Alignment of the Adult Foot: Axes and Angles

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Objectives

- Demonstrate a systematic approach to evaluate the alignment of the adult foot
- Present reference axes and angles of the foot and focus on basic measurements to diagnose common deformities
- Discuss commonly seen adult foot deformities using cases

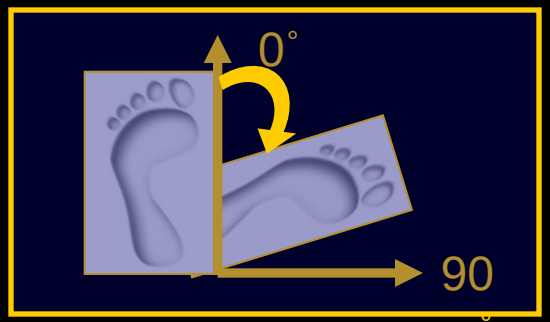
Alignment of the Adult Foot

- Weightbearing radiographs are a useful first step for assessing foot alignment.

- Further advanced imaging may then be indicated.

Terminology

- Pes: Acquired deformity
- Talipes: Congenital deformity
- Adduction: Motion of body part toward axis of the body
- Abduction: Motion of body part away from axis of the body
- 2nd toe is midline of foot



- Varus: Position of body part distal to a joint toward axis of the body
- Valgus: Position of body part distal to a joint away from axis of body
- Supination: Inversion of forefoot and adduction of hindfoot
- Pronation: Eversion of forefoot and abduction of hindfoot

Basic Approach to the Foot

- **2 Columns**

Lateral:

- inherently stable

Medial:

- adaptive during weight-bearing
- stabilizes during propulsion

These columns, most importantly the medial column, make up the longitudinal arch of the foot.

Basic Approach to the Foot

- **2 Columns**

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Basic Approach to the Foot

3 Divisions of the Foot

Forefoot

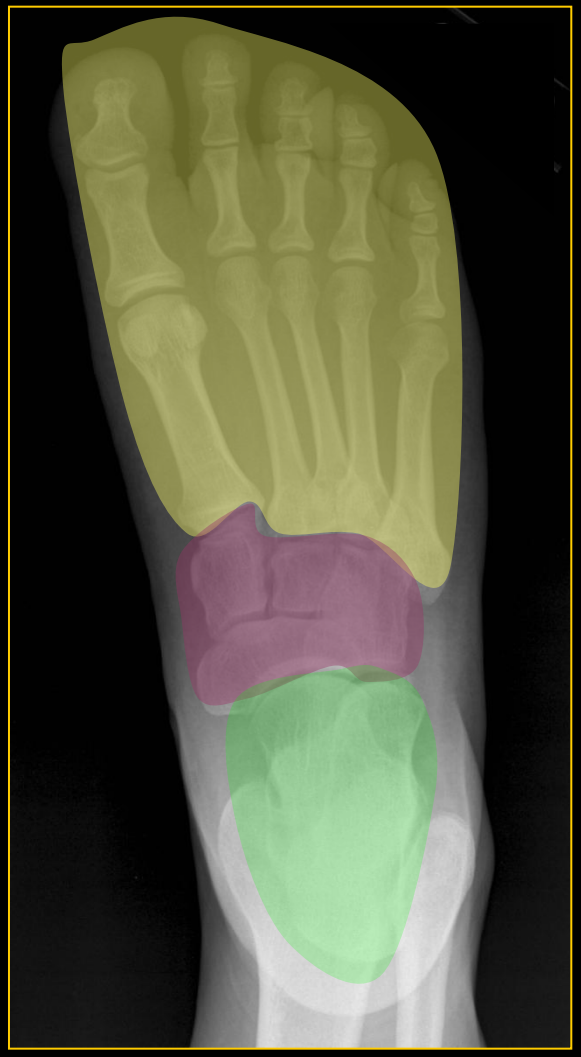
- phalanges, metatarsals

Midfoot

- cuboid, navicular, cuneiforms

Hindfoot

- talus, calcaneus



* **Full weight-bearing radiographs are essential in evaluating the alignment of the foot.**

