Wound Coverage Techniques for the Injured Extremity

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Objectives

- Initial Assessment/Management
- Timing of coverage
- Soft tissue coverage options
  - Wound closure
  - VAC assisted closure
  - Skin grafting
  - Flaps
- Principles of free tissue transfer
- Soft tissue coverage by anatomic location
- Summary

Initial Assessment

- History
  - Mechanism of injury
  - Timing of injury
  - Functional status of the patient
  - Patient variables/comorbidities
    - Age
    - Obesity
    - Diabetes
    - Chronic renal disease
    - Smoking
    - Malnourished
  - Occupation

Initial Assessment

- Physical Exam
  - Zone of injury
  - Severity of injury/soft tissue disruption
  - Fracture morphology
    - Pattern
    - Diaphyseal vs. Periarticular
    - Periosteal stripping
  - Bone loss
  - Blood supply

Initial Treatment

- Prophylactic antibiotics within 1 hour of injury
  - 1st generation cephalosporin
  - Penicillin for dirt contaminated wounds (clostridia)
  - Additional antibiotics based on wound size/contamination
    - 3rd generation cephalosporin, vancomycin, ciprofloxacin, etc based on local antibiogram
- Surgical management requires:
  - Aggressive, appropriate debridement in OR
  - Skeletal stabilization
  - Timely soft tissue coverage
  - Restoration of vascular flow and fasciotomies if needed

Initial Treatment

- Debridement and irrigation
  - Thorough debridement, rather than irrigation, is most important portion
  - Convert from traumatic wound to a surgical wound
    - Need to extend incisions to expose zone of injury
  - Need to debride necrotic muscle, fascia, fat, skin, devascularized bone
    - Maintain articular fragments for later reconstruction
  - Tissue damage/recovery evolves over time
    - May require multiple debridements
    - Questionable injured tissue may heal without excision

Timing of Debridement

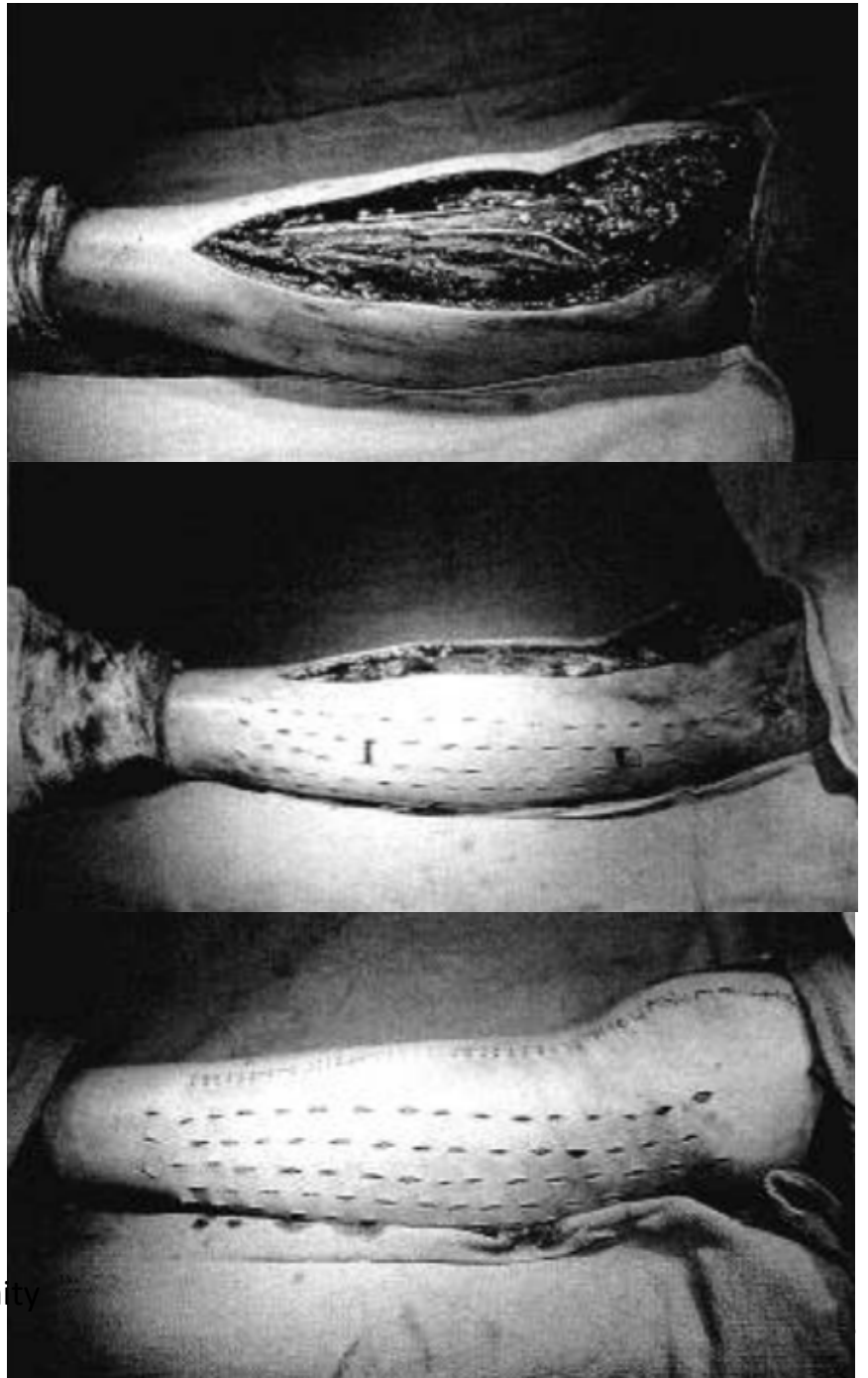
- Original recommendations were debridement within 6 hours of injury to decrease infection/colonization rates
  - Friedrich PL. Archiv fur Klinsche Chirugie. 1898.
  - Robson MC, et al. J Surg Res. 1973. 14
- More recent data suggests timing is not as important as early antibiotic administration
- No significant difference in infection rates, osteomyelitis and nonunion in 0-6 hours, 6-12 hours, 12-24 hours after injury
  - Schenker ML, et al. JBJS Am. 2012. 94(12).
  - Weber D, et al. JOT. 2014. 28(11).
  - Pollak AN, et al. JBJS Am. 2010. 91(1).

Soft Tissue Coverage Options

- **Reconstructive Ladder**
  - Primary closure
  - Secondary closure
  - Skin Grafts
    - STSG
    - FTSG
  - Local and Regional Flaps
    - Random
    - Axial
  - Distant Pedicle Flaps
    - Random
    - Axial
- Free Flaps
  - Cutaneous
  - Fasciocutaneous
  - Myoculocutaneous
  - Osteocutaneous

