Compartment Syndrome

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Disclosure

- Design Team
  - Depuy / Synthes
  - Biomet
- Educational Consultant
  - Depuy
  - Biomet

What are the soft tissues?

- Skin- Epidermis and dermis
- Subcutaneous fat
- Fascia
- Muscle
- Tendons/ligaments/
- periosteum
- Nerves and vessels

Why are they important?

- Good soft tissue envelope is crucial to fracture healing and overall limb function.
- Difficulty in treating open fractures most often related to soft tissue injury and not the bone.

Energy

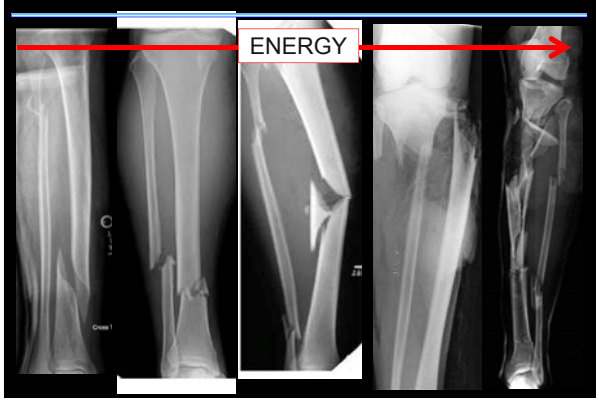
Kinetic Energy = $1/2\ mv^2$

Energy Imparted

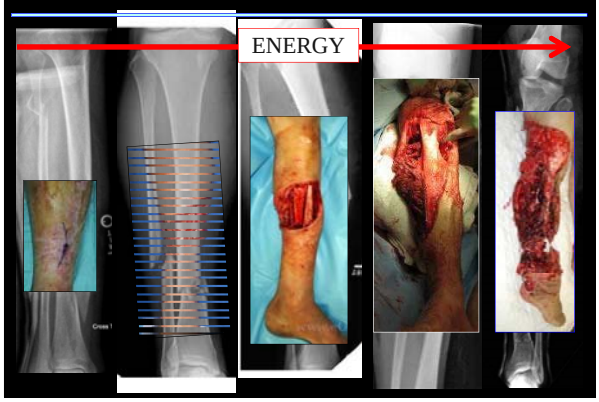
Fall	=	1x	100 ft/lbs
Skiing	=	3-5x	500 ft/lbs
GSW	=	20x	2,000 ft/lbs
Bumper injury	=	100x	20,000 ft/lbs

*Chapman

Fracture pattern predicts energy of injury

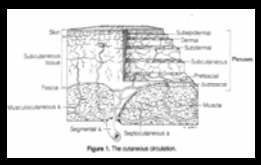


Fracture pattern predicts energy of injury



Angiosome concept

- Taylor and Palmer, Br Journ Plast Surgery, 1987
  - ***Angiosome*** - composite unit of skin and underlying deep tissue supplied by the source artery.
  - Beware of watershed areas!!



Soft Tissue Healing

- **Three phases:**
  - Hours: microthrombi, INFLAMMATORY CELLS.
  - Days: Epithelialization, wound contracture, and neoangiogenesis.
  - Weeks: Dermal reconstruction (remodeling)

Patho-physiology

- Different outcome with MASSIVE INJURY
  - Inflammatory response unable to control extent of tissue damage
  - Necrosis of inflammatory cells results with release of proteolytic enzymes
  - Further necrosis of surrounding tissue occurs
  - Vicious cycle results—leading to:
    - → Progressive inflammation
    - → Muscle ischemia
    - → Increased compartment pressures
    - → Tissue loss and death => Infection

Markers of Soft Tissue Injury

- Open Fractures
- Traumatic dislocations
- Segmental fractures
- Significant comminution
- Blistering: soft-tissue "internal degloving"

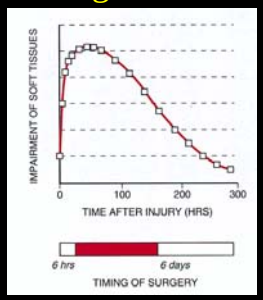
Blisters

- Cleavage of dermal / epidermal junction
- Clear
  - Occasional epidermal cells still in contact
- Blood-filled
  - Complete shear of epidermis
  - ? Contamination
  - Longer re-epithelialization

Koval KJ, et al: 1994, 1995, 2006

Surgical Timing

- Patience
- Timing critical
- Avoid 1-6 days
- Await soft tissue envelope (10-21 days)