Radiographs need to be Weight Bearing

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Good radiographs are with full weight bearing

53M

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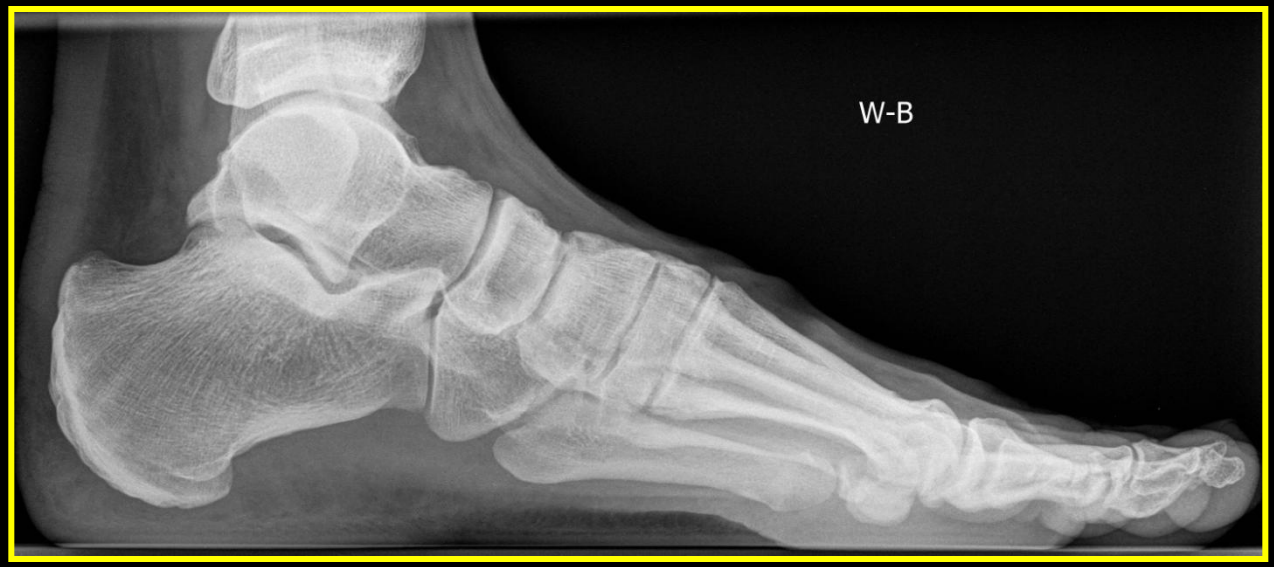
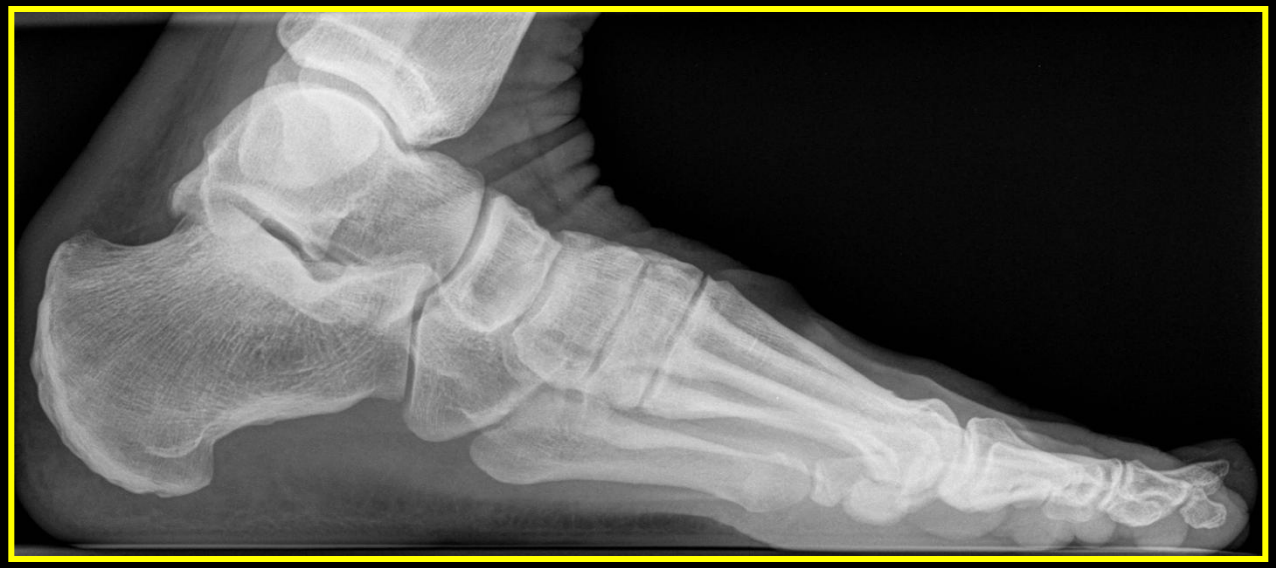
Good radiographs are with full weight bearing



