic properties.
6. Fibronectin: structural and functional roles
7. Interleukin-1: lymphoocyte activator, stimulates collagenase synthesis by fibroblasts.
8. Enzyme inhibitors: plasmin and alpha-2-macroglobulin

**D. Formation of the Wound Matrix:** Secreted by fibroblasts is composed if fibrous proteins embedded in a hydrated polysaccharide gel.

![Structure (collagen, elastin) with adhesion (fibronectin, laminin) holding fibroblasts under cells with glycosaminoglycans](image)
There are 4 types of GAG's:

<table>
<thead>
<tr>
<th>SYNONYM</th>
<th>DISACCHARIDE REPEATING UNIT</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chondroitin</td>
<td>Glucuronic acid - galactosamine</td>
<td>Cornea</td>
</tr>
<tr>
<td>Chondroitin-4-sulfate</td>
<td>Glucuronic acid - 4 sulfogalactosamine</td>
<td>Aorta, cornea, bone</td>
</tr>
<tr>
<td>Chondroitin-6-sulfate</td>
<td>Glucuronic acid - 6 sulfogalactosamine</td>
<td>Tendon, costal cartilage, umbilical cord, nucleus pulposus</td>
</tr>
<tr>
<td>Dermatan sulfate</td>
<td>Chondroitin sulfate B</td>
<td>Iduronic acid - 4 sulfogalactosamine</td>
</tr>
<tr>
<td>Heparin sulfate</td>
<td>Heparitin sulfate</td>
<td>Glucuronic acid + glucosamine</td>
</tr>
<tr>
<td>Keratin sulfate</td>
<td>Keratosulfate</td>
<td>Galactose - sulfogluconaminine</td>
</tr>
<tr>
<td>Hyaluronic acid</td>
<td>Glucuronic acid - glucosamine</td>
<td>Cartilage</td>
</tr>
</tbody>
</table>

### III FIBROBLASTIC PHASE

The transition to this phase is marked by a predominance of macrophages followed by fibroblasts and a decrease in the number of neutrophils. It is comprised of 5 parts, including fibroblast migration, matrix formation (including collagen synthesis), wound contracture, angiogenesis, & epithelization. The first step of this phase is to turn OFF the inflammatory phase by decreasing the production (by macrophages removing the source) and by inactivating the inflammatory mediators already present.

A. **Fibroblast Migration & Proliferation:** (5th day to 2nd week)

By the 5th day the fibroblast is the predominant cell in the wound. This is secondary to mediators such as CSa, fibronectin, and growth factors (PDGF; FGF). The early matrix is rich in Hyaluronate & Fibronectin → Both facilitate cellular migration

↓↓hydrophillic permits

↓↓chemotactic gradient

binds matrix & fibroblasts

a physical walkway for fibrobl - a rope

### TABLE 4-5. FIBROBLAST STIMULATION

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>SOURCE</th>
<th>EFFECT</th>
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<tbody>
<tr>
<td>Serootonin</td>
<td>Plateless</td>
<td>Proliferation</td>
</tr>
<tr>
<td>Interleukin-1</td>
<td>Macrophage</td>
<td>Collagen Synthesis</td>
</tr>
<tr>
<td>Collagen</td>
<td>Wound matrix</td>
<td>Collagenase synthesis</td>
</tr>
<tr>
<td>Collagen degradation products</td>
<td>Fibronecin</td>
<td>Chemotaxis</td>
</tr>
<tr>
<td>Fibronecin fragments</td>
<td>Macrophage-derived growth factor (MDGF)*</td>
<td>Proliferation</td>
</tr>
<tr>
<td>Platelet-derived growth factor (PDGF)</td>
<td>Platelets</td>
<td>Chemotaxis</td>
</tr>
<tr>
<td>Epidermal growth factor (EGF)</td>
<td>Endothelial cells</td>
<td>Proliferation</td>
</tr>
<tr>
<td></td>
<td>Submaxillary glands</td>
<td>Collagen secretion</td>
</tr>
<tr>
<td></td>
<td>Urine</td>
<td>Collagen synthesis</td>
</tr>
<tr>
<td></td>
<td>Small intestine</td>
<td>Collagen synthesis</td>
</tr>
<tr>
<td></td>
<td>Other sources</td>
<td>Collagen synthesis</td>
</tr>
</tbody>
</table>

