Acute Compartment Syndrome

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OBJECTIVES

- Review pathophysiology of acute compartment syndrome
- Risk factors
- Diagnosis
- Clinical findings
- Treatment

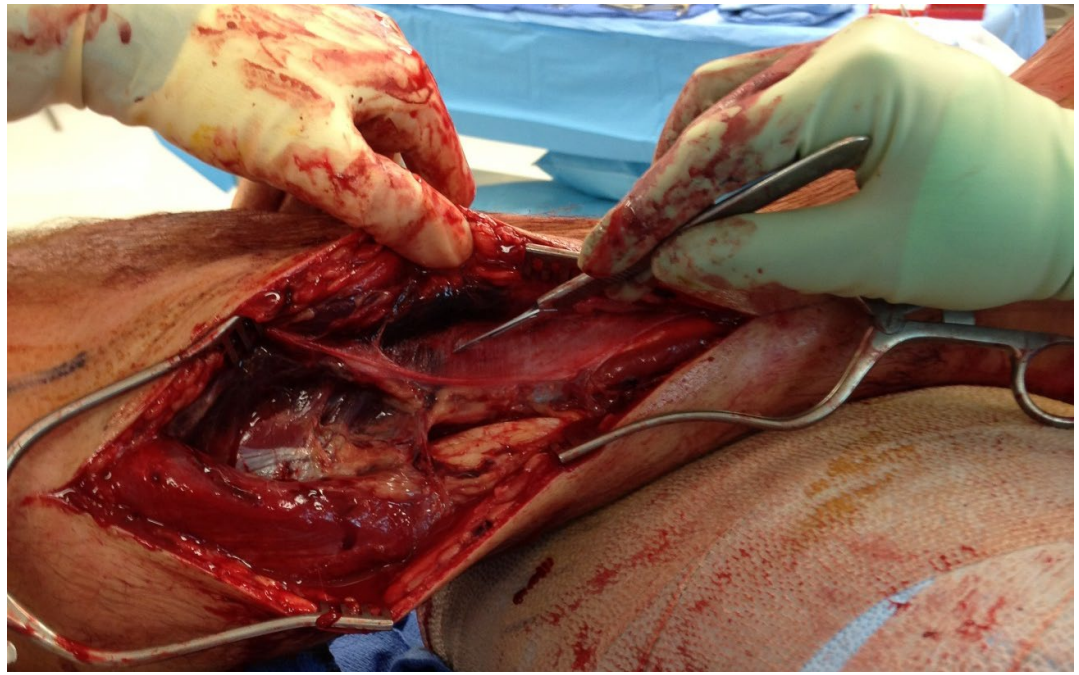


Image provided by Lisa Cannada, MD

DEFINITION

- Acute compartment syndrome (ACS) occurs when pressure rises within confined space →critical reduction of blood flow to tissues

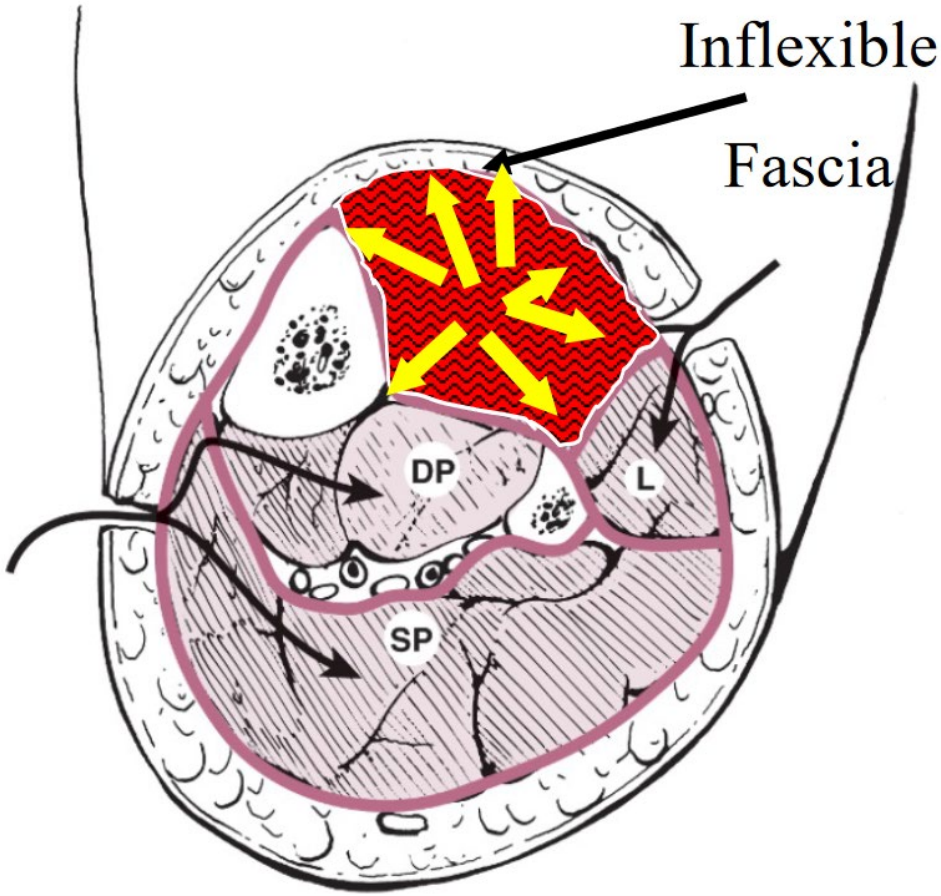


Image: Schmidt, OTA core curriculum presentation acute compartment syndrome 2018

DEFINITION

- Surgical orthopaedic **emergency**
- Late presentation/missed diagnosis can result in catastrophic consequences:
  - myonecrosis
  - rhabdomyolysis
  - contracture
  - sensory loss
  - infection
  - nonunion
  - amputation

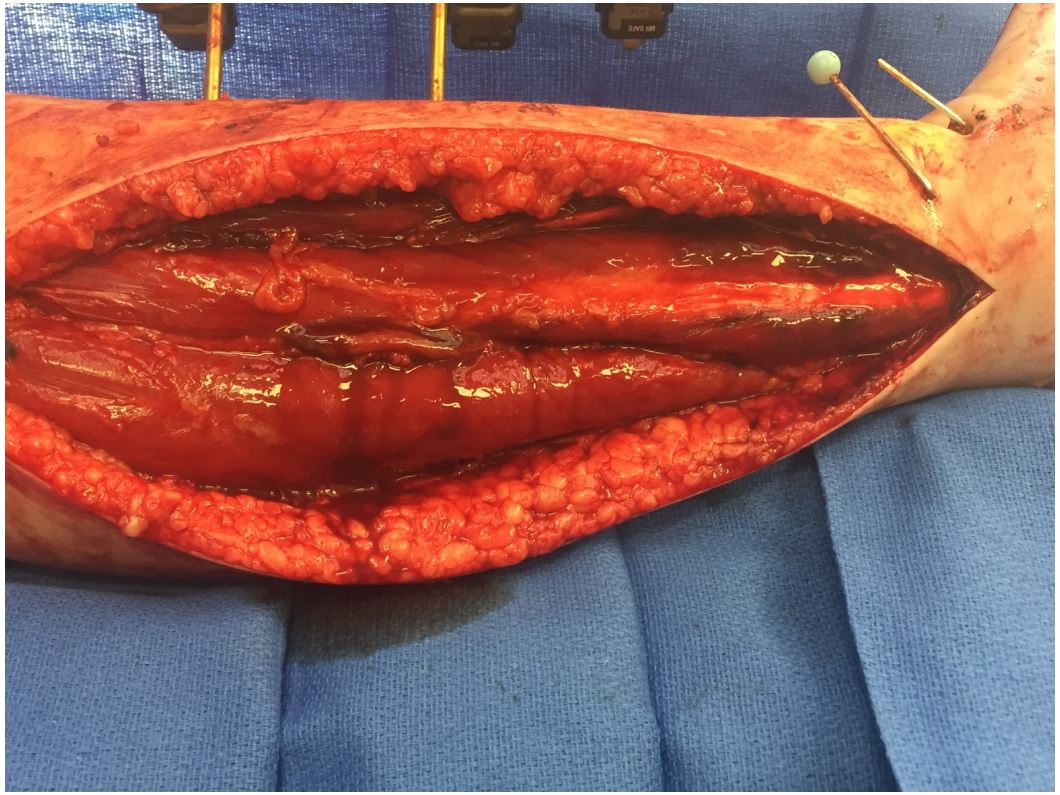


Image provided by Lisa Cannada, MD

PATHOPHYSIOLOGY

- In normal tissue, there is a steady state of flow between the high-pressure arterial and low-pressure venous systems
- An injury such as a fracture, a burn, or anything that damages the soft tissue can disrupt this gradient and “tilt the seesaw”

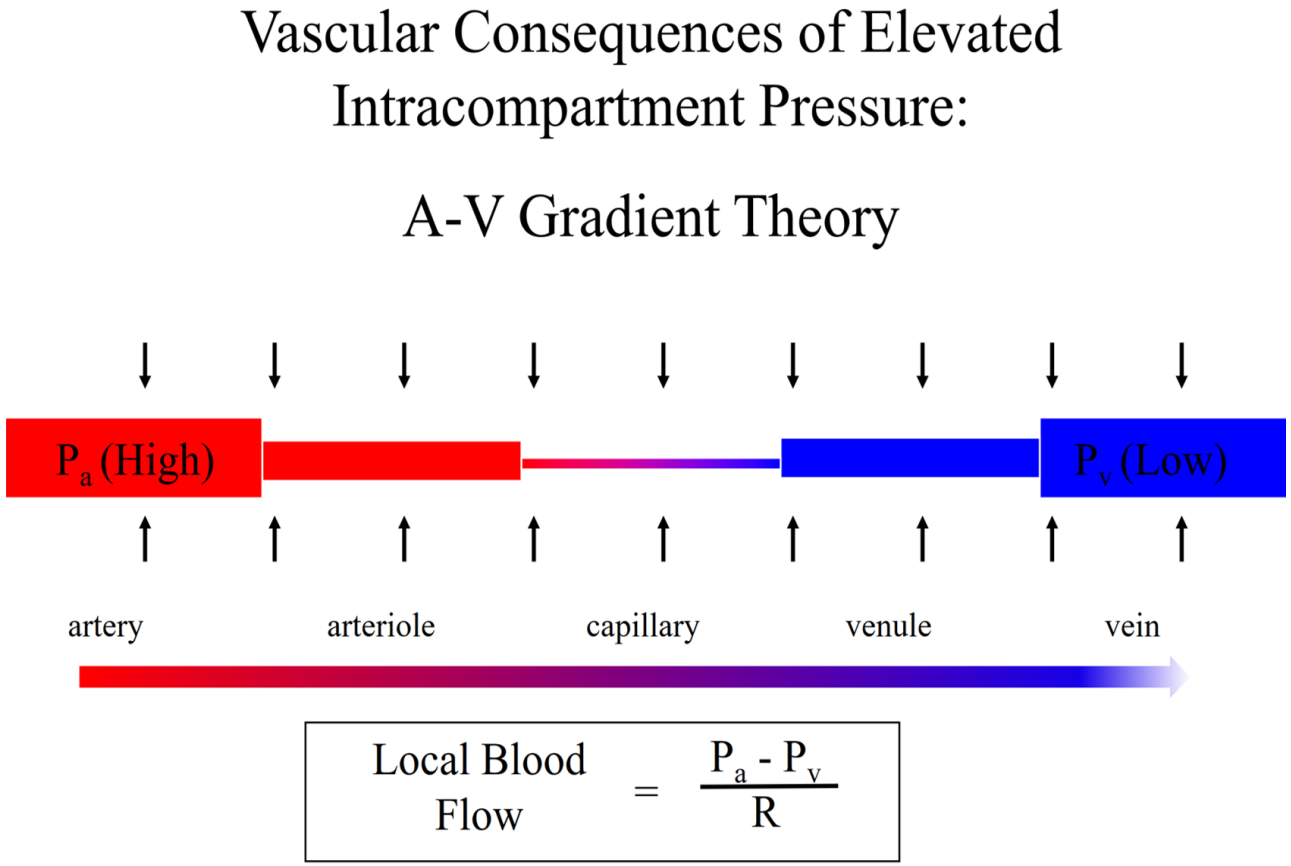


Image: Schmidt, OTA core curriculum presentation acute compartment syndrome 2018

PATHOPHYSIOLOGY

- In damaged tissue, rising pressure→reduction in flow to muscle
- Reduction in flow→tissue ischemia
- Tissue ischemia→More cellular injury and release of osmotically active cellular contents into interstitial fluid
- Release of fluid → further increase in pressure