Radiographs need to be Weight Bearing

Good radiographs are with full weight bearing

Tibia not vertical indicates partial weight bearing



53M

Radiographs need to be Weight Bearing

Good radiographs are with full weight bearing

Tibia not vertical indicates partial weight bearing

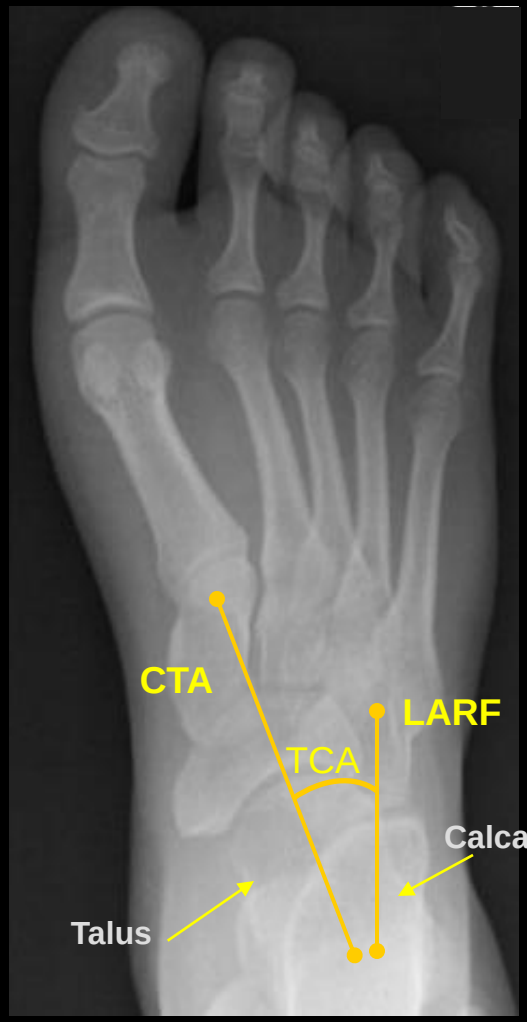
Radiographs need to be Weight Bearing

Spina bifida chronic foot malalignment 39M

Talus

- The keystone of the hindfoot
- Only bone in foot with no muscle attachments
- Many foot alignment problems related to neurologic or neuromuscular disorders.
- Therefore least affected by muscle imbalance and makes a good point that alignment can be assessed from.