B. **Matrix Formation:** As the fibroblast enters the wound it makes new things including:

1. **Proteoglycans:** a protein core with polysaccharides (GAG) attached.
2. **Structural Proteins:** Including fibroblasts secreting collagen, 10 types. FACT: Collagen is the most abundant protein in mammals.
The Five Major Collagen Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Chains</th>
<th>Major molecular form</th>
<th>Distribution</th>
<th>Function</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>α1(1)</td>
<td>[α1(1), α2(1)]</td>
<td>All connective tissues except hyaline cartilage and basement membranes</td>
<td>Formation of supporting connective tissues</td>
</tr>
<tr>
<td></td>
<td>α2(1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>α1(1)</td>
<td>[α1(1), α1(1)]</td>
<td>Cartilage-like tissues</td>
<td>Shock absorption and joint mobility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>α1(1)</td>
<td>[α1(1), α1(1)]</td>
<td>Distensible connective tissues, e.g., blood vessels, increased in fetal skin</td>
<td>Formation of small fibrous elements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>α1(1V)</td>
<td>[α1(1V), α2(IV)]</td>
<td>Basement membranes and basal lamina in skin</td>
<td>Formation of meshlike scaffold for filtration</td>
</tr>
<tr>
<td></td>
<td>α2(IV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>α3(IV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>α4(IV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>α1(V)</td>
<td>[α1(V), α2(V)]</td>
<td>Essentially all tissues</td>
<td>Similar to Type III collagen and cytoskeleton around cells</td>
</tr>
<tr>
<td></td>
<td>α2(V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>α3(V)</td>
<td></td>
<td></td>
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</table>

Components of the Extracellular Matrix and Their Function

<table>
<thead>
<tr>
<th>Component</th>
<th>Structure Description</th>
<th>Function</th>
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<tbody>
<tr>
<td>Collagen</td>
<td>Triple helical glycoprotein molecule rich in proline, hydroxyproline, and glycine</td>
<td>Strength, support and structure for all tissues and organs</td>
</tr>
<tr>
<td>Elastin</td>
<td>Stretchable hydrophobic protein interacting with glycosylated microfibrils</td>
<td>Allows tissues and structures to expand and contract</td>
</tr>
<tr>
<td>Fibronectin</td>
<td>Specialized adhesive glycoprotein</td>
<td>Mediates cell-matrix adhesion</td>
</tr>
<tr>
<td>Laminin</td>
<td>Large, complex adhesive glycoprotein</td>
<td>Binds cells to Type IV collagen and heparan sulfate</td>
</tr>
<tr>
<td>Proteoglycans</td>
<td>Heterogeneous, long glycosaminoglycan chains covalently linked to a core protein</td>
<td>Moisture stores, shock absorption, sequestration of cytokines</td>
</tr>
<tr>
<td>Hyaluronic acid</td>
<td>A very large, specialized, non-sulfated glycosaminoglycan</td>
<td>Provides a fluid environment for cell movement and differentiation and binds to cytokines</td>
</tr>
</tbody>
</table>

3. **Elastin**: A nonglycoslated protein rich in proline and lysine, secreted into matrix not as a tight alpha helix but as random coils. It allows for stretch and recoil.

4. **Regulation of Collagen Metabolism**: Macrophage is the key, its secreting growth factors.

C. **Contracture**: Describes a gradual decrease in the wound area by retraction of the central granulation mass. Argument over role (or even existence) of the myofibroblast.