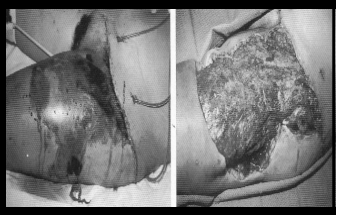


Wagner HE and Jakob RP: Unfallchirurg 1986

It's not the fracture
It's the **Soft Tissues**

Personality of soft tissue injury

- Abrasion/Avulsion:
  - Impart shear forces to the extremity.
  - May be superficial or deep.
  - Concentrate on removing foreign matter from wound with abrasions.
  - In avulsion injuries *subcutaneous planes separate from fascia, resulting in skin necrosis*
  - ***MOREL-LAVALLE***



Classifications - *Gustilo*

- ***Type I***: open fx w/ wound < 1cm
  - Usually spike of bone "inside-to-outside"
  - No crush injury
- ***Type II***: Larger wound (1-10cm) & slight crush

Classifications - *Gustilo*

- ***Type III***: severe soft tissue injury and contamin
  - IIIA: Delayed closure possible after I&D w/o flaps
  - IIIB: Bone exposed and require muscle flaps
  - IIIC: Arterial injury and possible limb salvage procedure needed
- ***Infxn***: I-2%, II and IIIA-7%, IIIB and C 10 to 50%

Gustilo and Anderson Caveats

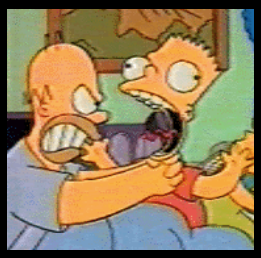
- ***Zone of injury***
- ***NOT ER determination***

Classification - ***Tscherne Closed Fx's***

- ***Grade 0:*** indirect forces w/ negligible soft tissue damage
- ***Grade I***: low energy w/ superficial contusion / abrasion
- ***Grade II***: signif muscle contusion, possible deep contamin, "bumper fx", **high risk compartment syndrome*
- ***Grade III***: severe subcutaneous degloving ± arterial injury ± compartment syndrome

Compartment Syndrome:

- A condition characterized by ***RAISED PRESSURE WITHIN A CLOSED SPACE*** with a potential to cause ***irreversible damage*** to the contents of the closed space



Pathophysiology:

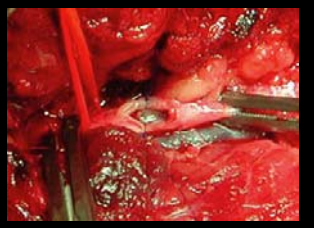
- ***CAUSES:***
- **Increased Volume - internal :** hemmorhage, fractures, increased fluid secondary to burns, post-ischemic swelling
- **Decreased volume - external:** tight casts
- ***Most common causes of hemmorhage into a compartment:*** fractures of the tibia, elbow, forearm or femur

Pathophysiology:

Most common cause of compartment syndrome is ***muscle injury*** that leads to edema

Arterial Injuries

- ***Secondary to revascularization***
- Prophylactic Fasciotomies !!!



Responses to Ischemia

- Complete ischemia: muscle survives ***< 4 hrs without irreversible damage & neuropraxia***

- Total ischemia ***>8 hrs produces complete irreversible changes*** in muscle and ***axonotemesis***

Difficult Diagnosis

- Classic signs of the 5 P's - ***ARE NOT RELIABLE***:
  - ***Pain***
  - ***Paresthesias***
  - ***Pallor***
  - Pulselessness
  - Paralysis

- These are signs of an ESTABLISHED compartment syndrome where ischemic injury has already taken place

Diagnosis

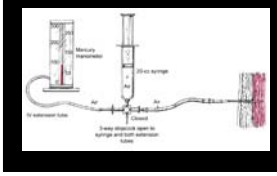
- The presence of an ***open fracture does NOT rule out the presence of a compartment syndrome***
- McQueen et al found ***no significant differences in compartment pressures between open and closed tibial fractures***

Compartment Syndrome

- ***Normal tissue pressure***
  - 0-4 mm Hg
  - 8-10 with exertion
- ***Absolute pressure theory***
  - 30 mm Hg - Mubarak
  - 45 mm Hg – Matsen
- ***Pressure gradient theory***
  - < 20 mm Hg of DP --> Whitesides
  - < 30 mm Hg of DP --> McQueen, et al