Hindfoot: Subtalar Joint
Normal Alignment on AP view



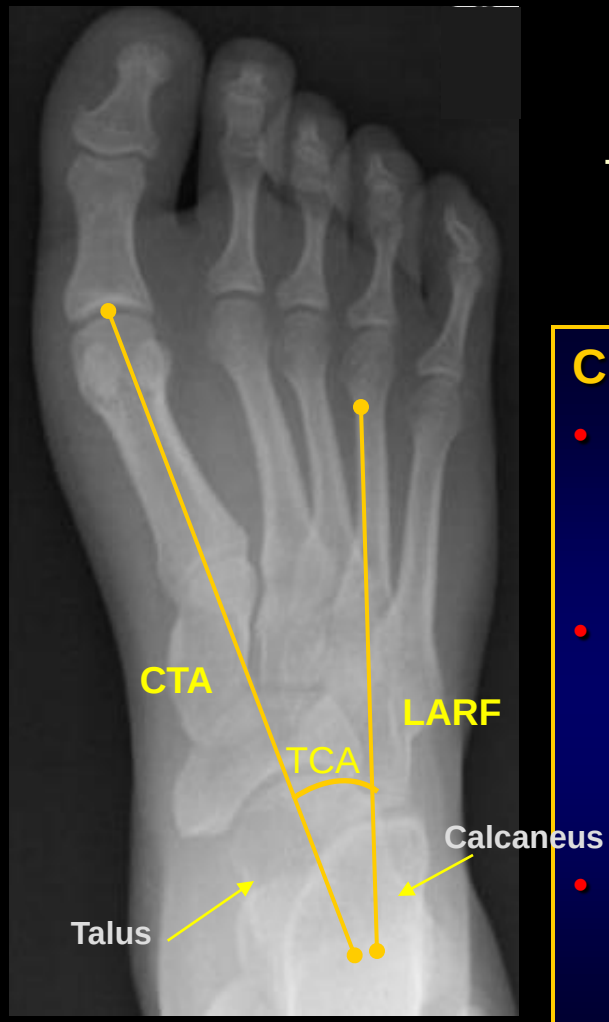
The subtalar joint is evaluated with the talus as the reference point.

The talocalcaneal relationship depends on the motion of the calcaneus.

CHECKLIST

- Collum tali axis (CTA) or long axis of talus
- Longitudinal axis of the rear foot (LARF): Mid calcaneal line parallel with lateral calcaneus
- Talocalcaneal (Kite's) angle (TCA) = 15-30˚ (average 21˚)

Hindfoot: Subtalar Joint
Normal Alignment on AP view



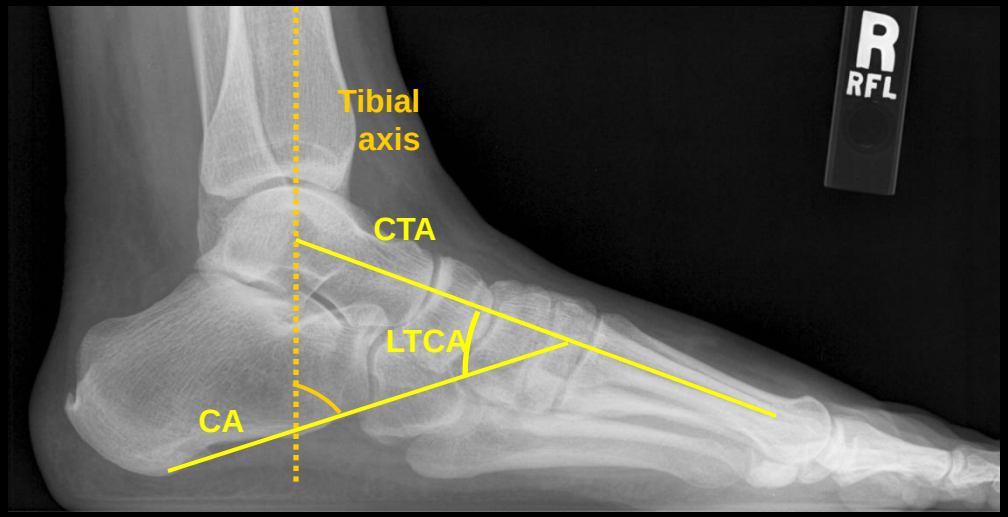
The subtalar joint is evaluated with the talus as the reference point.