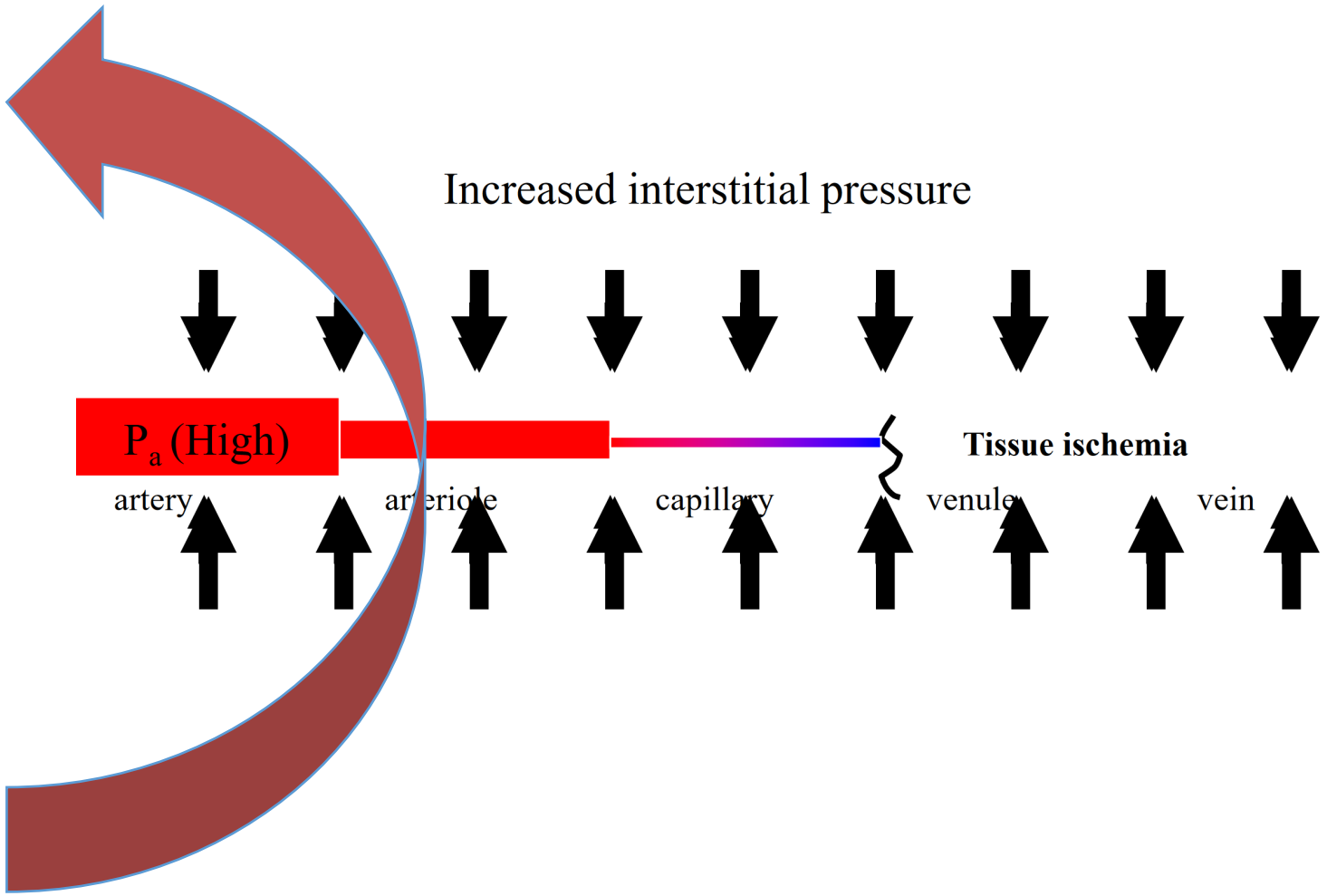


Image: Schmidt, OTA core curriculum presentation acute compartment syndrome 2018

TIMING OF CONSEQUENCES

Effect Time	Muscle	Nerve
2-4 hours	Reversible Damage	Loose Conduction
4-6 hours	Variable Damage	Neurapraxia
>6 hours	Irreversible Damage	Irreversible Damage

RISK FACTORS

- Trauma
  - Fracture (69%)
  - Crush Syndrome
  - Soft Tissue Injury
- Tibia most common involved bone (35-40% ACS in fractures)
- Key: an open fracture **CAN** get compartment syndrome!
  - Does not “self-fasciotomize”
  - Risk higher due to higher-energy soft tissue injury

Underlying Condition	% of Cases
Tibial diaphyseal fracture	36
Soft tissue injury	23.2
Distal radius fracture	9.8
Crush syndrome	7.9
Diaphyseal fracture forearm	7.9
Femoral diaphyseal fracture	3.0
Tibial plateau fracture	3.0
Hand fracture(s)	2.5
Tibial pilon fractures	2.5
Foot fracture(s)	1.8
Ankle fracture	0.6
Elbow fracture dislocation	0.6
Pelvic fracture	0.6
Humeral diaphyseal fracture	0.6

Image: Rockwood + Green, 9th ed

RISK FACTORS

- Most cases of compartment syndrome involve traumatic injury with high-energy forces
  - Sports injuries common
- BUT can also occur in relatively low-energy and atraumatic injuries (drug overdose)

Conditions Increasing the Volume of Compartment Contents

Fracture

Soft tissue injury

Crush syndrome (including use of the lithotomy position)[84]

Revascularization

Exercise[94]

Bleeding diathesis/anticoagulants[66,124]

Fluid infusion (including arthroscopy)[10,132]

Arterial puncture[133]

Ruptured ganglia/cysts[30]

Osteotomy[45]

Snake bite[152]

Nephrotic syndrome[146]

Leukemic infiltration[151]

Viral myositis[78]

Acute hematogenous osteomyelitis[144]

Conditions Reducing Compartment Volume

Burns

Repair of muscle hernia[4]

Medical Comorbidity

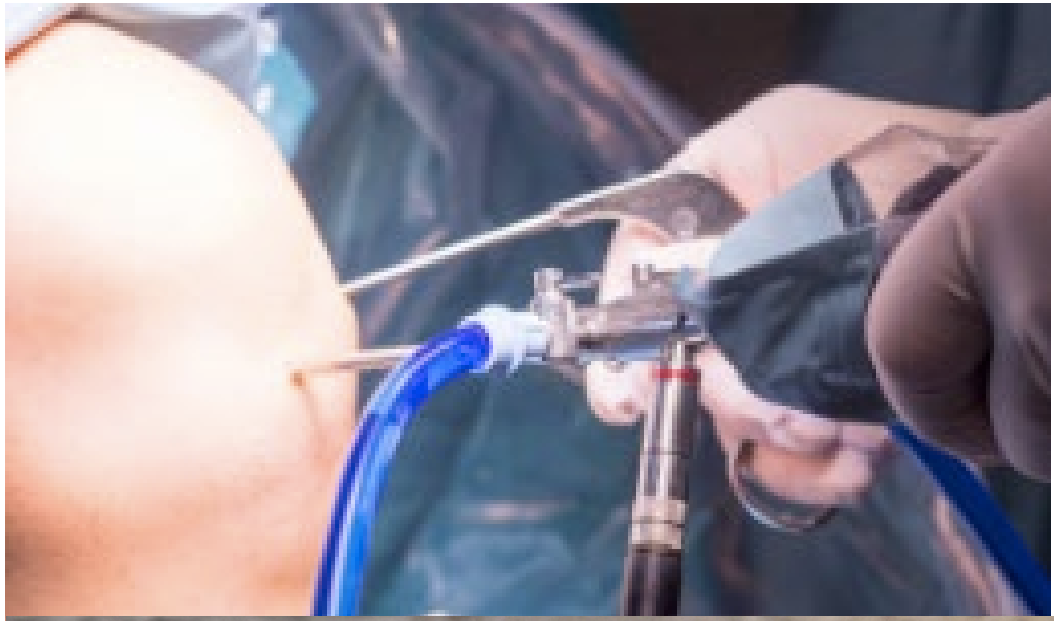
Diabetes[21]

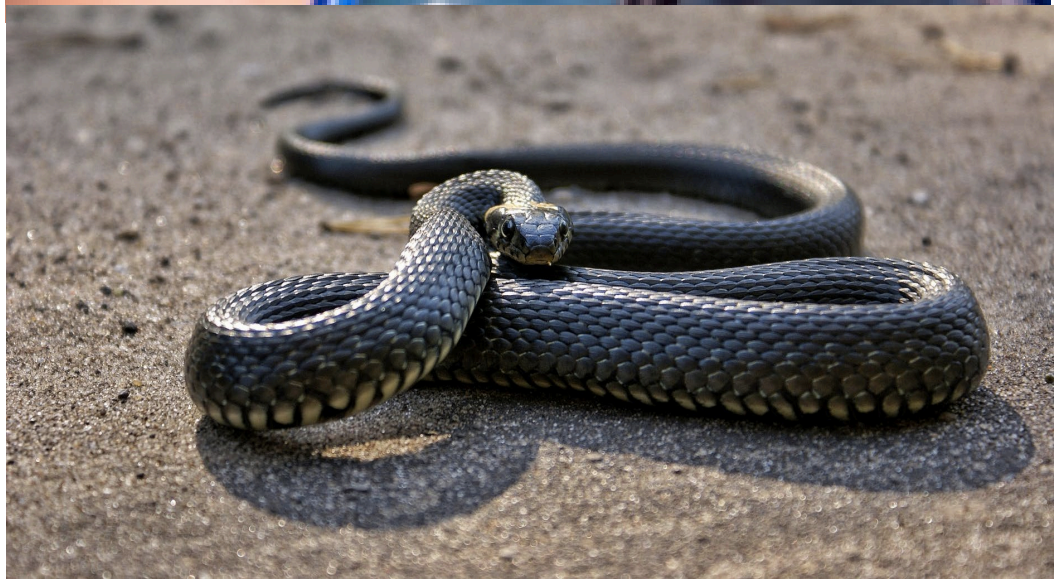
Hypothyroidism[67]

Image: Rockwood + Green, 9th ed

OTHER RISK FACTORS

- Revascularization
- Blood thinners/Medications
- Exercise
- Burns
- Injection injuries
- Fluid infusion (including arthroscopy)
- Osteotomy
- Snake bite
- Acute hematogenous osteomyelitis





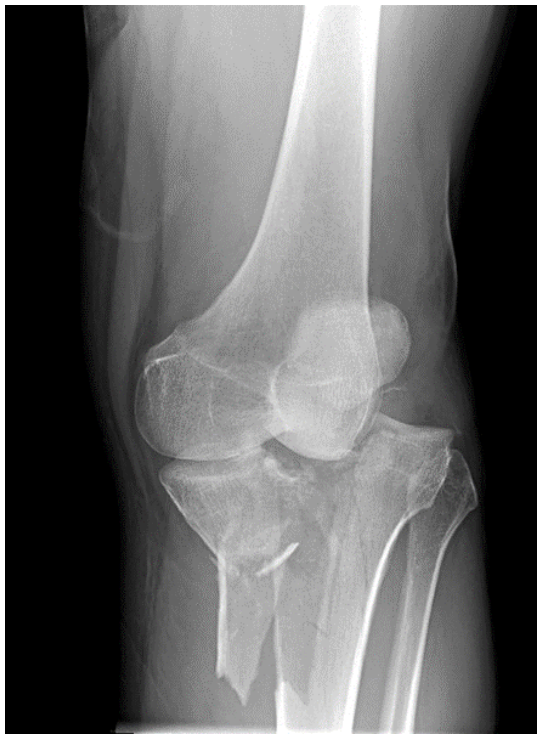
SPECIFIC HIGH RISK INJURIES

- Injury Factors
  - High energy long bone fractures
    - Tibial fractures 2-10%
  - Bleeding diathesis/anticoagulation
  - Polytrauma with transfusions

Images provided by Sergei Pushilin, MD

SPECIFIC HIGH RISK INJURIES

- Injury Factors
  - Medial knee fracture-dislocations 53%
  - Schatzker VI plateau fractures 18%



Images provided by Sergei Pushilin, MD

SPECIFIC HIGH RISK INJURIES

- Any patient with altered pain perception or an unexaminable patient should be watched carefully
  - Regional anesthesia
  - Altered consciousness – intubated, ICU
    - May need serial exams
  - PCA / pain medication
  - Associated nerve injury
  - Children (unreliable exam)

TIBIA FRACTURES: RISK

- Age (strongest predictor): 12-29 years
  - Male sex especially
  - Potential cause: higher muscle mass and less “room to swell”

- Anterior compartment most common, followed by deep posterior.