Compartment Syndrome
Pressure Measurements

- Infusion
  - manometer
  - saline
  - 3-way stopcock (Whitesides, CORR 1975)
- Arterial line
  - 16 - 18 ga. Needle (5-19 mm Hg higher)
  - transducer
  - monitor
- Stryker device
  - Side port needle

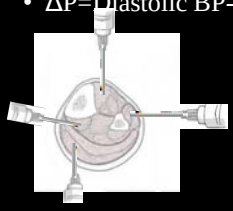


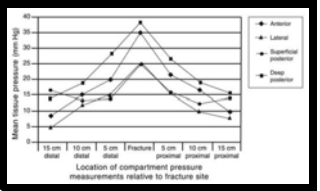
Compartment Syndrome
Pressure Measurements

- Needle
  - 18 gauge
  - Side ported
- Performed within 5 cm of the injury if possible-Whitesides, Heckman

Measuring Compartment Pressures

- ΔP=Diastolic BP-compartment pressure



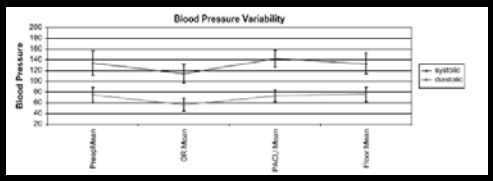


ΔP ≤ 30mmHg=ACS

Shadgan et al JOT 2008: Olson et al JAAOS 2005; Heckamn et al JBJS 1994

Diastolic Blood Pressure in Patients With Tibia Fractures Under Anaesthesia: Implications for the Diagnosis of Compartment Syndrome

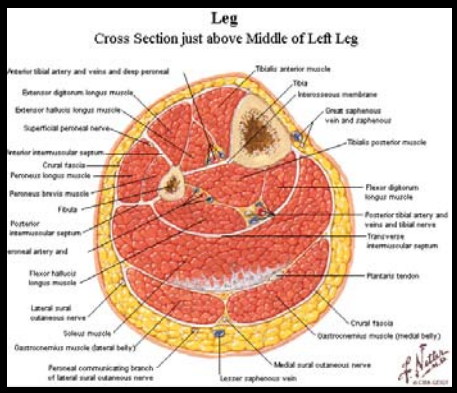
Sanjeev Kakar, MD, MRCS Eng, Reza Firoozabadi, MD,† Jason McKean, MD,‡ and Paul Tornetta III, MD**



Intra-op Delta-P may be lower than Pre- & Post-op

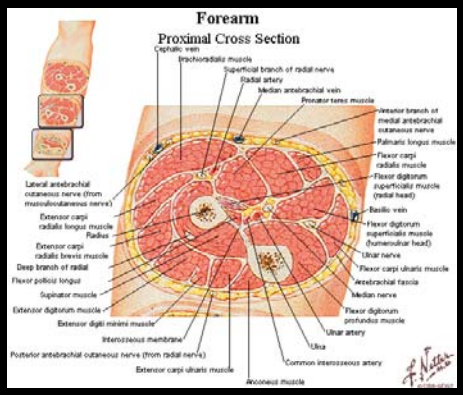
Most Common Locations

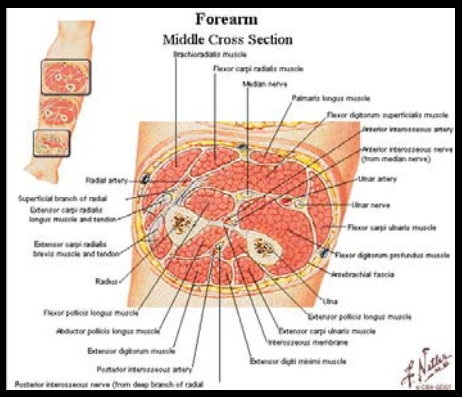
- Leg: ***deep posterior and the anterior compartments***
- Forearm: ***volar compartment***, especially in the deep flexor area

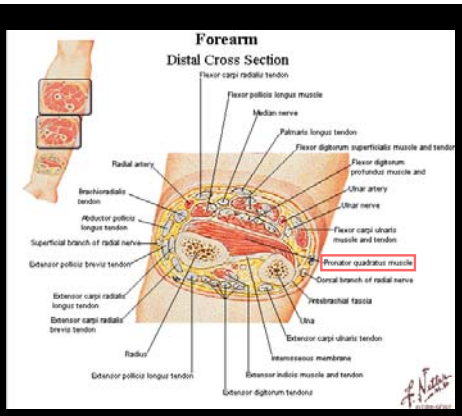


Compartments of the Forearm

- Forearm can be divided into 3 compartments:
  - Dorsal (EPB, EPL, ECU, EDC)
  - Volar (FPL, FCR, FCU, FDS, FDP, PQ)
  - Mobile Wad (Brachioradialis, ECRL, ECRB)







Treatment

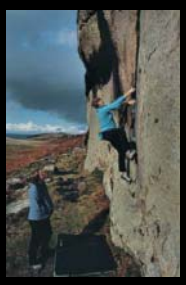
THE ONLY EFFECTIVE WAY TO DECOMPRESS AN ACUTE COMPARTMENT SYNDROME IS BY SURGICAL FASCIOTOMY!!!