The talocalcaneal relationship depends on the motion of the calcaneus.

CHECKLIST

- Collum tali axis (CTA) or long axis of talus passes through base of 1st metatarsal
- Longitudinal axis of the rear foot (LARF): Mid calcaneal line parallel with lateral calcaneus passes through base of the 4th metatarsal
- Talocalcaneal (Kite's) angle (TCA) = 15-30˚ (average 21˚)

Hindfoot: Subtalar Joint
Normal Alignment on Lateral View



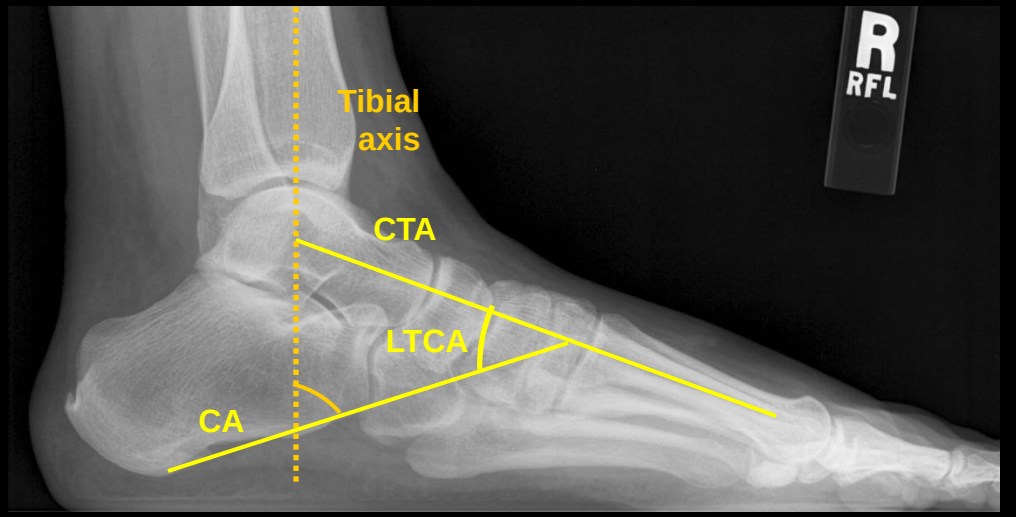
Tibiocalcaneal angle (between long axis of tibia and CA) is more important in pediatric congenital abnormalities.

If >90°, equinovarus with plantar flexion of calcaneus is present.

CHECKLIST

- Collum tali axis (CTA):
  - long axis of talus should parallel 1st metatarsal
- Calcaneal inclination axis (CA): line connects inferior tuberosity to distal inferior point of calcaneus
- Lateral talocalcaneal angle (LTCA):
  - Measured between these axes
  - Normal=25-45˚