DIAGNOSIS

- Acute compartment syndrome is a **clinical** diagnosis
  - If you think patient needs to go to the OR (**regardless** of pressure measurements), they probably do
- Physical exam in awake patient = benchmark for diagnosis
- Intracompartmental pressure readings = useful adjunct

CLASSIC SIGNS/SYMPTOMS

- Pain on passive stretch/out of proportion
- Pressure/swelling
- Paresthesia
- Paralysis
- Pallor
- Pulselessness

Image provided by Lisa Cannada, MD

CLASSIC SIGNS/SYMPTOMS

- Pain on passive stretch/out of proportion
- Pressure/swelling
- Paresthesia
- Paralysis
- Pallor
- Pulselessness

Late Findings!

Image provided by Lisa Cannada, MD

CLASSIC SIGNS/SYMPTOMS

- Pain on passive stretch/out of proportion
  - Low sensitivity – cannot reliably rule out compartment syndrome
  - Unreliable – can vary in intensity or be less severe posteriorly
  - Difficult to evaluate in altered/unconscious patients

Image provided by Lisa Cannada, MD

CLASSIC SIGNS/SYMPTOMS

- Pain on passive stretch/out of proportion
- Pressure/swelling
  - Ability to identify elevated pressures via palpation has 24% sensitivity, 55% specificity
  - Even among trauma surgeons, in the same institution, treating same population the rate of fasciotomies varies from 2-24%

Image provided by Lisa Cannada, MD

CLASSIC SIGNS/SYMPTOMS

- Pain on passive stretch/out of proportion
- Pressure/swelling
- Paresthesia
  - Low sensitivity
  - When combined with other findings, probability increases

Image provided by Lisa Cannada, MD

COMPARTMENT PRESSURE MEASUREMENTS

- Adjunct technique in unclear cases, but does **NOT** supersede the clinical exam when diagnosing ACS
- Absolute compartment pressures are now rarely used as a cutoff
- Most common method is ΔP:
  - Diastolic BP – compartment P
  - ΔP<30 is suspicious for ACS
  - Conservative benchmark to avoid missing ACS

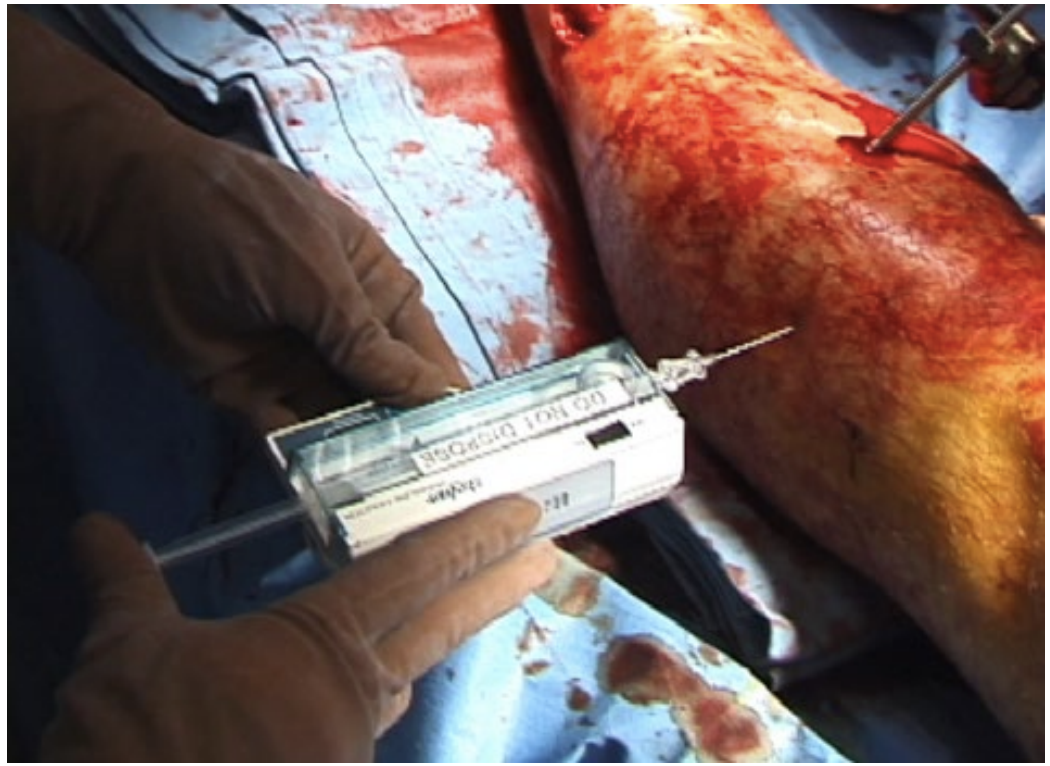


Image: Schmidt, OTA core curriculum presentation acute compartment syndrome 2018

COMPARTMENT PRESSURE MEASUREMENTS

- Several issues with ΔP:
  - ΔP (via a single stick device) is a static measurement, but ACS is a dynamic entity, and pressures rise and fall with time
  - Individual muscle ability to tolerate ischemia varies
  - Some have suggested continuous monitoring, which improves sensitivity and specificity but may not improve outcomes

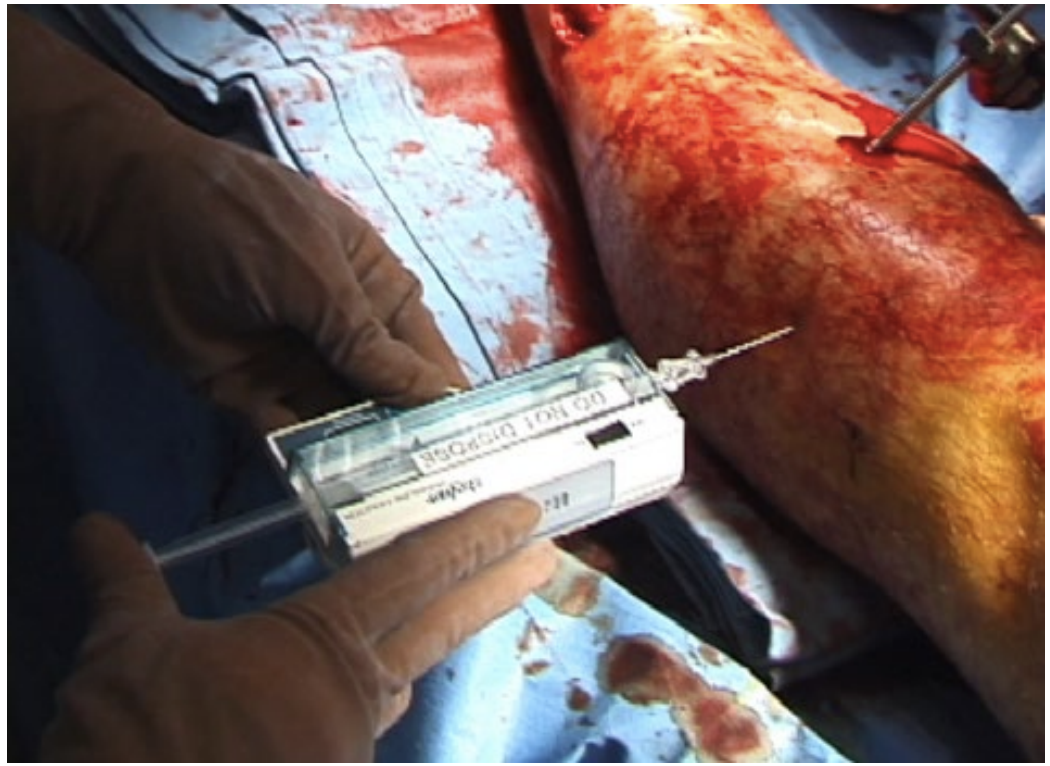


Image: Schmidt, OTA core curriculum presentation acute compartment syndrome 2018

CONTINUOUS PRESSURE MEASUREMENT

Perfusion Pressure Lacks Diagnostic Specificity for the Diagnosis of Acute Compartment Syndrome

Andrew H. Schmidt, MD,[a] Junrui Di, MS,[b] Vadim Zipunnikov, PhD,[b]
Katherine P. Frey, PhD, MS, MPH, RN,[c] Daniel O. Scharfstein, ScD,[b] Robert V. O'Toole, MD,[d]
Michael J. Bosse, MD,[e] William T. Obremskey, MD, MPH, MMHC,[f] Daniel J. Stinner, MD,[g]
Roman Hayda, MD,[h] Madhav A. Karunakar, MD,[e] David J. Hak, MD, MBA,[i] Eben A. Carroll, MD,[j]
Susan C.J. Collins, MSc,[c] Ellen J. MacKenzie, PhD,[c] and METRC

- Used an expert panel as a reference standard in known ACS cases with continuous monitoring
- Used thresholds of ΔP in increments of 5 from ΔP=10 to ΔP=30
- Findings:
  - A uniform single threshold for ACS diagnosis may not exist
  - There is a high chance of over-treatment and we still do not have a "gold standard" of diagnosis