Different for missed compartment syndrome

Treatment

The affected limb should not be elevated: elevation reduces mean arterial pressure and therefore reduces blood flow into the compartment; the limb should be placed at the level of the heart

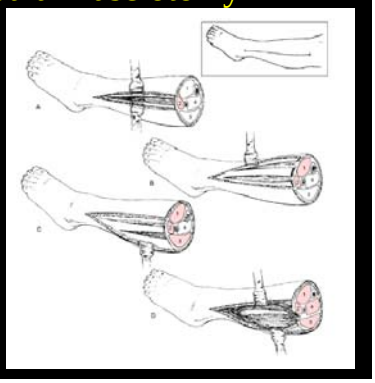
"It's like climbing uphill!"



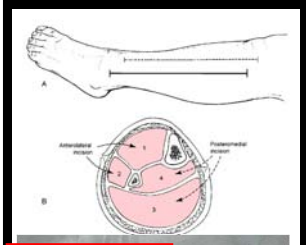
Perifibular Fasciotomy

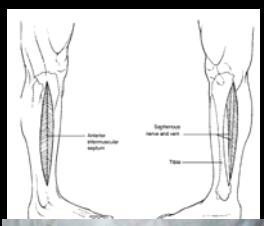
Posterior access

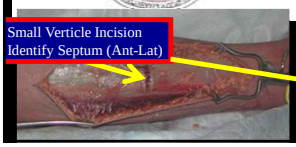
- Distally
  - Soleus / FHL
- Proximally
  - Soleus / fibula
- Deep
  - Deep muscles / IO membrane



Double-Incision Fasciotomy





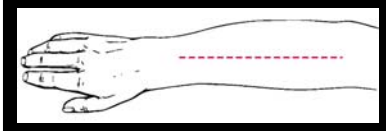


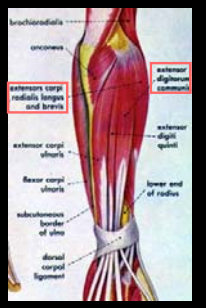
Henry Approach

- Incision begins PROXIMAL to antecubital fossa
- Extends across CARPAL TUNNEL
- Fascia over superficial muscles is incised
- Care of NV structures

Dorsal Approach

- Straight incision from the lateral epicondyle to the midline of the wrist
- Interval between the ECRB and EDC is used to access deep fascia





Debridement

- Modern methods of tissue transfer allows radical debridement without leaving vital structures exposed.
- ***Critical aspect is the thorough removal of all necrotic, contaminated, and nonviable tissue.***
- ***Single most important factor in the prevention and treatment of wound infections.***
- May be done in the acute and chronic wounds.

Debridement

- ***"Start at the skin and work your way in…"***
- ***Bovie is a NOT solely reliable to check muscle viability***

- Sub-Q tissue w/ scant b.s.
- Resect "stripped" fascia
- Muscle
  - Nidus for infection
  - Can have function with 10% muscle belly

Debridement

- **Muscle:** Evaluation of the four C's.
  - **Color**
  - **Consistency**
  - **Contractility**
  - **Capacity to bleed**

Debridement

- **Tendons:** Paratenon essential for survival if coverage not possible.
  - ***Disrupted tendons should be sutured to surrounding soft tissues for later reconstruction.***
- **Periosteum:** Should be excised to the level at which it is elevated off of the bone.

Debridement

- **Bone:** Viability
  - Punctate bleeding ***"paprika sign"*** (Cierny) should be encountered from the cortical bone
  - Swiontkowski utilized Laser Doppler flowmetry (LDF) to aid in the assessment of bone viability by measuring capillary level blood cell motion.

The reconstructive ladder

STSG vs FTSG
- STSG include only part of the dermis
- STSG more likely to "take" than FTSG.
- FTSG retain sensation better.
- Spontaneous reepithelialization not possible in FTSG, requiring closure of donor wound.
- FTSG's usually small and are primarily used in the hands and face.