Direct Closure

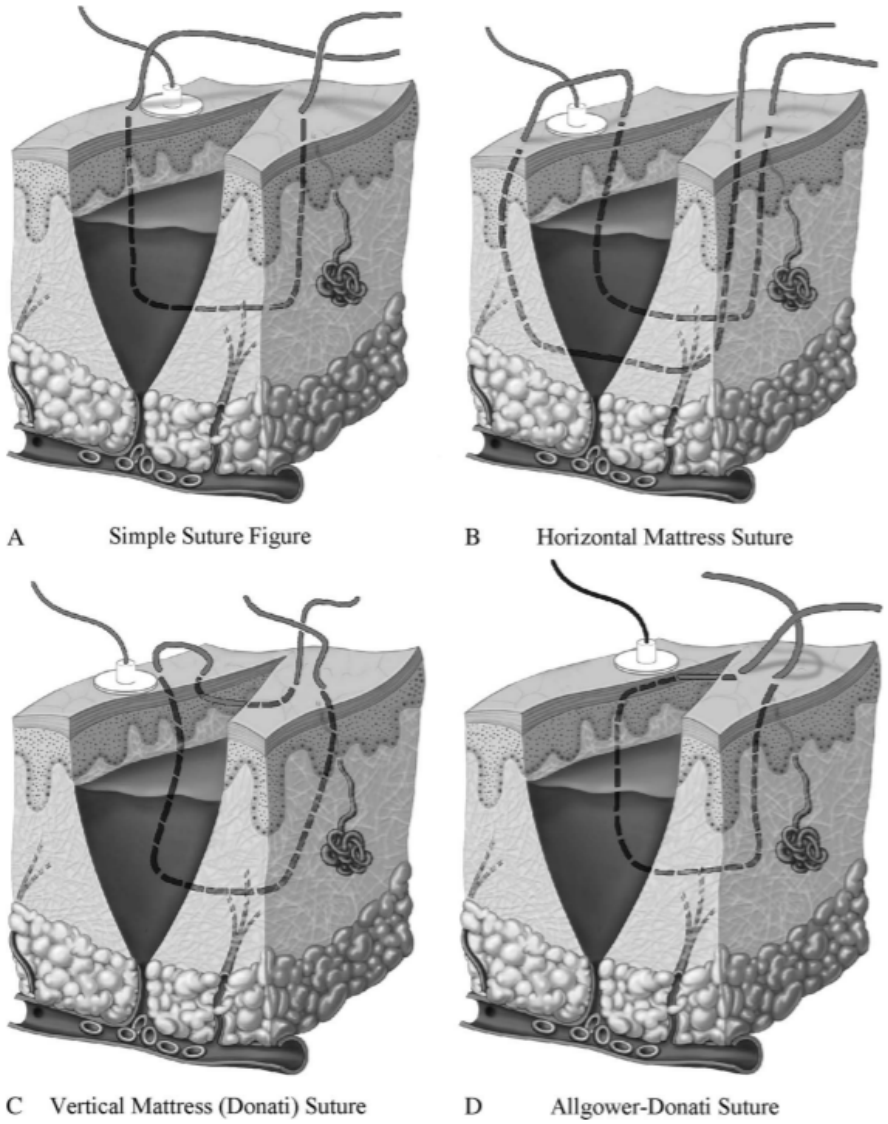
- Simplest and most effective method to achieve viable coverage (if possible)
- Requires a tension free closure to prevent strangulation of dermal vessels
  - Vessels enter dermis perpendicular to skin surface from below
- May require relaxing incisions or pie crusting to decrease tension
  - Single row (34%) second row (45%)
    - Capo J, et al. Injury. 2020. 51(6).



DiStasio AJ, et al. Multiple relaxing skin incisions in orthopaedic lower extremity trauma. JOT. 1993. 7(3): 270-74.

Primary Closure

- Multiple suture patterns to close wounds primarily
  - Simple
  - Horizontal Mattress
  - Vertical Mattress
  - Allgower-Donati
- Of these, Allgower-Donati has a statistically smaller change in cutaneous blood flow (improved incision perfusion)
  - Sutures grasp intra-dermal layer and leave microcirculation intact
  - Shannon SF, et al. JOT. 2017. 31(2)



Sagi HC, et al. The effect of suture pattern and tension on cutaneous blood flow as assessed by laser Doppler flowmetry in a pig model. JOT. 2008. 22(3): 171-75.

Subcuticular Closure

- Subcuticular suture has the lowest incisional perfusion impairment and greatest incisional perfusion compared to other suture methods
  - Shorten P, et al. JOT. 2020. 34(10)
- There is no patient perceived difference in cosmetic appearance of incision between 5 methods tested
  - Simple
  - Horizontal Mattress
  - Vertical Mattress
  - Allgower-Donati
  - Subcuticular
- It is unknown if there is a difference in tensile strength of wounds closed via the above methods

VAC Assisted Closure

- Advantages
  - Increased neovascularization
  - Increased granulation tissue formation
  - Decreased bacterial count
  - Decreased seroma formation
  - Wound contracture
- Disadvantages
  - Cost
  - Loss of seal/leak
  - Monitoring of wound difficult while in place
  - Caution when near exposed vessels

VAC Assisted Closure

- Routine use with open fractures is safe
- Wound still requires debridement of necrotic tissue
- VAC can help decrease size of wound needed for tissue coverage
  - In some patients can change type of soft tissue coverage needed
    - Herscovici D, et al. JOT. 2003. 17(10).
- Prolonged period of VAC use greater than 7 days before tissue coverage increases rate of infection
  - Goal is to cover wound <7 days even with VAC use
  - Hou Z, et al. J Trauma Acute Care Surg. 2011. 71(6).
  - Bhattacharyya T, et al. Plast Reconstr Surg. 2008. 121(4)

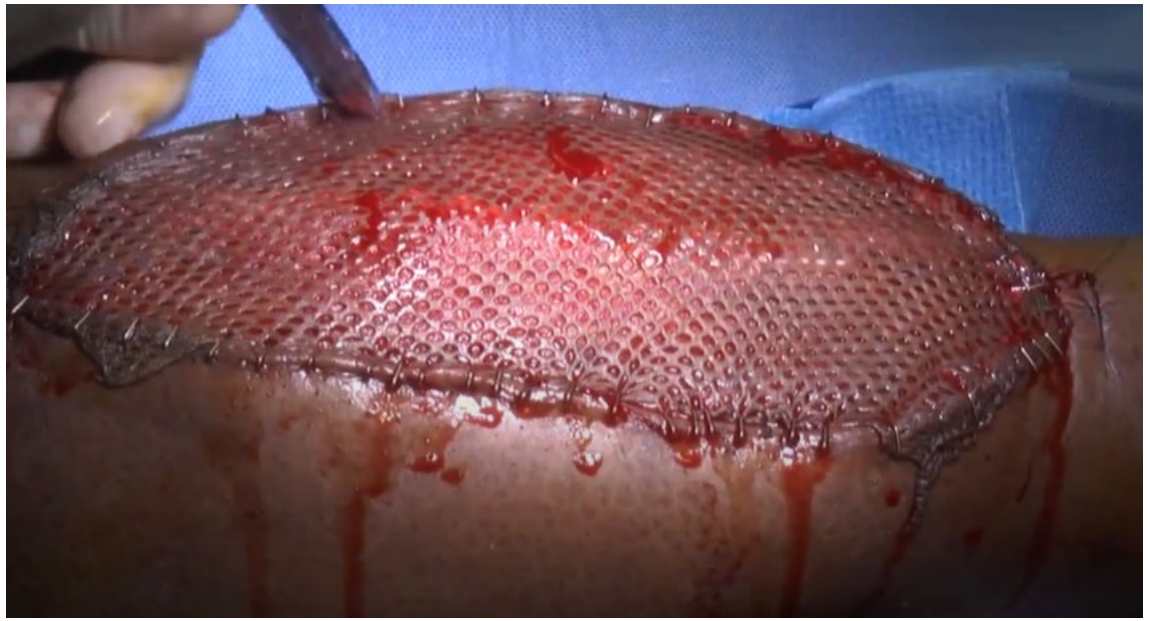
Herscovici D, et al. Vacuum-assisted wound closure (VAC therapy) for the management of patients with high-energy soft tissue injuries. JOT. 2003. 17(10): 683-88

Skin Grafting

- Split Thickness (STSG)
  - Dermatome set at 0.012” (thickness of scalpel blade)
  - Meshing
    - Advantages – increases coverage area without having to increase graft harvest size; increases graft success by avoiding fluid collection beneath graft
    - Disadvantages – poor cosmesis
- Full Thickness (FTSG)
- Cannot elevate for future orthopaedic procedures
- Provides no additional blood flow to injury zone

STSG

- Meshing allows small donor graft to cover large area
- Requires less vascularization
- Not technically demanding
- Poor cosmesis
- Cannot be used directly over bone, tendon, nerve, etc
- Contracts over time
- Donor site pain/infection



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FTSG

Benefits

- Increased sensation
- Much better cosmesis
  - Maintain texture, color, thickness and are better for highly visible areas of the body (face, hands)
- Improved durability
- No wound contracture

Limitations

- Takes longer to revascularize
  - Recipient site must have rich vasculature for incorporation
- Cannot mesh to increase size
  - Defect size limiting factor
- Greater risk of graft failure
- Donor site needs to be closed primarily

Donor Site Selection

STSG

- Lateral buttock
- Anterior and lateral thigh
- Lower abdomen
- Avoid medial thigh and forearm

FTSG

- Large grafts – lower abdomen and groin
- Small – medial brachium and volar wrist crease
- Plantar skin from instep