MEASUREMENT METHODS: ARTERIAL LINE

- May be used intraoperatively or in the ICU

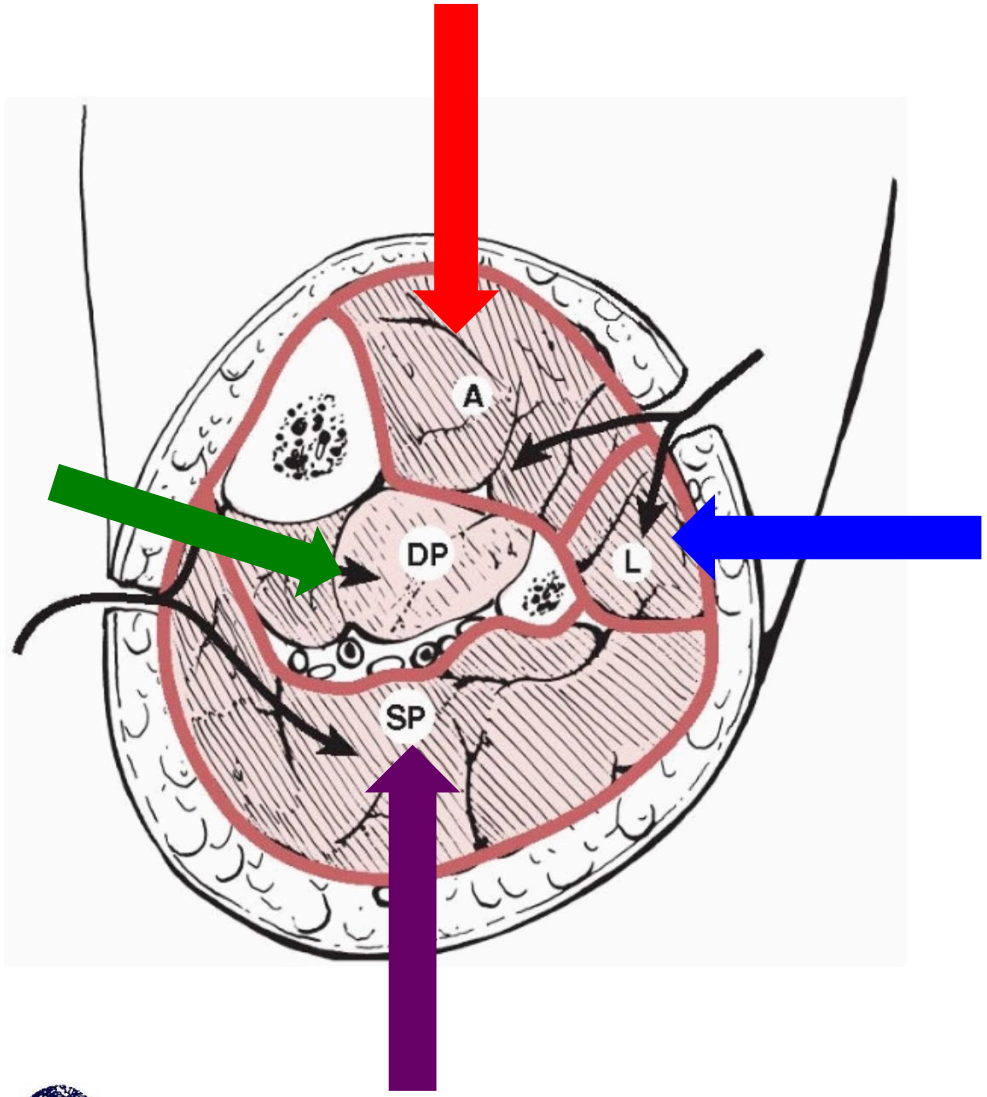
https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731429/acute-compartment-syndrome-of-the-lower-extremity

MEASUREMENT METHODS: STIC DEVICE

- Device setup described on STIC website (https://www.c2dxinc.com/sticmonitor/)
- Pressures measured at same level as compartment and within 5cm of fracture if possible
- Measuring pressure at fracture level may give false reading due to hematoma

Halanski, Matthew A. MD; Morris, Michael R. MD; Lee Harper, Benjamin MD; Doro, Christopher MD Intracompartmental Pressure Monitoring Using a Handheld Pressure Monitoring System, JBJS Essential Surgical Techniques: March 25, 2015 - Volume 5 - Issue 1 - p e6

MEASUREMENT METHODS: STIC DEVICE



- Lower Leg Compartments
  - Anterior: 1cm lateral to crest
  - Lateral: anterior to the posterior border of fibula
  - Superficial Posterior: posterior calf (do not go deep in midline)
  - Deep Posterior: behind posteromedial border of tibia

McQueen, MM., Duckworth, AD. (2020). *Acute Compartment Syndrome.* Tornetta, P.; Ricci, W.; Ostrum, W.; McQueen, M.; McKee, M.; Court-Brown, C. Rockwood And Green's Fractures in Adults, 9th Edition. LWW.

INTRAOPERATIVE PRESSURE MEASUREMENT

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**

- Tornetta et al, *JOT* 2007
  - N=246 tibial nails under general anesthesia
  - Measured diastolic blood pressure preoperatively, intraoperatively and postoperatively
  - Found ~20 point (lower) difference in intraop pressures
- Unless patient will be under for a long time, use pre-induction DBP for ΔP calculation

Kakar S, Firoozabadi R, McKean J, Tornetta P 3rd. Diastolic blood pressure in patients with tibia fractures under anaesthesia: implications for the diagnosis of compartment syndrome. J Orthop Trauma. 2007 Feb;21(2):99-103

TREATMENT: INITIAL

- Split or remove tight dressings
  - Including cast padding/webril
- Continuous close observation
- Keep limb at level of heart (avoid extreme elevation)
- Oxygen saturation to improve availability to muscle
- Correct systemic hypotension

TREATMENT: SUSPECTED/CONFIRMED ACS

- When there is high suspicion of compartment syndrome: THOROUGH AND COMPLETE FASCIOTOMY OF AFFECTED COMPARTMENTS

- "IF YOU HAVE TO THINK ABOUT IT, DO IT"

Image provided by Lisa Cannada MD

FASCIOTOMY CAVEATS

- Make an adequate incision (no short incisions, as seen below)
- Leave open and place wound vac or dressing – avoid immediate closure