- Rotational flaps:
  - ***May be limited secondary to wound location, size of defect, or regional donor-site deficiencies***.

Skin grafting

- Healing:
  - ***First 48 hours*** graft survives by a process called ***"imbibition"*** of wound bed exudate.
  - ***After 48 hours, neo-angiogenesis,*** new blood vessels sprout from the wound bed and grow into the graft.
  - By 5-7 days, a skin graft is usually adherent and vascularized.

TABLE 1. *Most common donor sites for split-thickness skin grafts*

Buttock and thigh
Abdomen
Back
Scalp
Chest wall
Arms

Regional Flaps

- Although cutaneous tissue may offer stable coverage in open fractures, ***muscle is the best tissue for providing revascularization of bone***, controlling subflap levels of bacteria, obliterating dead space, and improving antibiotic delivery.
- The vascularity of fasciocutaneous flaps is very often affected by the injury, leading to high donor site morbidity.
- Therefore, ***muscle flaps are the gold standard for the coverage of bony defects*** in the settings of acute trauma and infection.

Regional Flaps

- **Gastrocnemius muscle flap:**
  - Workhorse local transposition flap for soft tissue coverage about the knee and proximal third of the tibia.
  - Medial head is larger and is the preferred head for transposition.
  - Type I flap, vascularized by the ***sural arteries*** (medial and lateral) which arise from the popliteal artery at the level of the joint.
  - Reliable flap with minimal donor site morbidity.

Rotational v/s Free Flap

- LEAP study – 190 flaps at 6 mth F/U
- ***For more severe osseous injury free flaps have lesser complications compared to rotational flaps***
- Overall 27% complication rate

Management: Open Fx

- Irrigation and Debridement
  - ***Should be performed only in OR***
  - Copious irrigation with isotonic solution
  - Meticulous removal and resection of all foreign and dead material
  - Determination of full extent of injury zone
  - Delineation of viable zone by bleeding tissue

Wound Management

Wound Management

- Henry *et al* (CORR 1993) describe the use of an ***antibiotic bead pouch*** in the management of open fxs
- ***Cement quality***
- ***Elution quality***
- ***Surface area***
- ***Antibiotic quantity***

Wound Management

Deep Infection Rate

Gustillo Type	Gauze Packing	Bead Pouch
Type I	1/91 (1%)	0/13 (0%)
Type II	2/75 (2.6%)	1/52 (2%)
Type III	7/33 (21%)	8/70 (12%)

Wound Management

- Bead pouch technique (4%) is an effective method of infection prophylaxis when compared to gauze packing(16%)

Keating *et al* (JOT 1996)

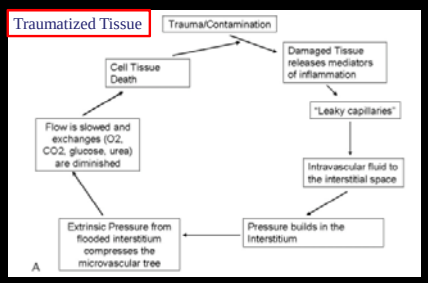
Vaccum Assisted Closure (VAC)

- Promotes granulation, allows constant drainage, decreases bacterial count.
- Can be wound dressing, over STSG
- Can be used over closed wounds to decrease swelling.
- Change 48-72 hours.

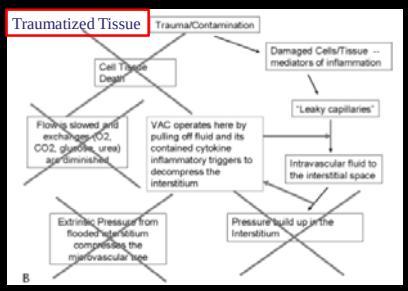
VAC

- Theory 1
  - Tissue strain increases
    - Mitogenesis
    - Growth factors
- Theory 2
  - Evacuation of excessive interstitial fluid and effect on capillary circulation
  - Decreases local cytokines and inflammatory markers
  - Helps with allowing normal O2 and CO2 and nutrient exchange

VAC



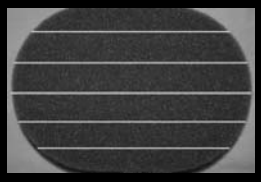
VAC



VAC

•Seals surgical wounds

- Decreased MRSA
- Decreased VRSA



At time of Fasciotomy

- Must get bone stability
  - IMN
  - Exfix
- ~48hrs after procedure patient should be brought back to OR for further debridement
- Delayed skin closure or skin-grafting may be attempted 3-7 days after the fasciotomies