STSG Harvesting

- Shave hair on donor site prior to prep
- Dermatome set to 0.012 inch
  - Width of scalpel blade
- Lubricate donor site with mineral oil
- Traction on skin with tongue blade or sponge
  - Flat skin surface for harvesting
- Dermatome at 45° angle with steady slow forward pressure
  - Avoid racing stripes from inadequate harvest
- Use forceps to pull graft from back of dermatome to prevent bunching
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731302/fuller-lower-leg-skin-graft

STSG

- Mesh at 1.5:1 for a graft same size of recipient site
  - Can mesh up to 6:1 if needed
- Suture graft to recipient site with staple or absorbable suture (chromic)
  - Trim excess
- Can use a moist bolster or a negative pressure wound vac (NPWV) to cover
  - Place non-adherent dressing between STSG and wound vac sponge
- Keep NPWV on for 5-7 days and then leave open to air
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731302/fuller-lower-leg-skin-graft

Donor Site Care

- Cover with a non-adherent dressing
- Removal is based on type of dressing
  - Example: can leave xeroform dressing in place and trim as harvest site heals

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731302/fuller-lower-leg-skin-graft

Indications for Flap Coverage

- When skin graft cannot be used
  - Exposed cartilage, tendon (without paratenon present), bone, joints, metal implants,
- When flap coverage is preferable
  - Flexor joint surfaces, exposed nerves and vessels, durability needed, dead space present

Timing of Flap Coverage

- Infection rate increases significantly when coverage delayed more than 7 days after injury
  - Gopal S, et al. JBJS Br. 2000. 82(7).
  - Lack WD, et al. JOT. 2015. 82(7).
- “Fix and flap” within 72 hours of injury has lowest infection and flap failure rates and higher functional outcome scores than waiting >7 days
  - Gopal S, et al. JBJS Br. 2004. 86(6).
  - VandenBerg J, et al. JOT. 2017. 31(6).
  - Al-Hourani K, et al. JOT. 2019. 33(12).

Classification of Soft Tissue Flaps

- Random vs. Axial
- Local vs. Distant
  - Local – advancement vs. rotation
  - Distant – direct, tubed, free
- Tissue involvement
  - Direct cutaneous
  - Myocutaneous
  - Fasciocutaneous
  - Osteocutaneous

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Direct Cutaneous Flaps

- Groin Flap
  - Superficial circumflex iliac artery

- Deltopectoral flap
  - 2nd and 3rd perforating branch of internal thoracic artery

Myocutaneous Flaps

- Used for wounds at high risk for infection or have large dead space
- Organized according to pattern of vascular supply (**Mathes Classification**)
  - **Type I** – single dominant vascular pedicle (TFL, gastrocnemius)
  - **Type II** –one dominant pedicle and minor pedicles (gracilis)
  - **Type III** – two dominant pedicles (rectus abdominis, gluteus maximus)
  - **Type IV** – segmental blood supply, no pedicles (Sartorius, tibialis anterior)
  - **Type V** – one dominant pedicle and secondary segmental pedicles (pec major, lat dorsi)
    - Can be supplied by secondary pedicles if dominant pedicle is sacrificed, unlike gracilis
- Mathes SJ, et al. Plastic Reconstr Surg. 1981. 67(2).

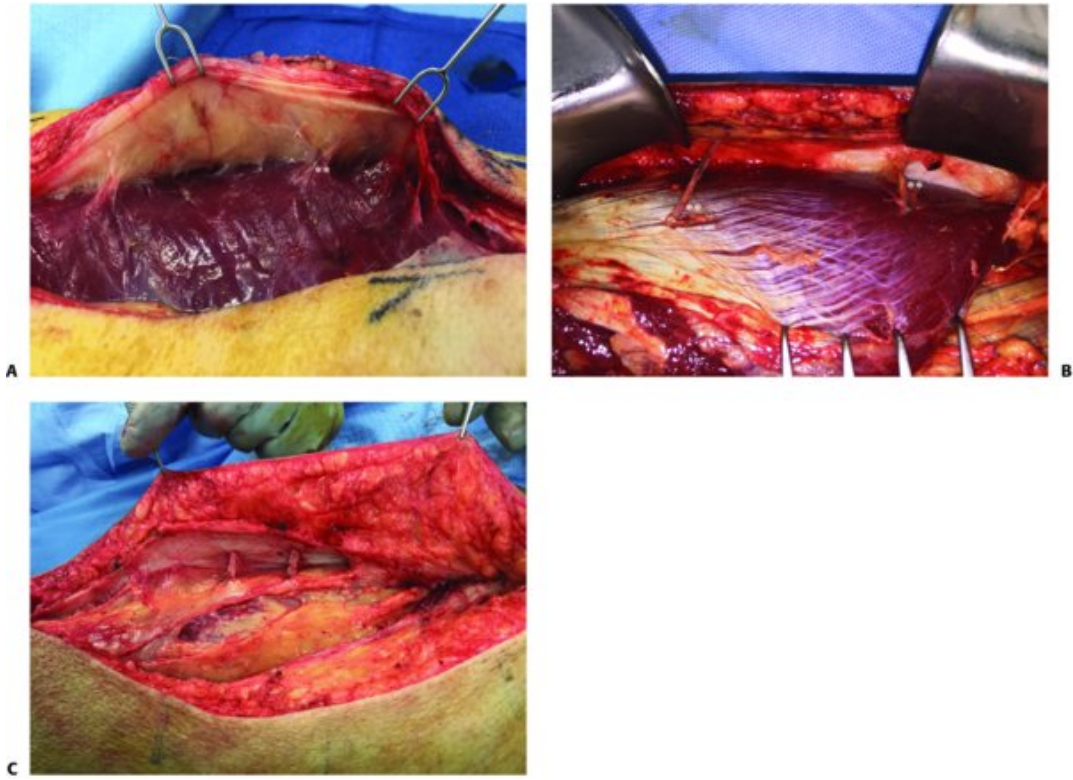
Fasciocutaneous Flaps

- Maintains all elements of soft-tissue envelope including vascularized fascia, adequate fat and full thickness skin
- Does not sacrifice a muscle unit
- Donor site can be closed primarily (ALT flap)
  - Less secondary skin grafting procedures needed
  - Bibbo C, et al. JOT. 2015. 29(12).
  - Cho EH, et al. Plastic Reconstr Surg. 2018. 141(1).
- Flap can be elevated for later orthopaedic procedures (nonunion, hardware removal, etc)
  - Ideal for bone defects or if staged fixation needed
  - Muscle flaps are prone to partial flap necrosis or poor healing after re-elevation
  - Cho EH, et al. Plastic Reconstr Surg. 2018. 141(1).

Classification of Fasciocutaneous Flaps

- **Type A** – flap dependent on multiple perforators oriented to long axis of flap
  - Parascapular flap
- **Type B** – single fasciocutaneous perforator of moderate size which is consistent in presence and location
  - Anterolateral thigh flap (3rd profunda perforator)
- **Type C** – multiple small perforators which pass from a deep artery through a fascial septum
  - Radial forearm flap
- **Type D** – Type C fasciocutaneous flap elevated in continuity with adjacent muscle and bone to create a osteo-myo-fasciocutaneous flap
  - Free fibula osteocutaneous flap

- Cormack GC, et al. Br J Plast Surg. 1984. 37(1).



