# Plantar Soft Tissue

## Introduction

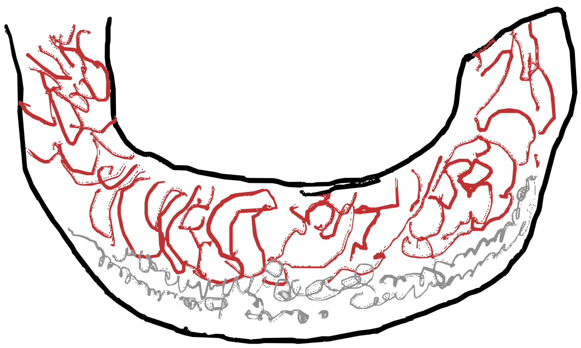
- "plantar soft tissue" tissue between skin & bone or skin and muscle
+ consists of adipocytes enclosed within elastic septal walls, like closed cell foam
+ cells can deform, but fat inside cells does not move around
+ found throughout plantar surface of foot, inferior to the calcaneus, foot arch, lateral foot, metatarsal heads, even the toes

## Anatomy

### Gross Anatomy

- 2 German Texts from 1921 and 1934 (whoa)
- heel pad = body of fat surrounds calcaneus like hood
+ connective tissue within fat "mechanical in nature"
- embryonic tissue = adult around 7 months ("complete")
- septa arranged in "turbine-like" shape as "whorl"

coronal section of calcaneus 60 mm left to right



finer interior is elastic septa, chambers filled with adipocytes

+ adult septa below calcaneus changes from transverse → oblique, then become whorl
- older, elderly with heel pain / obese had loss of elasticity in heel pad, bony proliferation
+ Septa of fractured / distorted

Histological or Biochemical
- sole of foot has elastic fibers + collagen w/ 5 layers: epidermis, papillary dermis, reticular dermis, superficial subcutaneous stratum, deep subcutaneous stratum
+ thick fibrous strands bind dermis to subcutaneous
- normal fat: globules of fat surrounded by septa attached superficially to skin
+ dysvascular feet: less fat, elastic fibers more & thicker
* despite fraying, no mechanical property loss
- papillary & reticular dermis = intertwined elastic & collagen
- significant diff in normally vs atrophied diameter + area in superficial & deep tissue

+ **panniculus carnosus** = muscle between skin & fascia allow twitching

- diabetic tissue has increased septal wall thickness

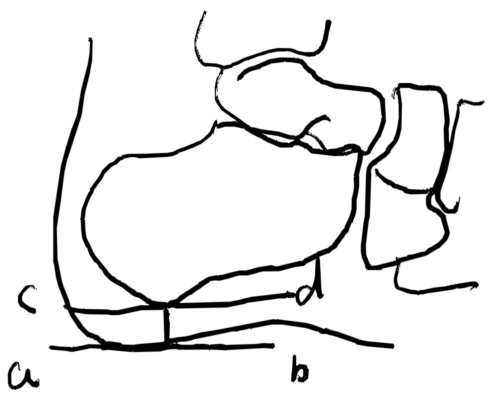
Medical imaging of tissue thickness

- thickness as primary measure (as opposed to secondary)

+ examine from bone to "ground" or "air"

* normal : 13-21 mm
* acromegaly : 17-34 mm

lateral radiograph
thickness is measured
between $\overline{cd}$ and $\overline{ab}$




- one study on healthy vs diabetic heel pads showed a 1.2 mm diff (more in db) but age confounding

- a diff paper found opposite results, but subjects were much closer in age

- diff study, unloaded vs loaded thickness
+ sig. thicker in men and older.
* not based on gender, but age and weight
* older, sig. less elastic

+ heel pain vs normal: thicker and stiffer
- unilateral calcaneus fracture: ↑ thickness
- athletic activity seemed to have no impact on heel pad thickness
- studies about heel pad thickness are pretty wonky
- plantar macro & micro chambers
+ plantar soft tissue is a layered structure
* epidermis, dermis → superficial adipose tissue → muscle → deep adipose tissue
+ ultrasound shows micro & macro chambers in superficial and deep adipose layers
+ possible mechanical effects