D. **Angiogenesis**: Process where vessels grow into a previously avascular space.

1. An endothelial pseudopod extends through basal lamina. All relies on angiogenic factors which are derived from various tissues including, lymphocytes, macrophages, neutrophils and mast cells. These factors include TGF alpha: direct stimulation; and beta released from platelets and attracts macrophages.

2. Migration: endothelial cell migration increased by mast cells releasing proteases. Other factors that stimulate include thrombin, fibrin, fibronectin.

3. Proliferation: stim by factors FGF, TGF-alpha

4. Regulation: oxygen plays a role.

5. Remodeling: after angiogenic stimuli are withdrawn a period of stasis and endothelial cell death. Clinically see an decor in vascularity.

E. **Epithelialization**: Within 12 hours after insult epithelial cells begin to migrate over the collagen-fibronectin wound surface from the edges. The leading cells do not proliferate, it is the stem cells at the edge.
IV WOUND MATURATION

An extended period from 2 weeks to ??? in which cell and matrix changes continue to increase wound strength without further collagen deposition. This suggests ongoing remodeling: an interplay b/t synthesis and degradation.

A. **Hyaluronidase**: an enzyme that facilitates the change from a hyaluronate rich environment to a dermatan and chondroitin sulfate rich environment.

B. **Plasminogen Activators**: responsible for matrix turnover and degradation of fibrin, fibronectin, and laminin, they also stimulate angiogenesis, and regulate collagen and elastin turnover.

C. **Collagenases**: secreted by macrophages, fibroblasts etc in the inactive form to be activated extracellularly by proteases (plasmin)

D. **Collagen Maturation**: with time the collagen fibers b/c more organized along stress lines with increased intra and interfibril crosslinking. Over time the collagen is stronger and more resistant to proteolysis.

**THE NORMAL WOUND HEALING RESPONSE**

- Scar Maturation
- Collagen Fibril Crosslinking
- REMODELING

**ANGIOGENESIS**

**EPITHELIZATION**

- Collagen Deposition
- Fibroblasts

**PROTEOGLYCANS**

**FIBROPLASIA**

- Lymphocytes
- Macrophages

**TISSUE INJURY**

**COAGULATION**

- Platelets
- PDGF, TGFβ
- EGF, TGFα

**INFLAMMATION**

- Neutrophils
- TGFβ
- Macrophages
- PDGF, TGFβ
- FGF, TGFα
- IL-1, TNFα
- Lymphocytes
- TGFβ
- IL-2
- IFN

**REPAIR**

- Fibroblasts
- TGFβ, PDGF
- KGF, FGF
- IGF-1, IFN

- Epithelial Cells
- TGFα
- Smooth Muscle Cells
- TGFβ
- Endothelial Cells
- FGF
- PDGF
- TGFβ

**REMODELING**

OVERVIEW OF WOUND HEALING

A wound can be defined as a disruption of the normal anatomical relationships of tissues as a result of injury. The injury may be intentional such as a surgical incision or accidental following trauma. Immediately following wounding, the healing process begins.

I. STAGES OR PHASES OF WOUND HEALING

Regardless of type of wound healing, stages or phases are the same except that the time required for each stage depends on the type of healing.

A. *Substrate* phase (inflammatory, lag, or exudative stage or phase)

1. Symptoms and signs of inflammation
   a. Redness, heat, swelling, pain, and loss of function

2. Physiology of inflammation
   a. Leukocyte margination, sticking, emigration through vessel walls
   b. Venule dilatation and lymphatic blockade
   c. Neutrophil chemotaxis and phagocytosis

3. Removal of clot, debris, bacteria, and other impediments of wound healing

4. Lasts finite length of time (approximately four days) in primary intention healing

5. Continues until wound is closed (unspecified time) in secondary and tertiary intention healing

B. *Proliferative* phase (collagen and fibroblastic stage or phase - approximately days 4-42)

1. Synthesis of collagen from tissue fibroblasts

2. Increased rate of collagen synthesis for 42-60 days

3. Rapid gain of tensile strength in the wound (Fig. 1)

![Graph showing tensile strength](image)