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Principles of Free Tissue Transfer

- Pre-operative assessment
  - Physical Exam
  - Choice of donor site
  - Vascular status
  - Comorbidities

Principles of Free Tissue Transfer

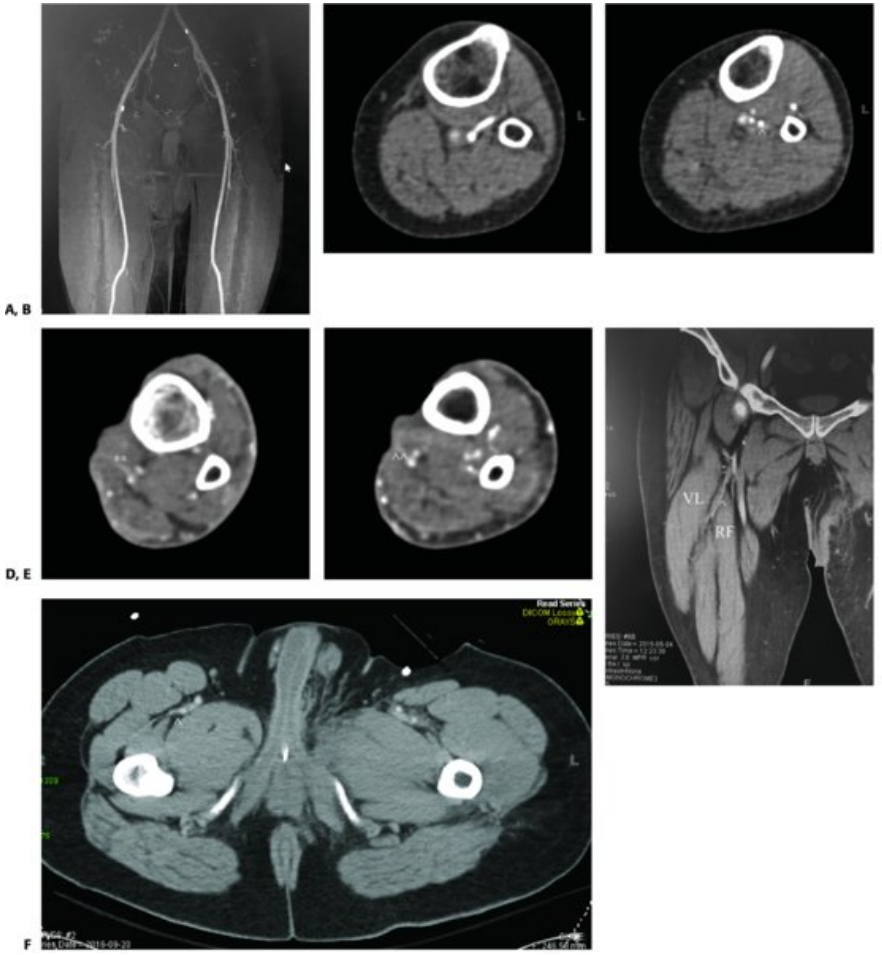
- Physical Exam
  - Size of traumatic wound and location (length, width, depth)
    - Small wounds may be amenable to rotational muscle flap
  - Exposed tissue within defect
    - Muscle, fascia, granulation tissue, paratenon-covered tendons only need STSG for coverage
    - Status of injured bone
      - Periosteal coverage?
      - Later reconstruction needed?

Principles of Free Tissue Transfer

- Choice of Donor Site
  - Flap type
    - Myocutaneous vs. fasciocutaneous
  - Other incisions/interventions may alter flap choice
    - Vascular access cutdowns
    - Fasciotomies
    - Chest tubes
    - Abdominal/pelvic incisions
  - Size necessary to fill defect
    - Length and width needed
    - Vascular pedicle length
  - Composite with bone?

Principles of Free Tissue Transfer

- Vascular Status
  - CT angiogram vs angiography
    - Identify perforators
    - Distal blood flow to connect flap to
  - Blood supply of flap
    - Important for middle 1/3 tibia fractures



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Principles of Free Tissue Transfer

- Relative/Possible Contraindications
  - Hypertension
  - Peripheral vascular disease
  - Diabetes
  - Nutritional status
  - Age
  - Need for pressors
  - Infection

Principles of Free Tissue Transfer

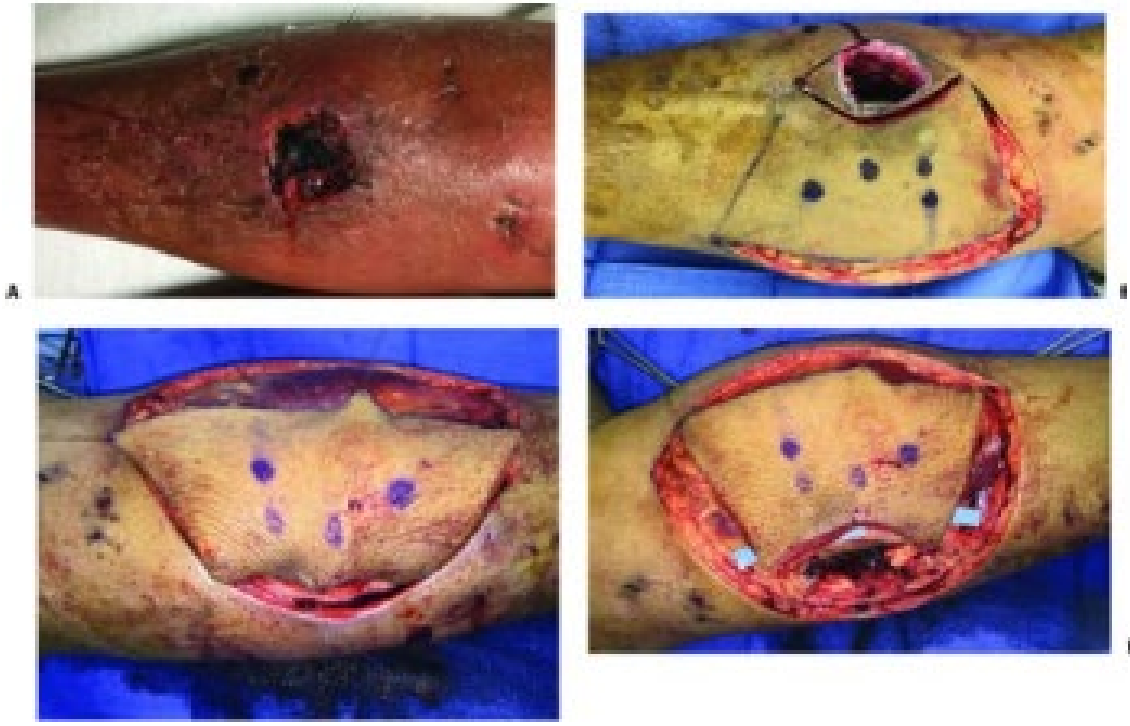
- Intraoperative considerations
  - Team approach
    - Who is doing flap?
  - Prevent spasm
  - Meticulous surgical technique
  - Warm room
  - Flap Type/Shape

Principles of Free Tissue Transfer

- Flap Types
  - Keystone
  - Propeller
  - Pedicled perforator
  - Advancement

Principles of Free Tissue Transfer

- Keystone Flap
  - Shaped like keystone at the top of a Roman arch
  - Mobilized on all four sides and transposed toward defect to create suture line without tension
  - Perforators are located within perimeter of flap undersurface



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Principles of Free Tissue Transfer

- Propeller Flap
  - Fasciocutaneous perforator based flap
  - Flap is elevated on single pedicle and rotated up to 180 degrees to fill a defect close to perforator
  - Perforator comes from deep surface of flap

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Principles of Free Tissue Transfer

- Pedicled Perforator Flap
  - Has perforator at base of flap

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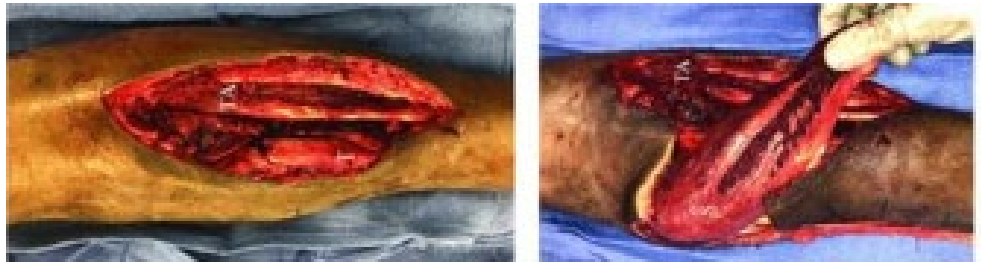
- Advancement Flap
  - Similar to random pattern flaps
  - Allow for greater than 1:1 length to width ratio to be transposed
  - Presence of identifiable perforator vessels within base of flap



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Common Lower Extremity Flaps