Wound Management

- When FLAP COVERAGE needed → TIMING:
  - There are proponents of immediate soft-tissue transfer- "Fix and flap" (Gopal *et al* JBJS(B), 2000)
  - However, wound may have not "declared itself"
  - This makes serial debridement, if necessary, difficult

Timing of Definitive Fixation of Severe Tibial Plateau Fractures With Compartment Syndrome Does Not Have an Effect on the Rate of Infection

J Trauma 2010

Robert D. Zura, MD, Samuel B. Adams, Jr., MD, Kyle J. Jeray, MD, William T. Obremskey, MD, Sandra S. Stinnett, DrPH, and Steven A. Olson, MD; for the Southeastern Fracture Consortium Foundation

- 81 patients
  - Fix then close: 23%
  - Fix and close: 12%
  - Close then fix: 16%
  - P= .05012

- 6 trauma centers
- Small (n)
- Barely not stat. sig.

Remember…

- Fasciotomies are not benign
- Complications are real >25%
  - Chronic swelling
  - Chronic pain
  - Muscle weakness
  - Iatrogenic NV injury
  - Cosmetic concerns

****** BUT if they are needed do not come up with excuses to not do them !!!***

VAC

- Reddix et al (OTA 2007)
  - 212 acetabular VACs
    - 1.4 % deep infection
    - 0.5 % dehiscence
    - 0 % wound complication w/ obese patients
  - 60 acetabular No-VACs
    - 6.7 % deep infection
    - 3.3 % dehiscence

- Stannard et al
  - VAC use in multiple high-risk LE wounds
  - Significantly lower incidence wound complications

VAC

•Gomoll et al JOT 2006

- Technique of incisional VAC
- Hip, distal tibia, knee region
- 35 pts
  - 22-80 y.o.
- 0 % wound complications

Wound Management

Henry *et al*: Timing of soft tissue coverage

Flap Time	Patients	Infection	Flap Failure
0-6 days	29	4 (13.7%)	4 (13.7%)
7-13 days	56	4 (7.1%)	4 (7.1%)
14-20 days	29	5 (17.1%)	2 (6.9%)
>20 days	37	10 (27%)	4 (11%)

The Mangled Extremity - QUESTIONS

- Amputation vs. limb salvage
  - Ischemia time:
    - Warm > 6 hrs
    - Cold > 8 hrs
  - Presence of type IIIC open fx
  - Posterior tibial nerve disruption

Amputation vs. Limb Salvage

- Lange (CORR, 1989) criteria for primary amputation
  - Absolute Indications:
    - Anatomic disruption of posterior tibial nerve
    - Crush injuries with warm ischemia time >6h
  - Relative Indications:
    - Serious associated polytrauma
    - Severe ipsilateral foot trauma
    - Anticipated protracted course to obtain soft-tissue coverage and tibial reconstitution

Amputation vs. Limb Salvage

- MESS Score
  - Points assigned for multiple criteria:
    - Skeletal/soft tissue injury
    - Limb Ischemia
    - Shock
    - Age
  - Score >7 → 100% predictive of amputation

NOT NECESSARILY TRUE!
Bosse MJ *et al*, JBJS 2001

Amputation vs. Limb Salvage

- Cannot reliably use scoring systems to predict necessity of amputation

Amputation vs. Limb Salvage

LEAP: The Insensate Foot

- Compared patients with insensate feet who underwent amputation vs. patients who underwent limb salvage
- No significant difference in functional outcome at 2-year follow-up

Jones AL *et al*, 2000 OTA

Amputation vs. Limb Salvage

- Surgeon's experience may be that functional outcome will be better with an early amputation
- Francel *et al* (1992) reported 28% of salvaged limb patients returned to work at 2 years, compared to 68% of amputees.

Amputation vs. Limb Salvage

- When to amputate acutely???
  - Absolute indications:
    - Unreconstructable vascular injury
    - Protracted warm ischemia time
    - Unreconstructable skeletal injury
    - Unreconstructable soft tissue envelope
    - Patient is too sick to undergo salvage
    - Patient preference

Take Home Points

- Must RECOGNIZE the signs → EMERGENCY
- Don't think that other concomitant conditions "prevent" the possibility of compartment syn
  - Vascular Injury
  - Open Fracture
- Wound mgmt. key to avoid late infection
- Timing of definitive fixation considerations
- Fasciotomy is a Limb Salvage Procedure but NOT without long-term effects