Images provided by Sergei Pushilin MD

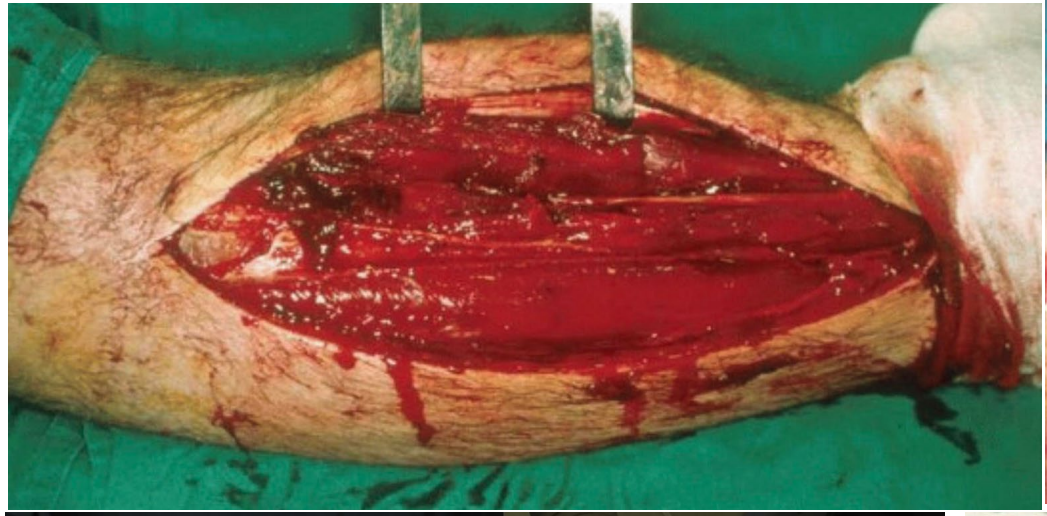
FASCIOTOMY CAVEATS

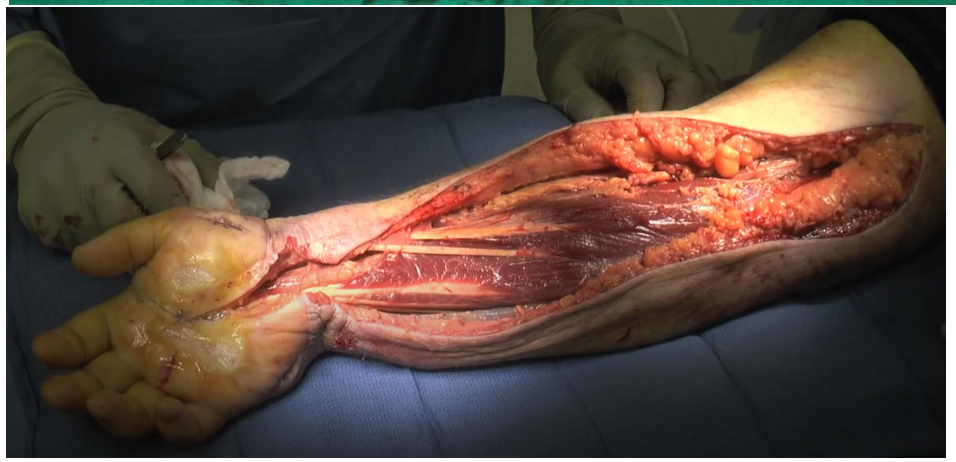
- Incomplete release → dead muscle

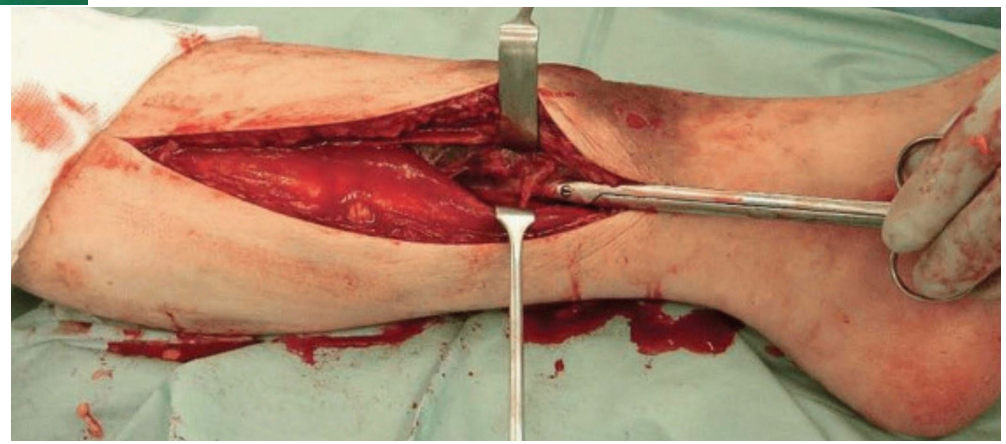
Image provided by Lisa Cannada MD

SITES

- Gluteal
- Thigh
- Leg
- Foot
- Arm
- Forearm
- Hand



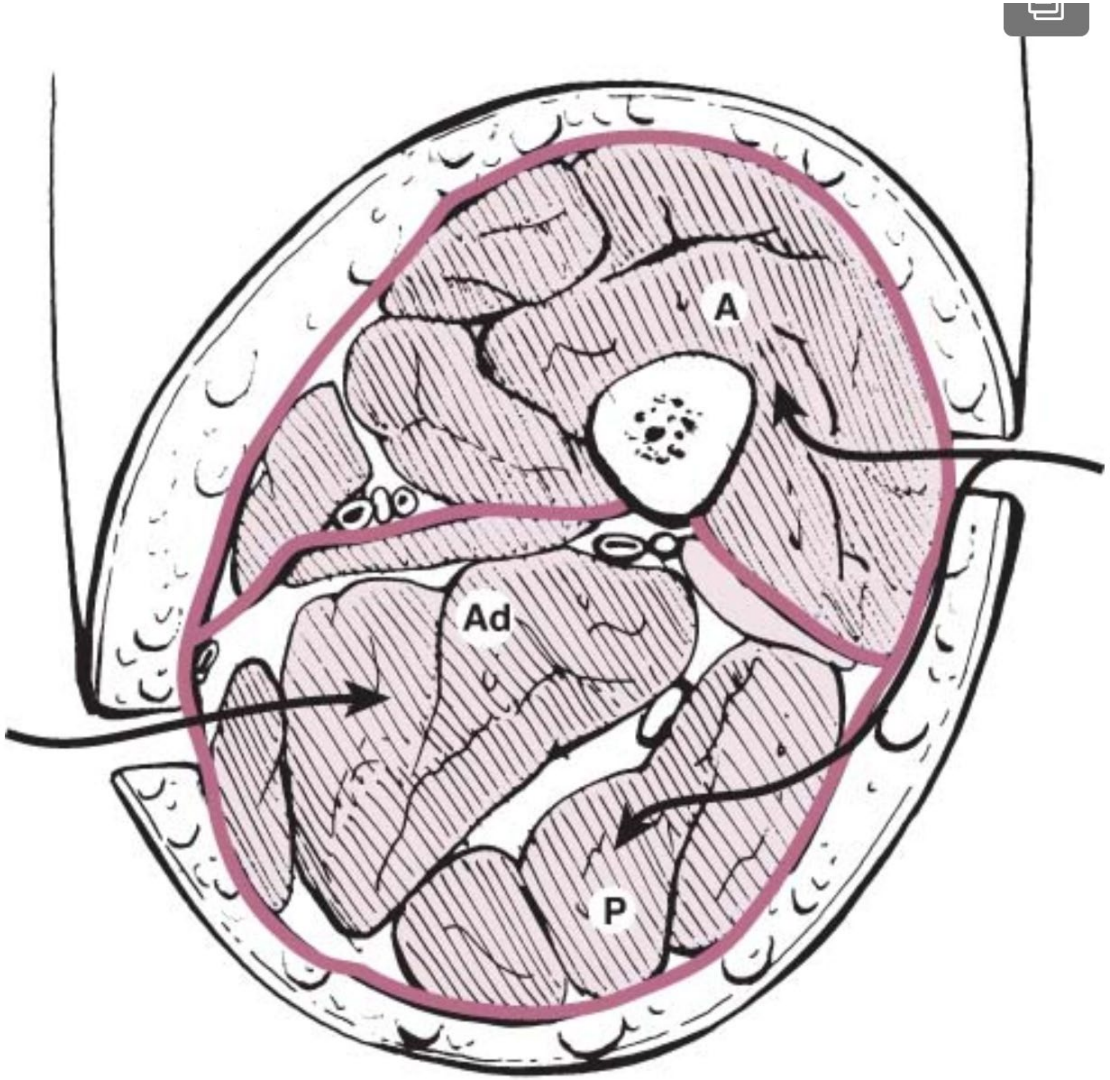




Turkula SC, Fuller DA. Extensile Fasciotomy for Compartment Syndrome of the Forearm and Hand. J Orthop Trauma. 2017 Aug;31 Suppl 3:S50-S51. doi: 10.1097/BOT.0000000000000903. PMID: 28697090.
McQueen, MM. (2010). *Acute Compartment Syndrome.* Bucholz, R.; Heckman, J.; Court-Brown, C.; Tornetta, P. Rockwood And Green's Fractures in Adults, 7th Edition. LWW.

THIGH FASCIOTOMY

- 3 compartments: anterior, posterior, and adductor
- Single anterolateral incision for anterior and posterior compartments
  - Incise lateral intermuscular septum for posterior access
- Adductor compartment may not be needed after other 2 are released



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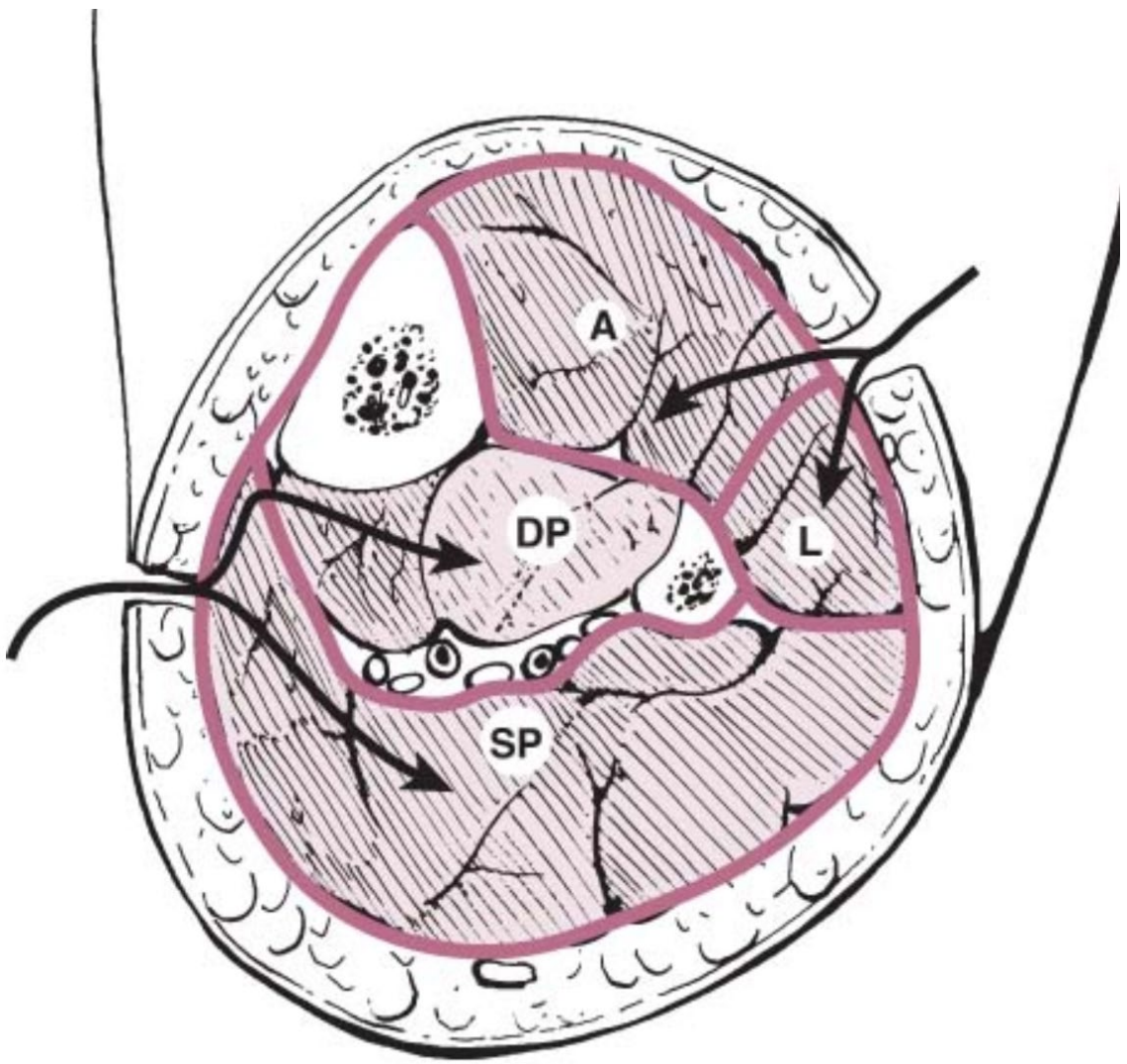
LEG FASCIOTOMY

- 4 compartments: anterior, lateral, superficial posterior, deep posterior
- Dual (more common) or single incision (following slides)
- Tips:
  - Protect superficial peroneal nerve in lateral compartment
  - Protect saphenous vein and nerve medially
  - Deep posterior identified easiest distally (FDL behind tibia); proximally have to peel soleus off



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LEG FASCIOTOMY

- Draw all anticipated surgical incisions – do not place implants through a fasciotomy incision that is left open
  - Infection Risk

- Planned plateau incision

Image provided by Lisa Cannada MD

LEG FASCIOTOMY

- If the patient has not received definitive bony fixation, plan for some form of support for soft tissues
    - Usually external fixation with planned staged treatment of underlying fracture

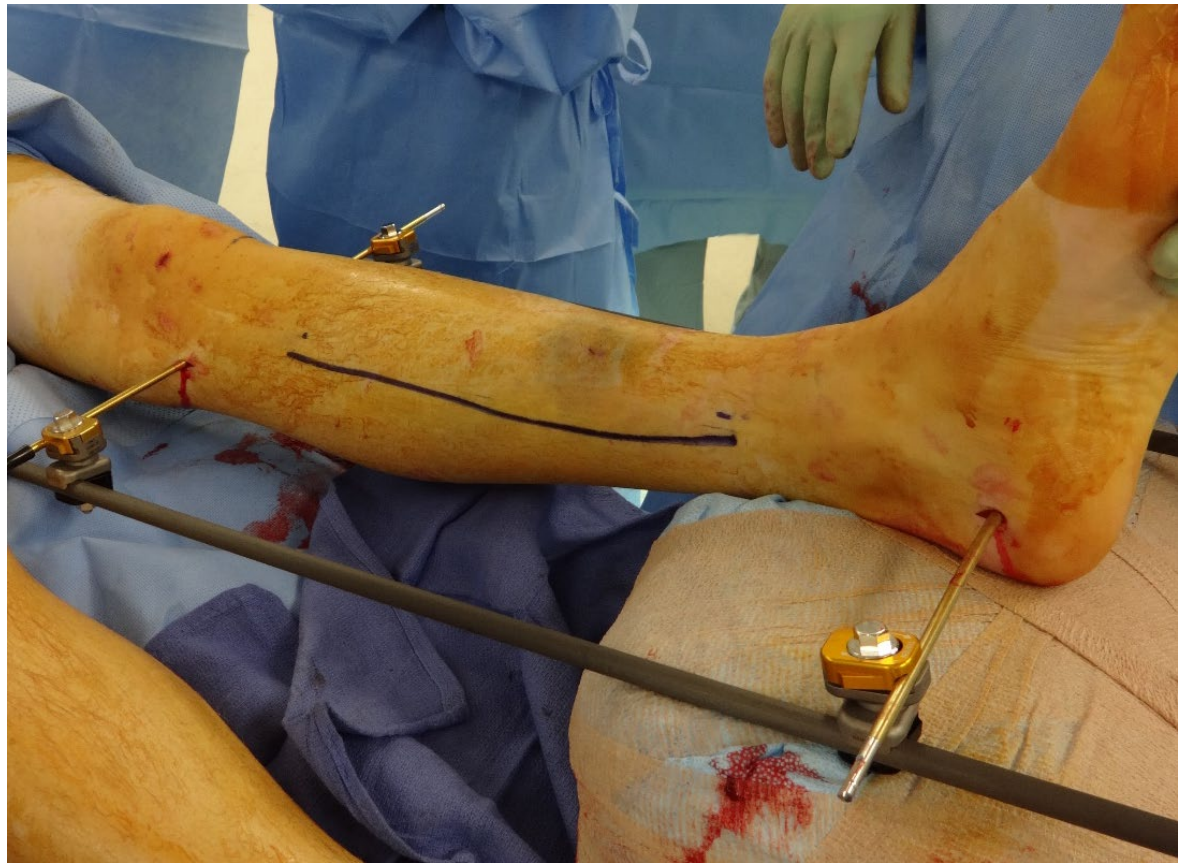


Image provided by Lisa Cannada MD

LEG FASCIOTOMY

- Dual Incision
  - Incision over the lateral leg with two deep fascial incisions using scissors (anterior and lateral compartments)
  - Identification of superficial peroneal nerve in the lateral compartment