Location	Flaps
Hip and groin	Skin graft Rectus abdominis turndown flap Keystone flap Sartorius flap Rectus femoris flap Vastus lateralis flap or pedicled anterolateral thigh flap
Femur	Skin graft Local muscle rotation flap Osteocutaneous fibula flap if vascularized bone needed
Popliteal fossa	Skin graft Medial or lateral head gastrocnemius flap
Anterior knee	Medial or lateral head gastrocnemius flap Keystone flap Distally based gracilis muscle flap
Medial proximal tibia	Medial head gastrocnemius flap Keystone flap
Lateral proximal tibia	Lateral head gastrocnemius flap Keystone flap
Middle third tibia	Keystone flap Soleus muscle flap Hemisoleus muscle flap
Distal third tibia	Keystone flap Peroneus brevis flap Local perforator-based fasciocutaneous flap Free flap (fasciocutaneous or muscle)
Distal fibula	Keystone flap Peroneus brevis flap Reverse sural artery adipofascial cutaneous flap and skin graft Local perforator-based fasciocutaneous flap Free flap (fasciocutaneous or muscle)

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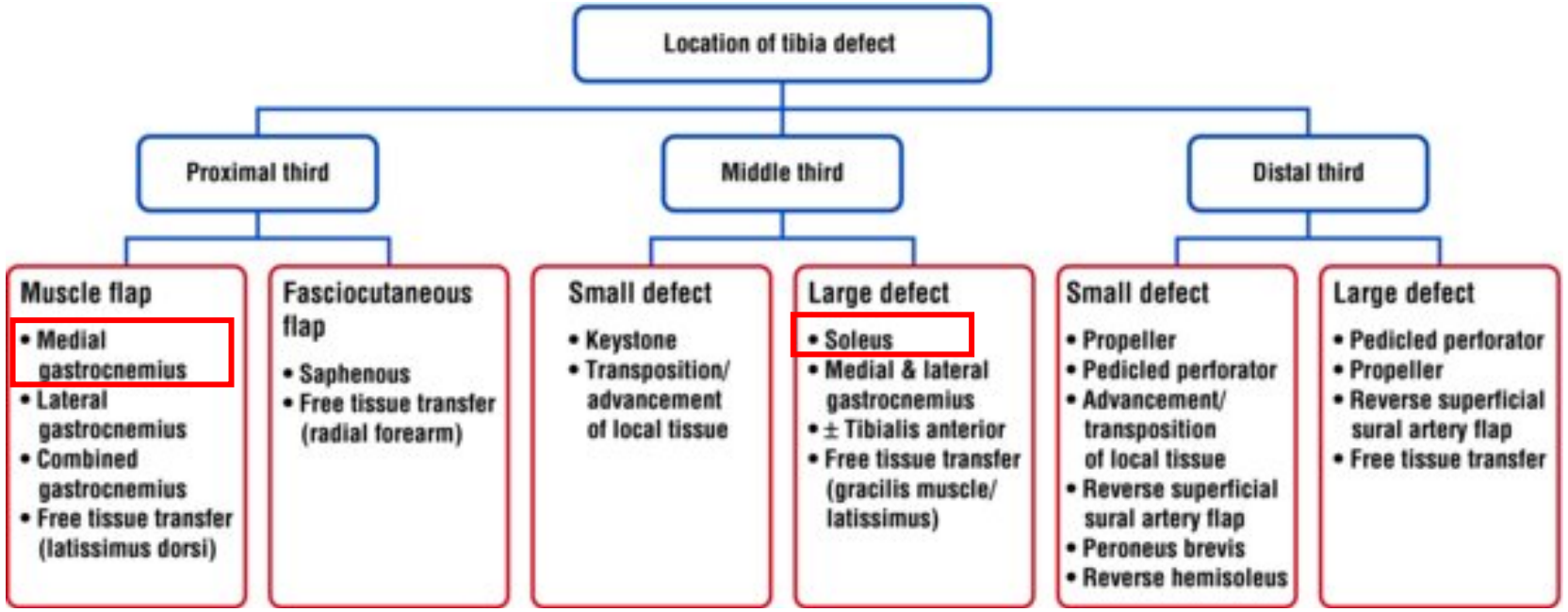
Soft Tissue Coverage for Tibia



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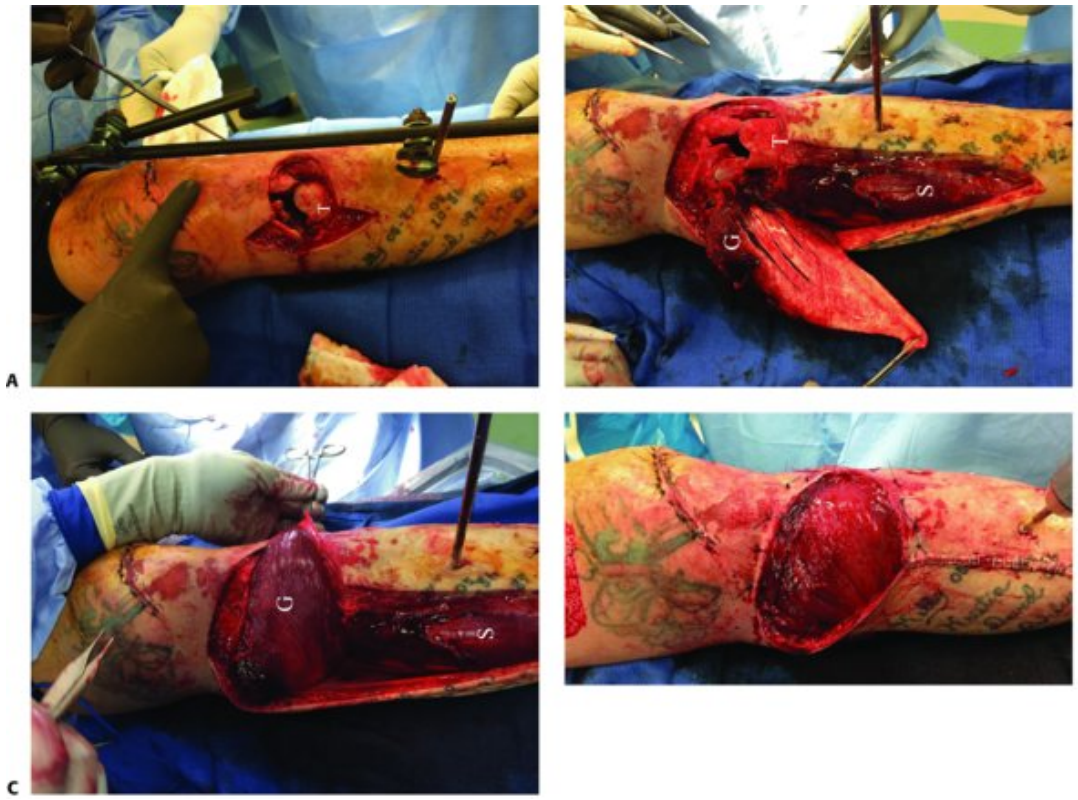
Medial Gastrocnemius Rotational Flap

- Indications: defect of proximal/medial/central tibia, patellar tendon or popliteal fossa
- Medial incision similar for fasciotomy
- Separate medial gastroc from underlying soleus
- Plantaris marks junction between medial and lateral heads

- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723106/medial-gastrocnemius-muscle-flap



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Medial Gastrocnemius Rotational Flap

- Can score deep fascia to lengthen, widen and thin flap
- Take some of medial Achilles tendon to help with suturing muscle into place
- Incise skin bridge rather than tunnel muscle under skin bridge
  - Tunneling may kink muscle or cause external compression

- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723106/medial-gastrocnemius-muscle-flap