* recent use of ML techniques to discover diff in superficial & deep layers
⊛ Adipose Tissue and Automated Feature Extraction in Diabetic Plantar Soft Tissue

## Biomechanical Function

- shock reduction, energy absorption, load distribution

+ 1. shock reduction = deceleration of an effective mass over a certain distance: decrease peak force / loading rate
+ consider peak force at heel strike, vertical velocity, & properties of heel pad, time to peak force & effective mass of heel pad estimated

* stiffer heelpad, more shock

+ 2. shock absorption = deformation to dissipate energy

* fat doesn't flow, resisting compression
* atrophied or diabetic cannot deform too easily

+ distributes plantar pressure; atrophy creates more peaks in pressure zones

* strong inverse correlation between MRI determined heel pad fat friction & peak plantar pressure in diabetic neuropathic

## Structural Ex Vivo Testing

- Study 11 cadaveric limbs, amputated due to vascular problems

- tested with and without attachment to calcaneus, applying differing frequencies and temperatures
  + small but significant change in energy dissipation seen from 0-37°C, but no differences found when going from tested, frozen, retested
- another study (Kerr) = 3 ex vivo heel pads (again, vascular problems), tested delay in loading & response
  + multiple regression model, y = energy loss $x_1$ = delay time $x_2$ = peak force
  + energy loss did increase with rest time
- study saw discrepancies in mechanical testing, modified setup to impact halfway through cycle on grounded tissue
  + results: 46.5% - 65.5% energy absorption, 4-5 mm deformation, $9.0 \times 10^5$ N/m stiffness
- in-vivo testing reveals less stiff, more deformation, however work ex-vivo done with unhealthy tissue

Material Ex Vivo Testing

- initial study quantifying isotropic nature of plantar soft tissue, model with hyperelastic & viscoelastic characteristics
  + problem: older people of unknown condition @ room temp
- Ledoux et. al explored compression & shear material props while handling diff conditions
  + fundamental finding: modulus of healthy plantar tissue ≈ 600 kPa, energy absorption roughly 70%

Ultrasound

- one study found diabetic neuropathic patient had sig. thinner and stiffer tissue
- pretty cool: embed ultrasound sensor in shoe for dynamic soft tissue deformation, exploring effect of heel cup in 16 normal subjects
- ↑ in shear wave elastography to quantify stiffness, pattern of ↓ stiffness from superficial to deep layer

Other In Vivo Techniques

- inverse finite element method to estimate mechanical properties
+ 2D work demonstrated no diff in diabetic vs non diabetic
+ 3D for better results, combined with ultrasound scanning
- MRI usage with indentation to measure shear and elastic modulus
+ hydraulic, cyclic loading, etc
- hand held force guage + tools = heel pad stiffness ↑ in painful subjects?
- single plane fluoroscopy

Effect of Aging

- age ↑, energy absorption ↓
- older tissue thinner, less elastic, less able to absorb energy

- older metatarsal heads, handled less strain, absorbed more energy?

## Diabetic Plantar Soft Tissue

- Cadaver investigation: thicker soft tissue, ↑ dermal thickness, ↑ thicker/frayed septal walls
- FEA (finite element analysis) models therapeutic footwear and changes in tissue mechanics & plantar pressure
- MRI/ultrasound find increased stiffness

## Other Pathology of Plantar Soft Tissue

- Acromegaly, caused by overproduction of growth hormone ⇒ abnormal growth of hands, feet, face
- Long term Dilantin treatment for seizure control associated with increase in heel pad thickness
- contradictory commentary on heel pad pain not worth noting

# Areas of Future Biomechanical Research

- exciting changes in technology are allowing for patient specific analysis of plantar soft tissue
- gap: how biochemical and histological characteristics associate with mechanical properties
- gaps will allow for technology like highly custom orthotics that mitigate diabetic foot complications and reduce ulcer rates

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