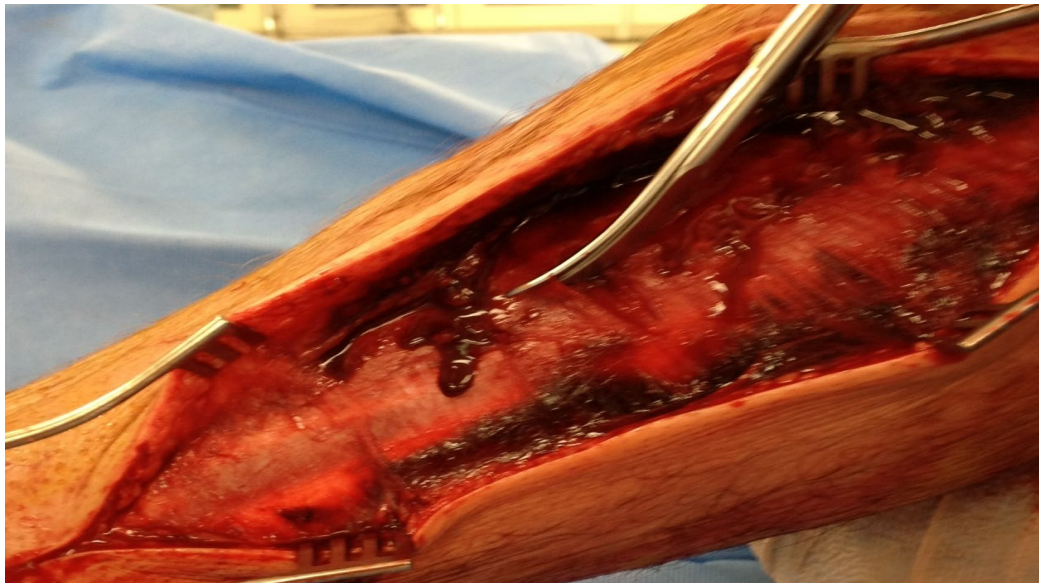
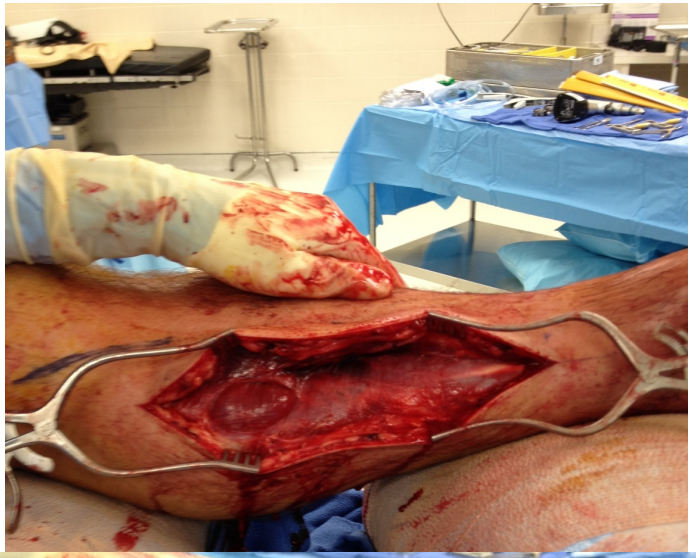


Image provided by Lisa Cannada MD

LEG FASCIOTOMY

- Dual Incision
  - Incision posterior to the posteromedial tibia with release of superficial and deep posterior compartments
  - Find the soleal bridge and enter the deep posterior compartment off the back of the tibia



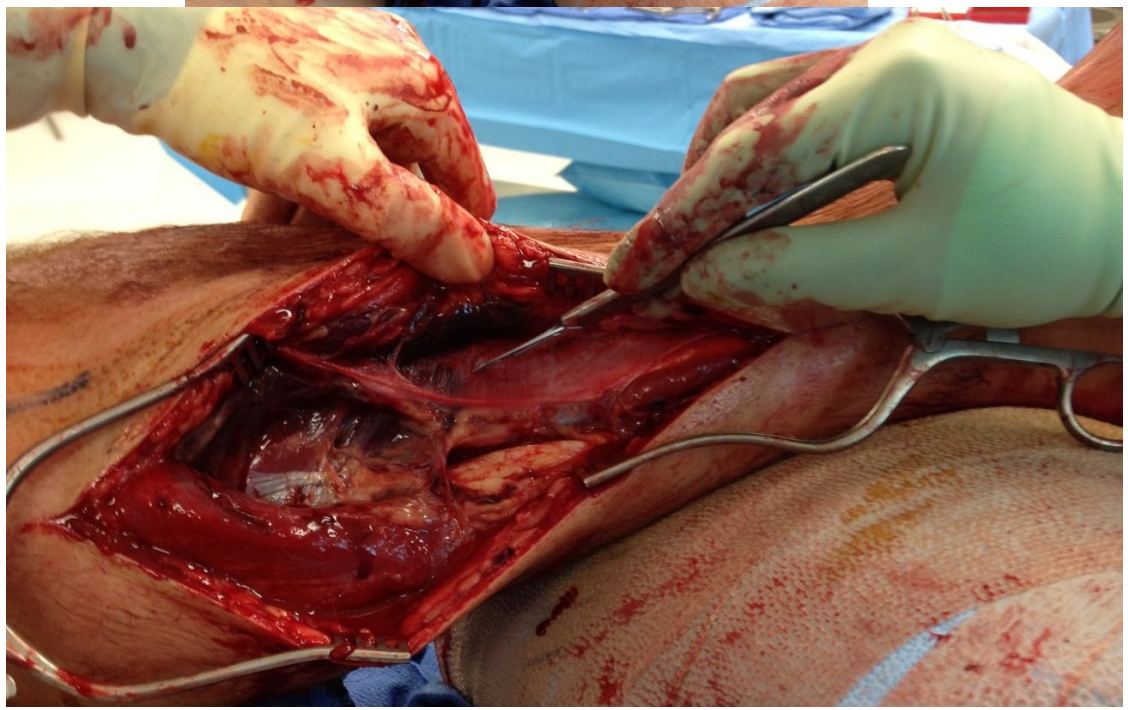


Image provided by Lisa Cannada MD

LEG FASCIOTOMY: DUAL INCISION VIDEO

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16776673/dual-incision-release

LEG FASCIOTOMY

- Single Incision
  - Incision over the lateral leg just anterior to fibula
  - Fasciotomy of anterior and lateral compartments

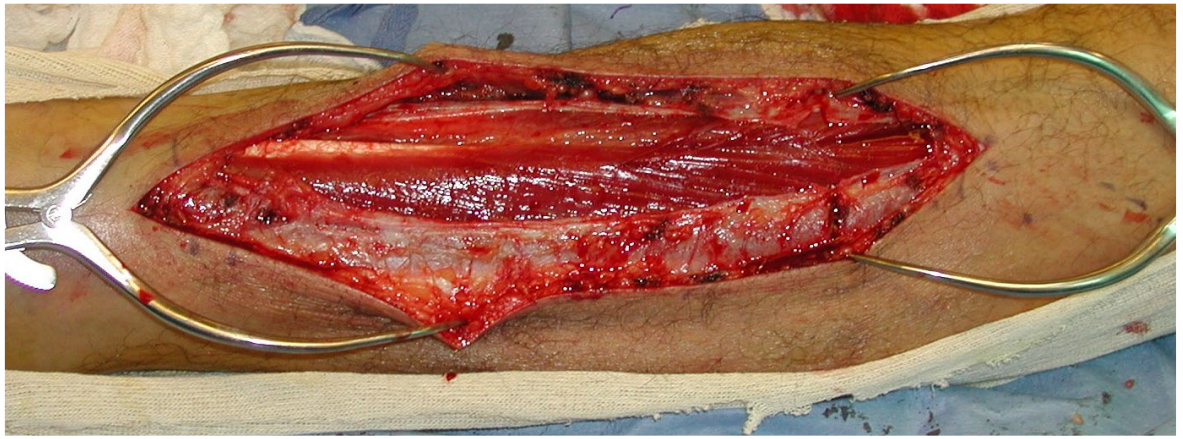


Image provided by Steven Olson MD

LEG FASCIOTOMY

- Single Incision
  - Elevation of peroneal muscles off the septum separating them from the superficial posterior compartment
  - Fasciotomy of superficial posterior compartment

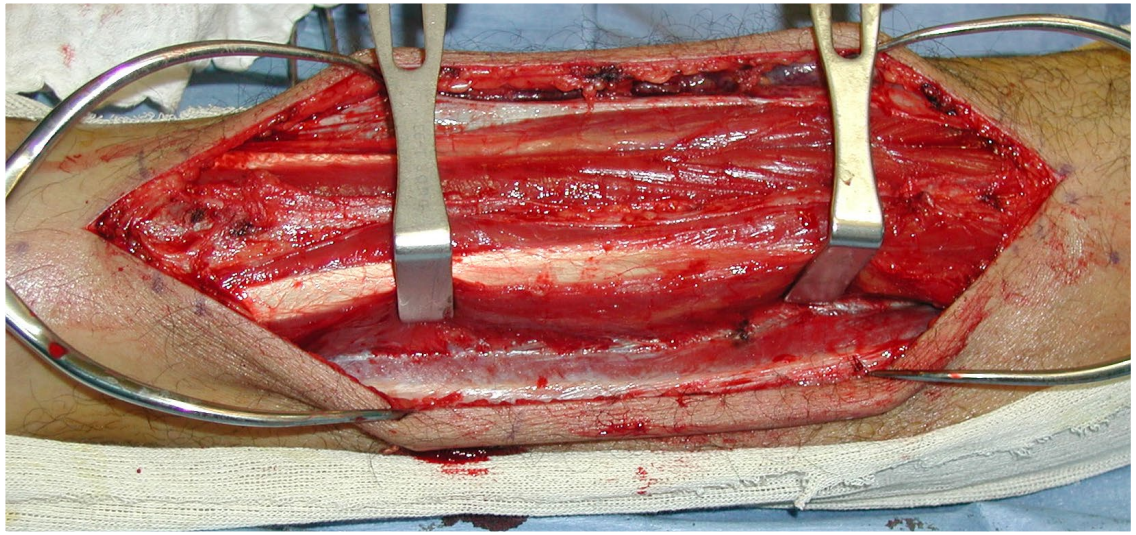
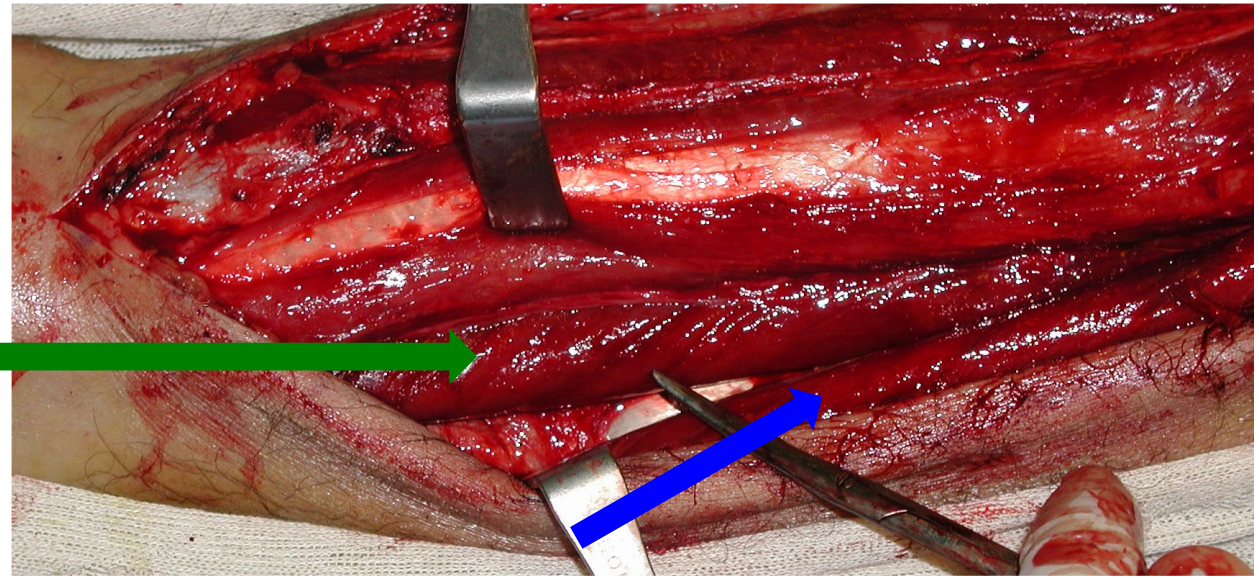


Image provided by Steven Olson MD

LEG FASCIOTOMY

- Single Incision
  - Dissect interval between gastroc-soleus and deep posterior compartment fascia
  - Fasciotomy of deep posterior compartment fascia