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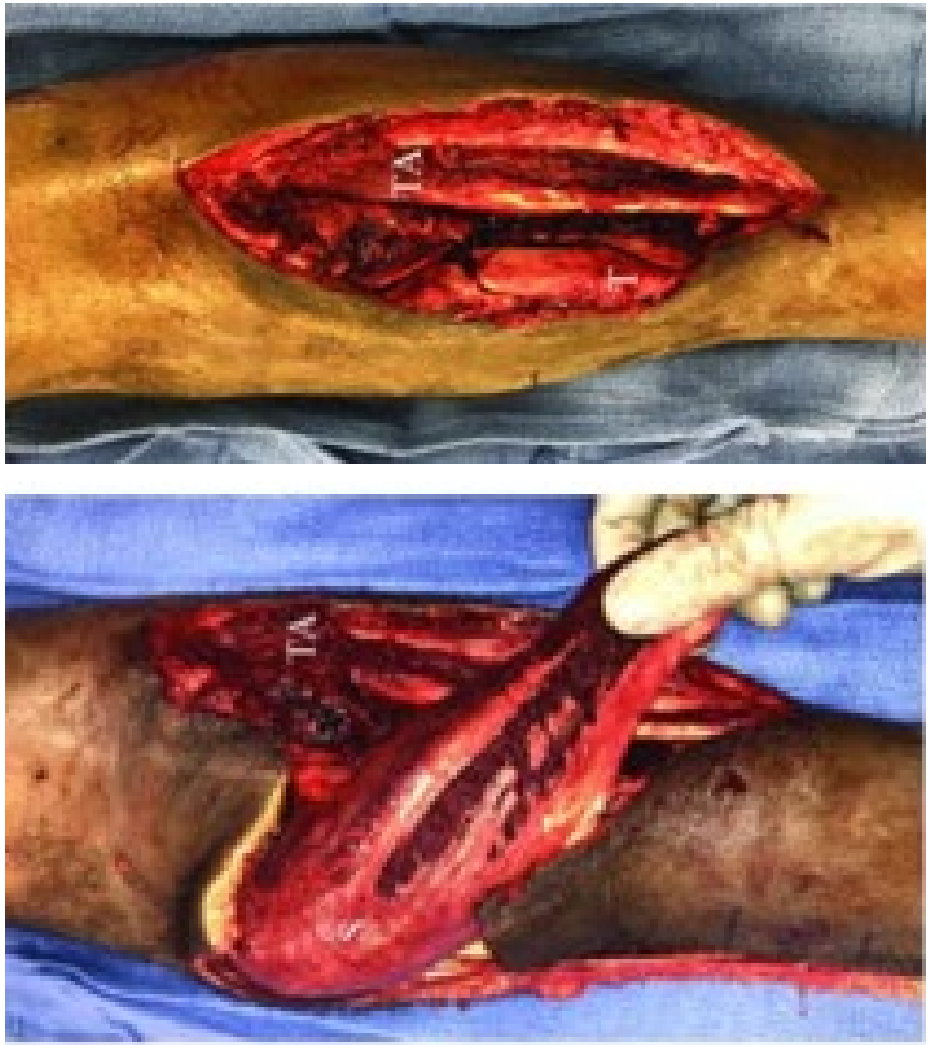
Medial Hemisoleus Flap

- Indications: middle and distal 1/3 tibia
- Narrower muscle belly with less robust vascular supply
  - Lower success rates then gastroc flap
- Less tolerant of tension
  - Makes case technically demanding
- Same incision as medial gastroc flap
- Separate medial gastroc from underlying soleus



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Medial Hemisoleus Flap

- Create plane between soleus and deep posterior compartment
- Release soleus off proximal tibia and from Achilles tendon
- Identify mediolateral junction
- Ligation of deep perforating vessels to allow adequate arc of rotation

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Severe Tibial Bony Defects

- Free flaps have significantly less wound complications with severe underlying tibial bone injury
  - Zone of injury may be larger than anticipated and include rotated muscle
  - More muscle available in free tissue transfer
  - Pollak AN, et al. JBJS Am. 2000. 82(12).
- Muscle flaps have better cortical healing than fasciocutaneous flaps in animal models
  - Also noted in retrospective clinical studies
  - Chan JKK, et al. Plast Reconstr Surg. 2012. 130(2).

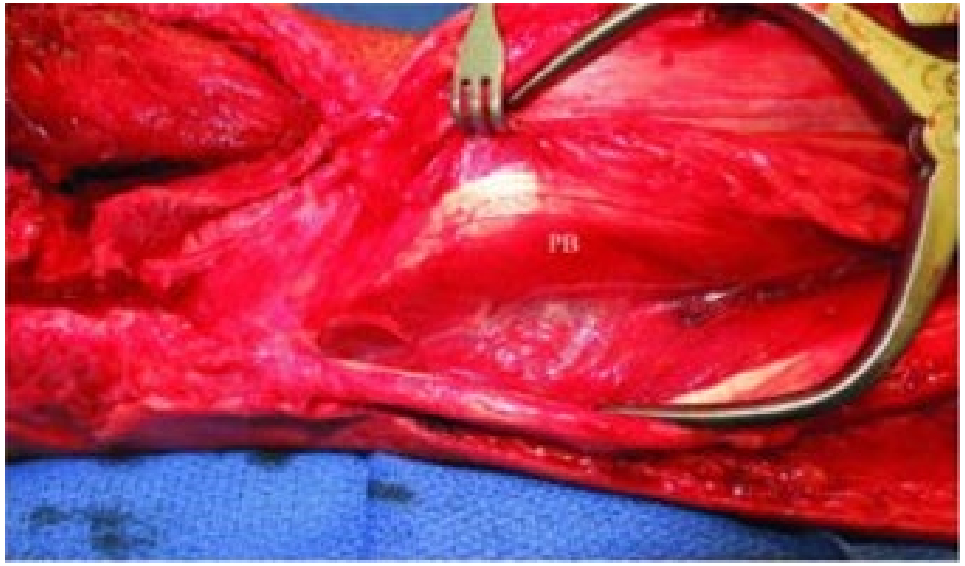
Soft Tissue Coverage of the Ankle

- Challenging location to cover
- Peroneus Brevis flap
- Reverse Sural artery

Images are from “Wound Coverage Techniques for the Injured Extremity” by Gil Ortega, MD. OTA Resident Core Curriculum Lectures

Peroneus Brevis Flap

- Indications: defects of lateral malleolus and lateral anterior ankle joint
- Cannot be reliably rotated to cover distal to lateral malleolus or medial anterior ankle joint
- Flap is based on distally based arterial supply
- Incision along posterior border of fibula
- Identify peroneal muscles (peroneus longus is anterior to brevis)



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Peroneus Brevis Flap

- Soleus retracted posteriorly and PL anteriorly
- Brevis muscle belly is elevated
- Vessel identified at musculotendinous junction and left intact
- Proximal blood supply is ligated
- Muscle is rotated into defect through subcutaneous tunnel
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/17896833/distally-based-peroneus-brevis-rotation-flap

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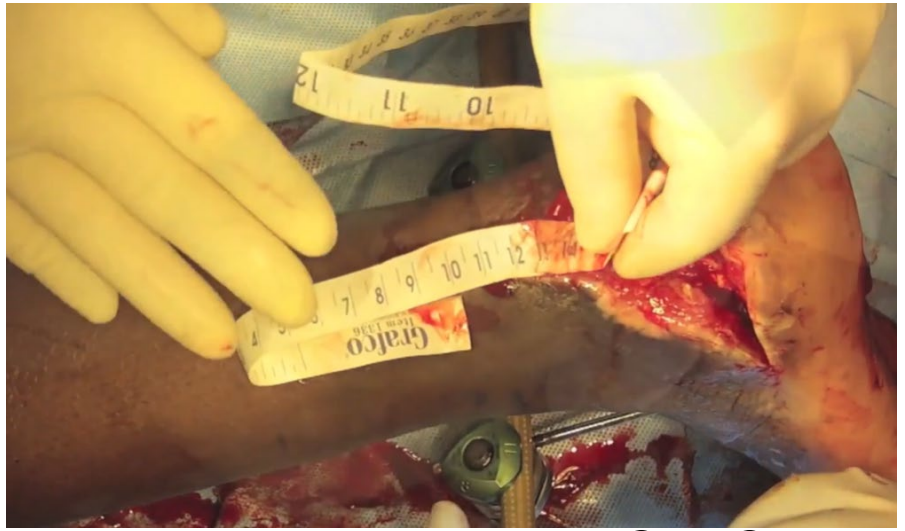
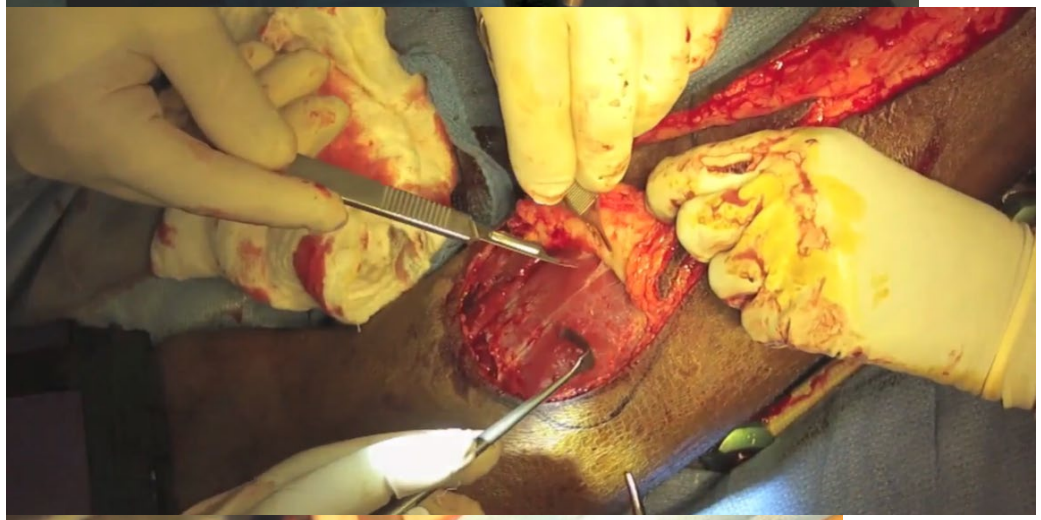
Reverse Sural Artery Flap