*Fig. 1*
C. Remodeling phase (maturation stage or phase – from approximately six weeks onward)

1. Maturation by intermolecular cross-linking of collagen leads to fattening of scar

2. Requires approximately 9 months in an adult - longer in children

3. Dynamic, ongoing

II. WOUND CLOSURE

A. Primary healing (by first intention) - wound closure by direct approximation, pedicile flap, or skin graft

1. Debridement and irrigation minimize inflammation

2. Dermis should be accurately approximated with sutures, which provide tensile strength until newly synthesized collagen in the dermis takes over in 42-60 days

3. Scar red, raised, pruritic, and angry-looking at peak of collagen synthesis

4. Thinning, flattening, and blanching of scar occurs over approximately 9 months in adults as collagen maturation occurs (may take longer in children)

5. Final result of scar depends largely on how the dermis was approximated

B. Spontaneous healing (by secondary intention) - wound left open to heal spontaneously - maintained in inflammatory phase until wound closed

1. Spontaneous wound closure depends on contraction and epithelization

2. Contraction results from centripetal force in wound margin provided by fibroblasts

3. Epithelization proceeds from wound margins towards center at 1 mm/day

4. Although contraction (the process of contracting) is normal in wound healing, one must beware of contracture (an end result - may be caused by contraction of scar and is a pathological deformity)

5. Secondary healing beneficial in some wounds, e.g., perineum
2. If needed, pre-anesthetic medication to allay anxiety

3. Local anesthesia - use epinephrine adjuvant unless contraindicated, e.g. digit, tip of penis

4. Tourniquet to provide bloodless field in extremities

5. Cleansing of surrounding skin - do NOT use strong antiseptic in the wound itself

6. Debridement - remove clot debris, necrotic tissue
   a. Irrigation good adjunct to sharp debridement

7. Closure - use atraumatic technique to approximate dermis so collagen synthesis can proceed
   a. Consider undermining of wound edges to improve approximation and relieve tension

8. Dressings - must provide absorption, protection, immobilization, even compression, and be aesthetically acceptable

C. Types of wounds and their treatment

1. Abrasion - cleanse to remove foreign material
   a. Consider scrub brush or dermabrasion to remove dirt buried in dermis to prevent traumatic tattoos (permanent discoloration due to buried dirt beneath new skin surface) - needs to be accomplished within 24 hours of injury

2. Contusion - consider need to evacuate hematoma if collection is present
   a. Early - minimize by cooling with ice (24-48 hours)
   b. Later - warmth to speed absorption of blood

3. Laceration - trim wound edges if necessary (ragged, contused) and suture

4. Avulsion
   a. Partial (creates flap) - revise and suture if viable
   b. Total - do not replace totally avulsed tissue except as a skin graft after fat is removed.
      1. Consider skin graft or biologic dressing (e.g. xenograft-pigskin)

5. Puncture wound - evaluate underlying damage
   a. Consider need to explore wound, e.g. foreign body
2. Debridement as important as in an acute wound
   a. Mechanical - sharp (scalpel, scissors)
   b. Mechanical - frequent dressing changes
   c. Enzymatic - seldom indicated

3. Systemic antibiotics of little use since they do NOT penetrate fibrous bed of granulating wound

4. Topical antibacterial creams
   a. Continual surface contact
   b. Good penetrating ability
   c. Decrease bacterial counts of wounds
   d. May inhibit wound healing

5. Biological dressings (allograft, xenograft, amniotic membrane) debride wound, decrease serum loss, decrease bacterial count (not xenograft), predict autograft success, decrease pain

6. Final closure of the chronic contaminated wound will be with a delayed flap, skin graft, or flap
   a. Successful closure depends on converting the chronic contaminated wound bacteriologically to an acute wound by decreasing the bacterial count to $10^5$ of fewer bacteria