Hindfoot: Subtalar Joint
Normal Alignment on Lateral View



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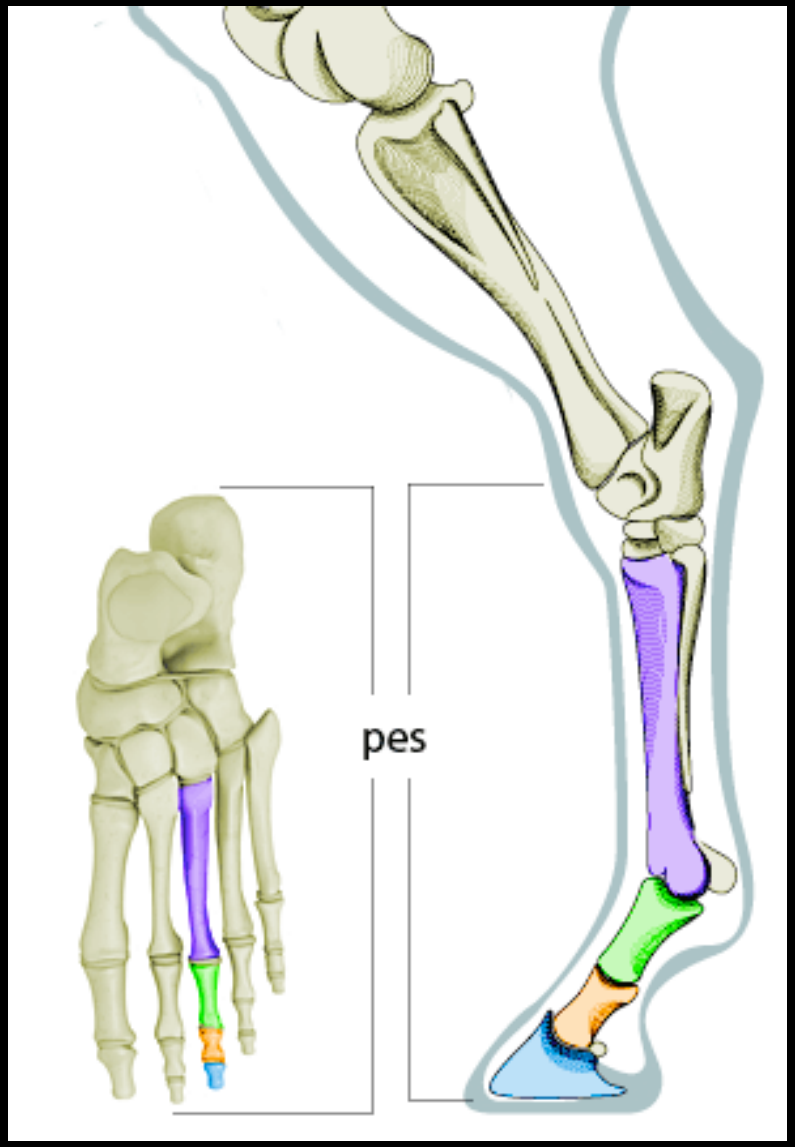
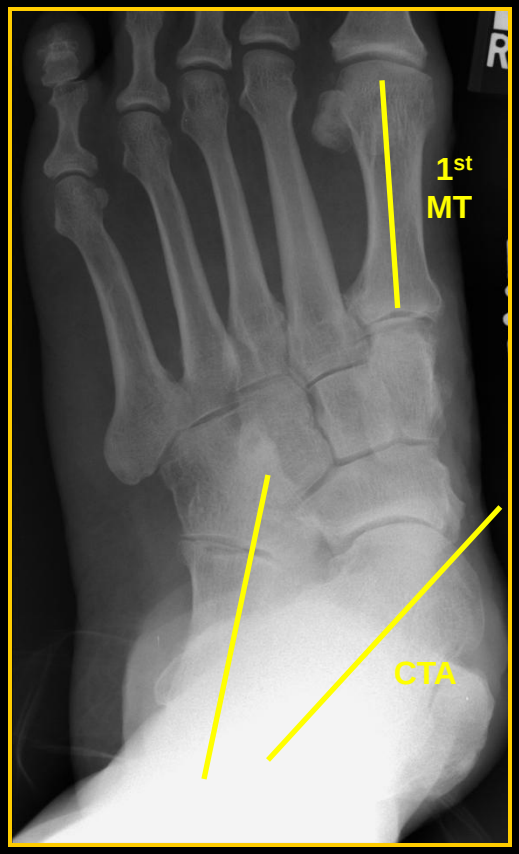
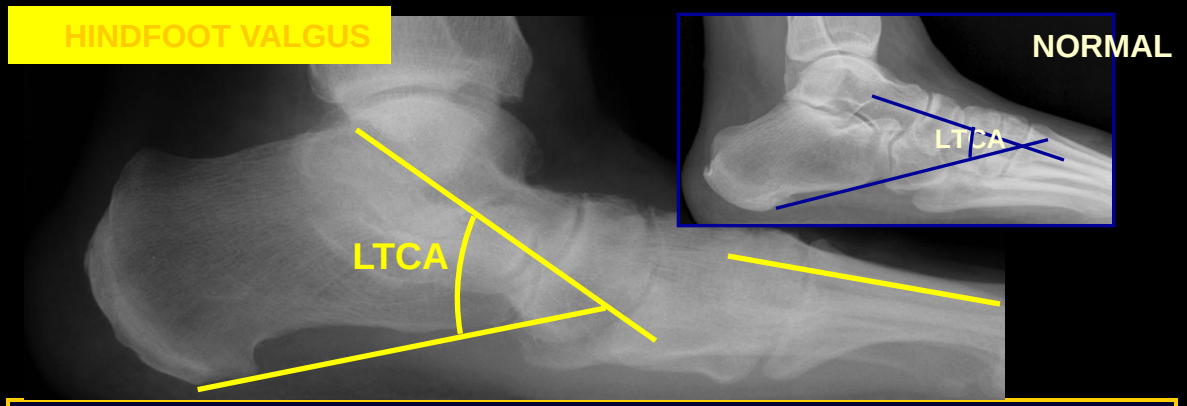