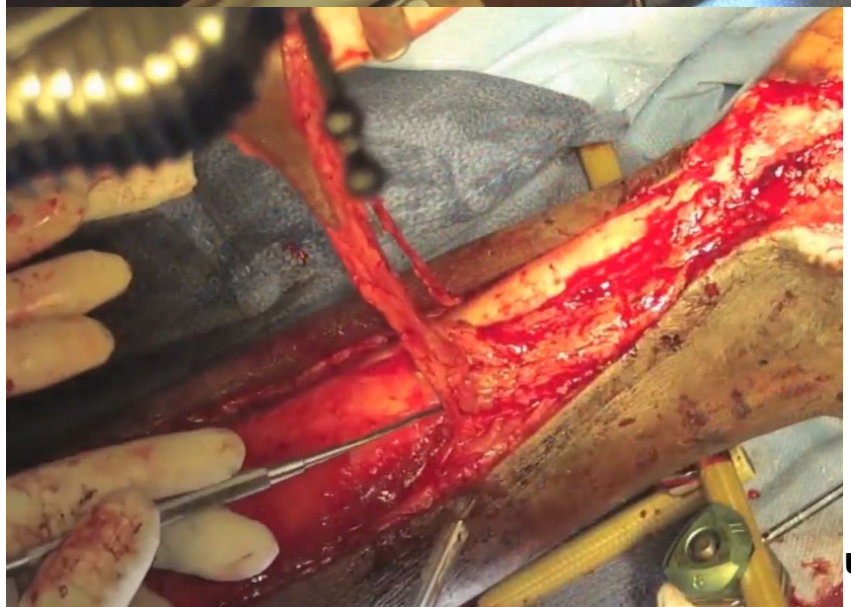
- Indications: lateral ankle/hindfoot defects
- Perforators provide retrograde arterial source to the turndown flap
  - Terminal perforator (pivot point) approximately 5 cm proximal to lateral malleolus
- Axis of flap is centered on a line from popliteal fossa to posterior aspect of lateral malleolus
- Pedicle for skin island should be of sufficient length
  - Skin island should lie in place without kinking or tension
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723104/reverse-sural-artery-flap



Reverse Sural Artery Flap

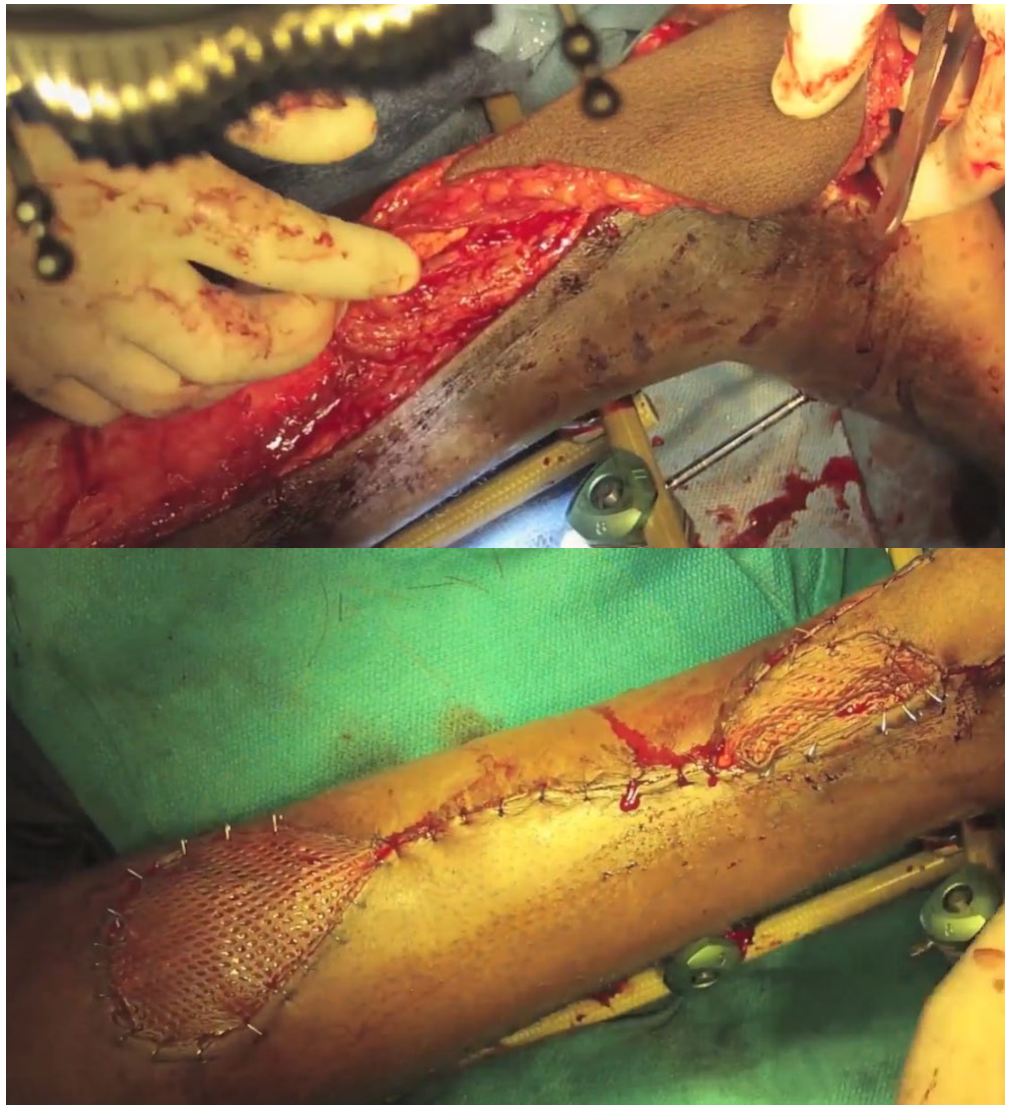
- Skin island elevated circumferentially from 8 o'clock position clockwise to 4 o'clock position
- Full thickness dissection deep to fascia onto gastroc muscle bellies
- Gastroc fascia is elevated with skin island
- Skin flaps carried distally to pivot point
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723104/reverse-sural-artery-flap





Reverse Sural Artery Flap

- Anchoring sutures in flap fascia
- Blood supply is tenuous at flap edges
- For mismatch between flap thickness and skin, better to suture fascia to skin subcutaneous tissue
  - Rather than trying to match skin edges
- Skin can be closed over pedicle but may compromise flap blood flow
  - Alternative is to apply STSG to pedicle
- https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723104/reverse-sural-artery-flap



Common Upper Extremity Flaps

Location	Flaps
Hand and wrist	Skin graft Reverse radial artery forearm flap Posterior interosseous artery flap Ulnar artery perforator flap Radial artery perforator flap Keystone flap Groin flap or periumbilical perforator flap Free flap (fasciocutaneous such as anterolateral thigh or lateral arm)
Forearm	Groin flap or periumbilical perforator flap Keystone flap Free flap (fasciocutaneous such as anterolateral thigh/lateral arm or muscle such as latissimus dorsi)
Elbow	Flexor carpi ulnaris flap Axial radial forearm fasciocutaneous flap Pedicled latissimus dorsi flap Keystone flap Free flap (fasciocutaneous or muscle; osteocutaneous fibula if vascularized bone required)
Humerus	Pedicled latissimus dorsi flap Keystone flap Free flap (fasciocutaneous or muscle; osteocutaneous fibula if vascularized bone required)
Shoulder	Pedicled latissimus dorsi flap Keystone flap Free flap (fasciocutaneous or muscle; osteocutaneous fibula if vascularized bone required)
Extensive	Pedicled latissimus dorsi flap Free flap (fasciocutaneous or muscle)