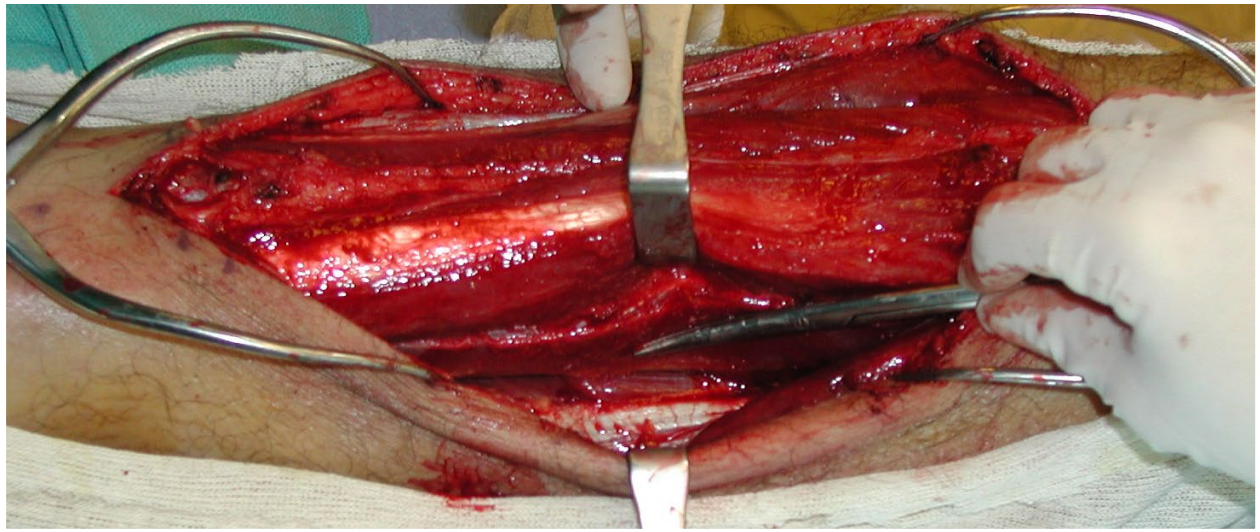


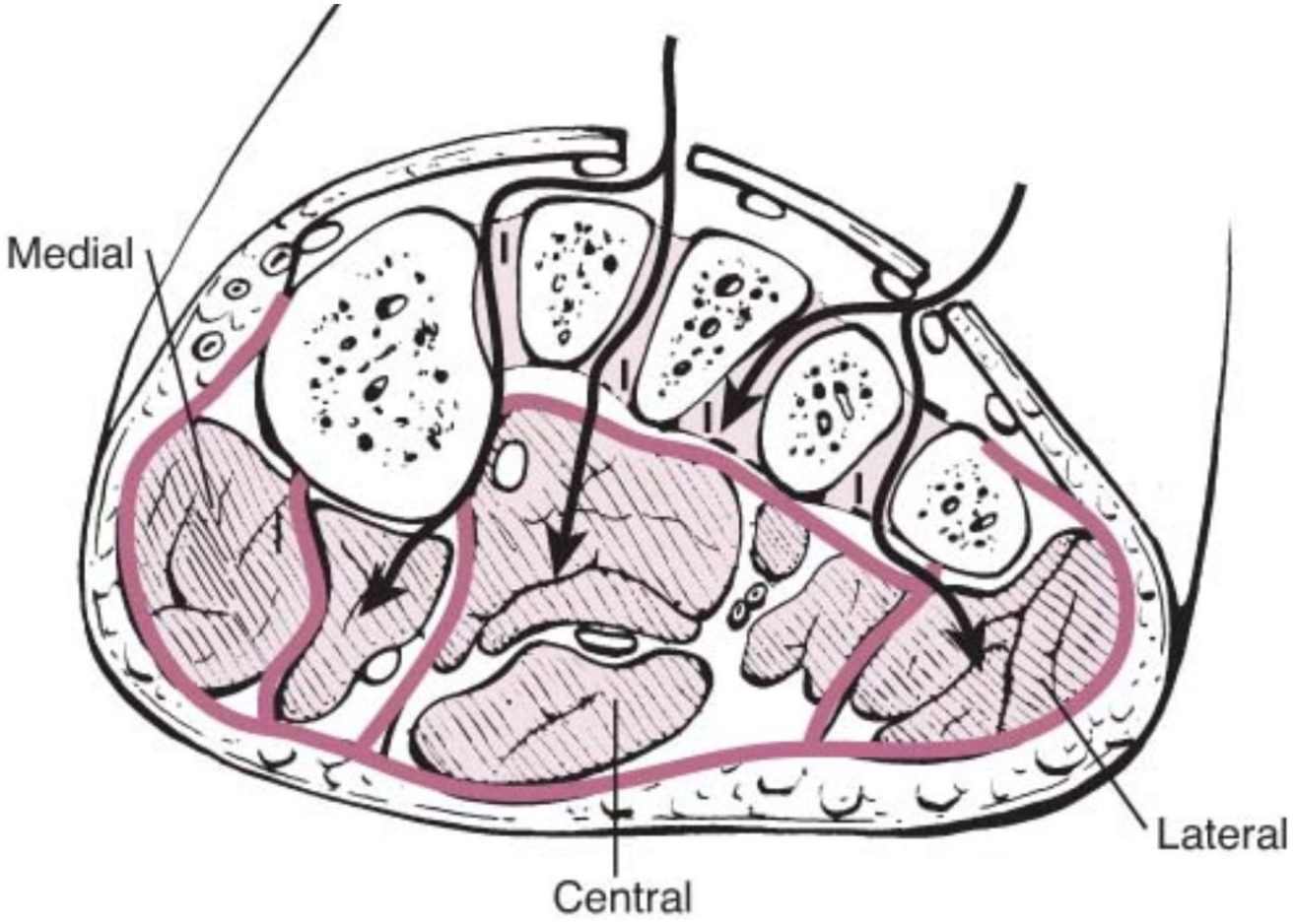
Image provided by Steven Olson MD

LEG FASCIOTOMY: SINGLE INCISION VIDEO

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16731431/single-incision-four-compartment-parafibular

FOOT FASCIOTOMY

- 9 compartments (authors disagree as to the number)
  - Medial, Superficial Lateral, Calcaneal
  - Interossei(4), Adductor
- Lisfranc, Calcaneus
  - Sequelae: claw toes, sensory disturbance, pain
- Dual incisions



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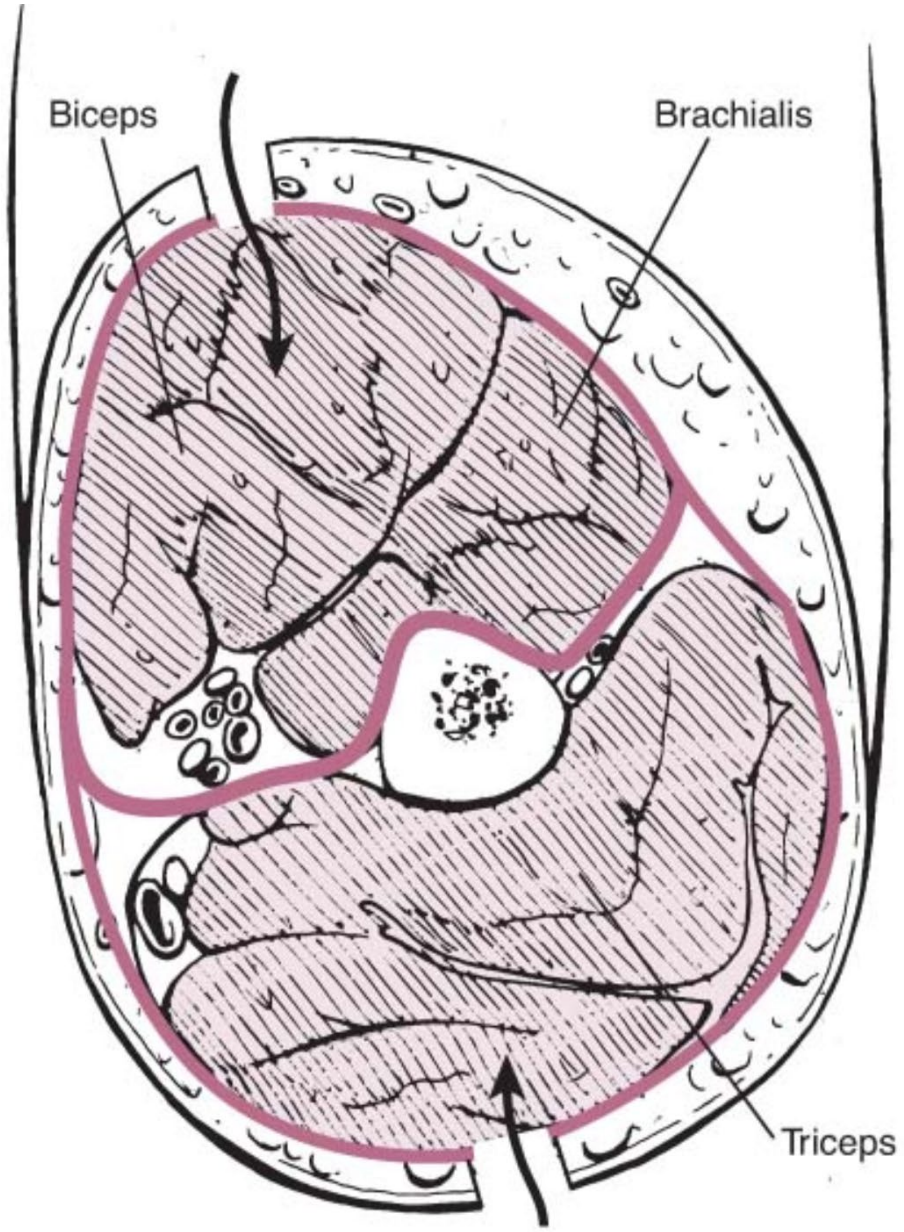
ARM FASCIOTOMY

- 3 compartments (but not all may need release)
  - Anterior, Posterior, Deltoid
- Dual incisions or single incision
  - Dual: anterior and posterior
  - Single: video next slide



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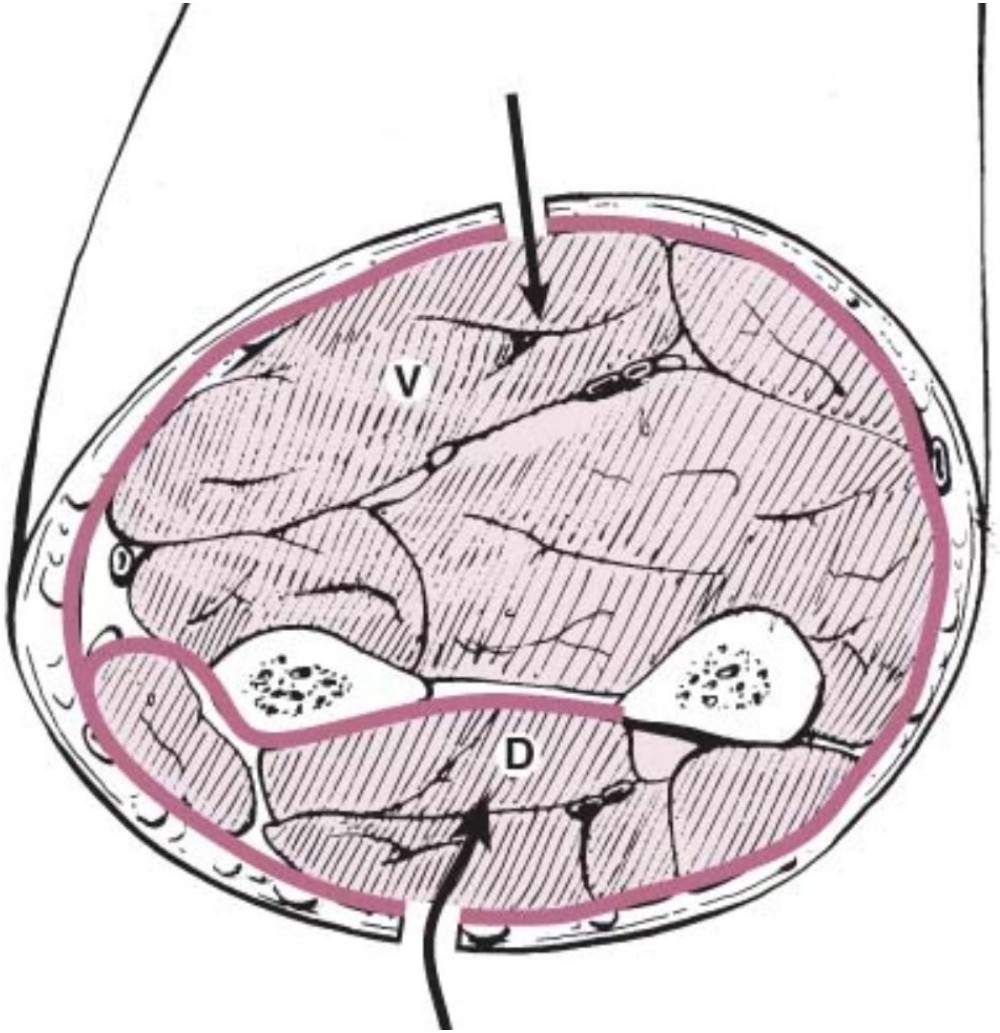
ARM FASCIOTOMY: SINGLE INCISION VIDEO

http://links.lww.com/JOT/A792

Associated paper:
https://journals.lww.com/jorthotrauma/Fulltext/2019/08001/Arm_Fasciotomy_Through_Lateral_Approach.9.aspx