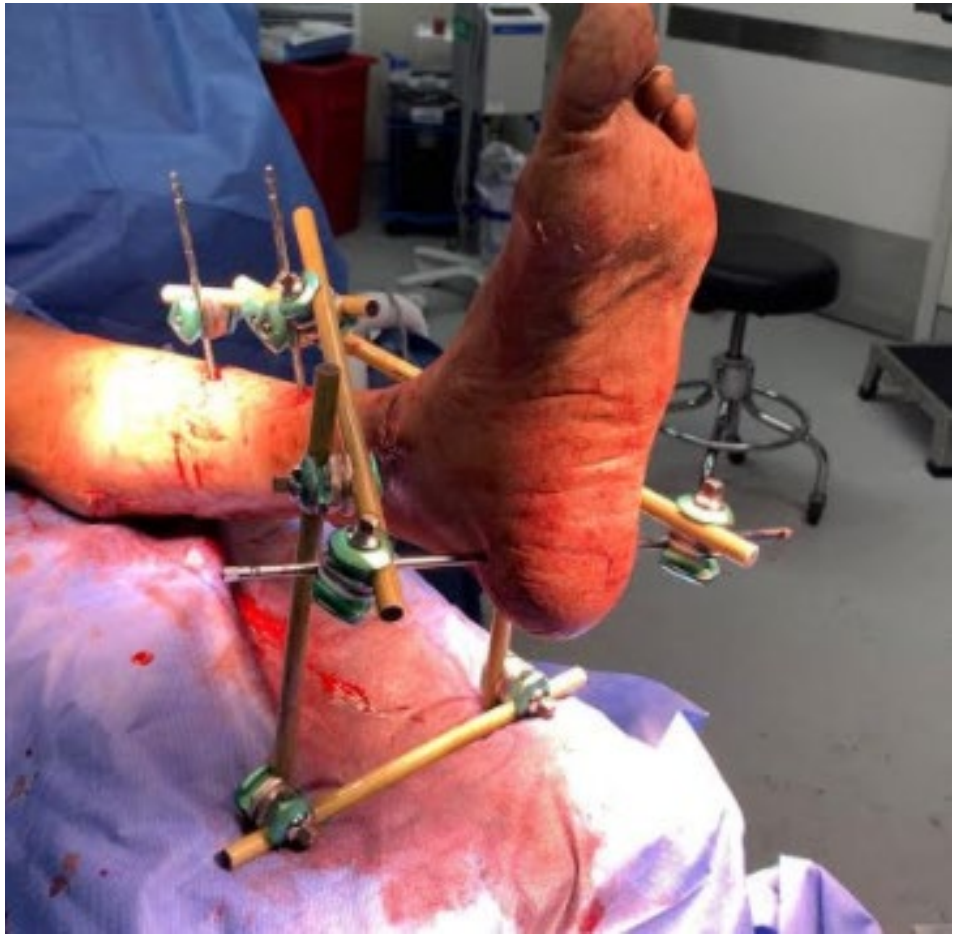
Boyer MI, et al. Soft Tissue Coverage for Injuries and Fractures. Rockwood and Green's Fractures in Adults. 9e. Editor: Paul Tornetta III, MD. Wolters Kluwer. 2019. 580-627.

Soft Tissue Coverage of the Elbow

- STSG for wounds without injury or exposure to neurovascular or osseous structures
- Flaps
  - Regional flap – FCU Flap
  - Intermediate flap – Radial forearm fasciocutaneous flap
  - Extensive soft tissue avulsion – parascapular flap
  - Functional restoration of elbow flexion – latissimus dorsi flap

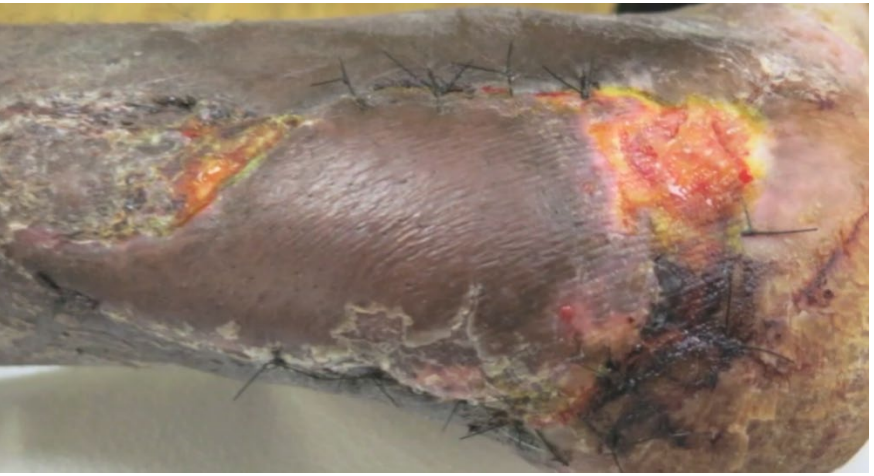
Post Operative Care of Flaps

- Maintain perfusion
- Monitor flap – temperature, Doppler, swelling
- Elevation of extremity
- Offloading/Kickstand external fixator for posterior wounds



Post Operative Care of Flaps

- Flap edge necrosis may occur in initial weeks
  - May require debridement for partial thickness
  - Re-elevation/advancement for full thickness
- Will take weeks before final healing
  - Requires patience and careful monitoring



https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723104/reverse-sural-artery-flap

Soft Tissue Coverage Complications/Outcomes

- STSG
  - Complications/Failure – seroma, infection, shearing, poor vascularity, technical error, graft contraction, graft detachment, necrosis
    - Consider immobilizing adjacent joint to prevent shear
  - Failure rate – 8-40%
    - Improved with use of NPWV (<10% failure rate)
    - Partial graft necrosis may require repeat skin grafting
      - Less likely with NPWV

- Llanos S, et al. Ann Surg. 2006. 244(5)
- Yin Y, et al. Int J Surg. 2018. 50.

Soft Tissue Coverage Complications/Outcomes

- Rotational Flaps/Free Flaps
  - Complications – flap failure, flap edge necrosis, thrombosis, seroma, ischemia, infection
  - Failure rate - 1-10%
  - Similar success rates between local (rotational) and free flaps
    - Cho EH, et al. Plastic Reconstr Surg. 2018. 141(1).
    - VandenBerg J, et al. JOT. 2017. 31(6).
  - Rotational flaps cannot be re-elevated for later orthopaedic procedures and require more skin grafts

Free Flap Donor Site Morbidity

- Sensory nerve deficits
  - >85% of patients with LFCN distribution numbness in ALT flap
- Weakness
  - Mild to no quad muscle weakness with ALT flap
  - Shoulder weakness with extension, adduction and IR (16-33%) latissiumus flap patients
  - Minor velocity weakness (5-7%) with pushoff and uphill walking with gastrocnemius rotational flap
    - Kramers-de Quervain IA, et al. JBJS Am. 2001. 83(2).
- Loss of function
  - Most patients return to preop level of function by 6-12 months with ALT flap
    - Hanasono MM, et al. Plast Reconstr Surg. 2010. 125(1).
  - Minor limitations with shoulder ROM (<10% of normal side)
    - Lee KT, et al. Plast Reconstr Surg. 2014. 134(2).

Summary

- Early antibiotic administration and thorough debridement key to reducing infection risk
- Remember reconstructive ladder
- Choose appropriate coverage method
  - Defect requirements
  - Exposed tissues and coverage needed
  - Patient needs
  - Surgeon factors

Summary

- If soft tissue defect needs coverage, best to perform within 5-7 days (<72 hours ideal)
- Know flap options for each anatomical area
- Protect limb and soft tissue coverage to optimize healing of both

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