UPPER ARM FASCIOTOMY

- 3 compartments
  - Volar, Dorsal, Mobile Wad
- Dual incisions
  - Volar approach (Henry) to release flexors and pronator/supinator; consider carpal tunnel release
  - Dorsal approach
    - May not always be needed after volar release
    - Dorsal and mobile wad



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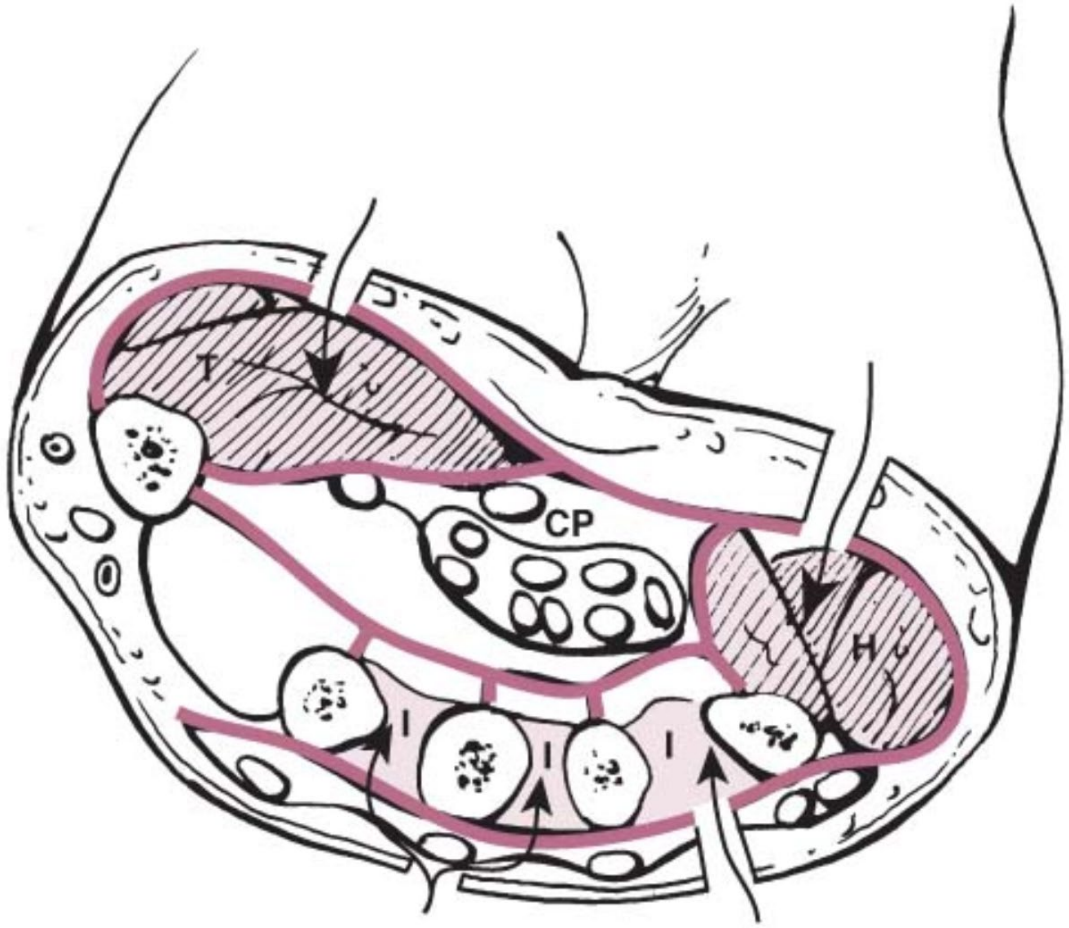
FOREARM FASCIOTOMY VIDEO

https://otaonline.org/video-library/45036/procedures-and-techniques/multimedia/16723114/extensile-fasciotomy-for-compartment-syndrome-of

HAND FASCIOTOMY

- 10 compartments
  - dorsal interossei (4)
  - palmar interossei (3)
  - thenar and hypothenar (2)
  - adductor pollicis (1)
- Can use different types of incisions but usually 2 dorsal (over 2nd and 4th MC), thenar (radial side of 1st MC), hypothenar (ulnar side of 5th MC)



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AFTERCARE

- Wound management options
  - Wound vac
    - Higher rates of primary closure when compared with standard dressing
  - Vessel Loops
    - Cheaper
  - Wet to dry (not recommended)

Images provided by Lisa Cannada MD

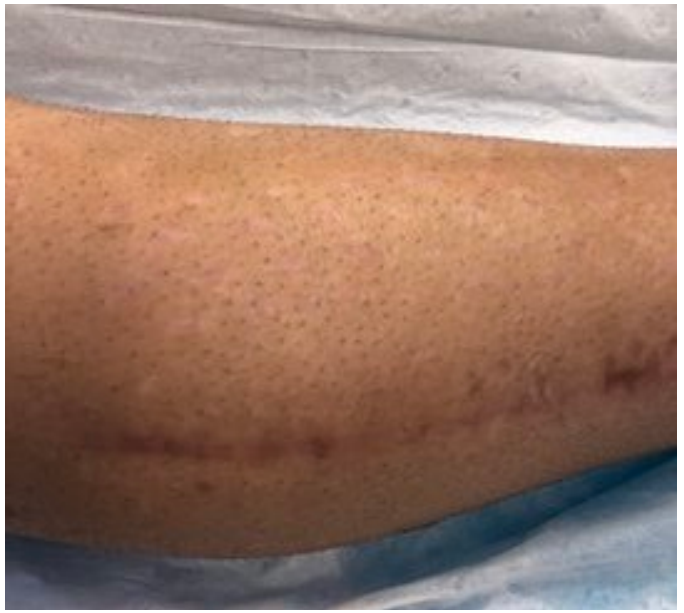
AFTERCARE

- Wound closure options
  - Primary
    - May require multiple trips to the OR
  - Primary with pie crust
  - Split thickness skin graft

Images provided by Lisa Cannada, MD

AFTERCARE

- Wound closure options
  - Primary
  - Primary with pie crust
    - 1cm long, 1cm apart
    - Decreases skin tension up to 34%
  - Split thickness skin graft



Images provided by Yelena Bogdan, MD

AFTERCARE

- Wound closure options
  - Primary
  - Primary with pie crust
  - Split thickness skin graft
    - Sensory and cosmetic issues

Images provided by Sergei Pushilin, MD and David Polonet, MD

FASCIOTOMY SEQUELAE

- Acute
  - Infection
    - Avoid placing implants through a fasciotomy wound
  - Need for skin graft
- Chronic
  - Altered sensation 77%
  - Dry scaly skin 40%
  - Pruritis 33%
  - Discolored wounds
  - Tethered scars
  - Swollen limbs
  - Recurrent ulceration
  - Muscle herniation
  - Pain related to wound
  - Tethered tendons

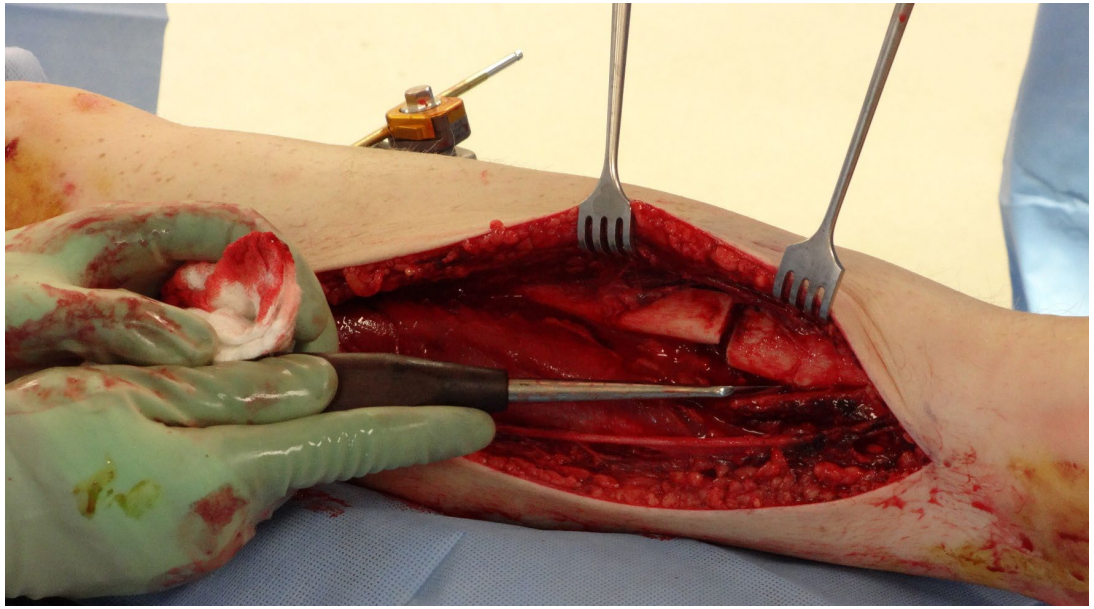


Image provided by Lisa Cannada, MD

COMPLICATIONS OF COMPARTMENT SYNDROME

- Volkmanns ischemic contracture
  - end stage of acute compartment syndrome; irreversible muscle necrosis
- Infection
- Permanent neurological injury
- Chronic pain
- Nonunion of associated fractures
- Amputation
- In-hospital increased stay, complications → malpractice claims

MISSED COMPARTMENT SYNDROME

Managing missed lower extremity compartment syndrome in the physiologically stable patient: A systematic review and lessons from a Level I trauma center

Graeme E. Glass, PhD, FRCS(Plast), Robert M.T. Staruch, MBBS, MRCS, Jonathan Simmons, MSc, FRCS(Plast), Graham Lawton, MD, FRCS(Plast), Jagdeep Nanchahal, PhD, FRCS(Plast), FRACS, Abhilash Jain, MSc, PhD, FRCS(Plast), *and* Shehan P. Hettiaratchy, MA(Oxon), DM, FRCS(Plast), *Oxford, United Kingdom*

- No high quality literature in guiding treatment
- Classic findings show 46% infection and 21% amputation
- Multiple authors recommend close monitoring of renal and metabolic function with nonop treatment
- Late decompression and fasciotomy associated with high amputation rate

SUMMARY

- Clinical signs and symptoms are the mainstay of diagnosis of ACS
- Intracompartmental pressure measurement is a useful adjunct; however, more research is needed in its use as a screening tool
- Treatment of ACS is fasciotomy with complete release of affected compartments

Image provided by Lisa Cannada MD

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