Hindfoot Malalignment: Valgus

- Hindfoot malalignment is caused by abnormal position of the calcaneus.
- When the calcaneus is valgus, it abducts and dorsiflexes. The talus then loses its support and moves medially and plantarward. This increases the talocalcaneal angle, best measured on the lateral view.





Lateral view:

Lateral talocalcaneal angle (LTCA) > 45˚.

Collum tali axis points plantarward compared to the 1st metatarsal.

AP view:

Kite's angle is increased

Collum tali axis points medial to long axis of 1st metatarsal.

Hindfoot Malalignment: Valgus

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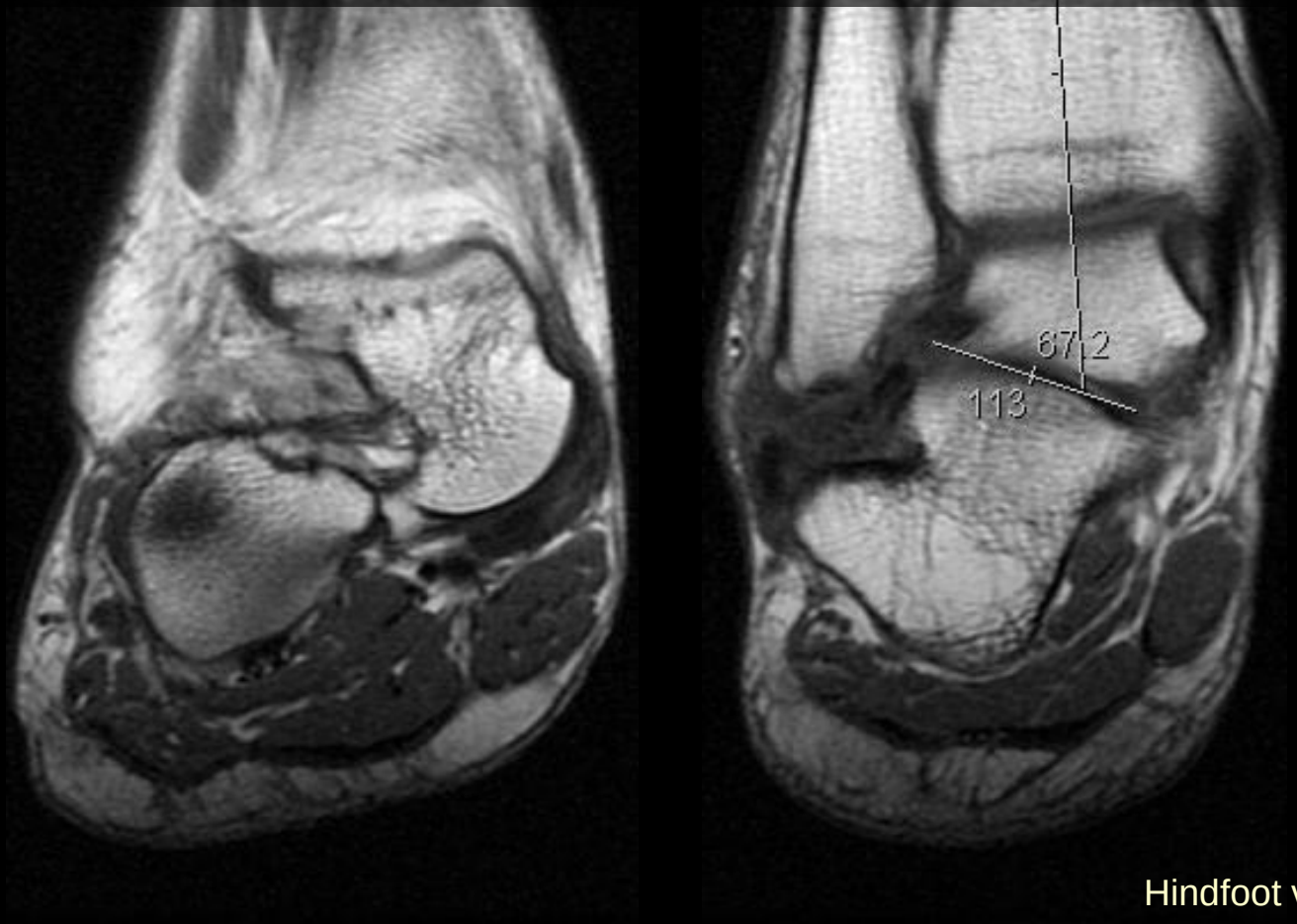
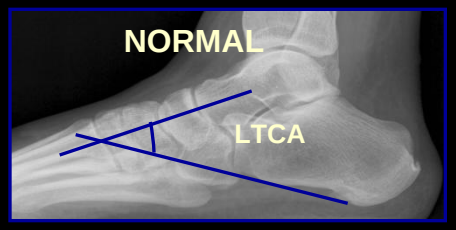
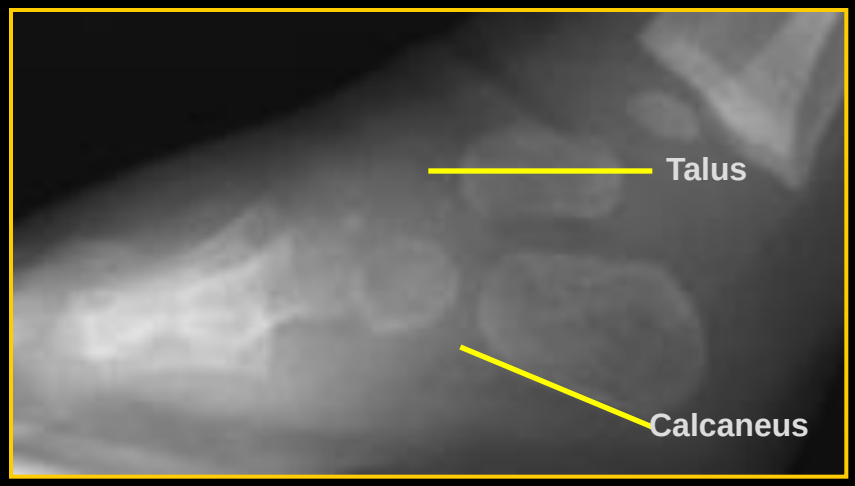


Hindfoot valgus on MRI 25F

Hindfoot Malalignment: Varus

When the calcaneus is varus, it adducts and plantarflexes. There is more overlap between the talus and calcaneus with the calcaneus positioned more medially. This decreases the talocalcaneal angle.





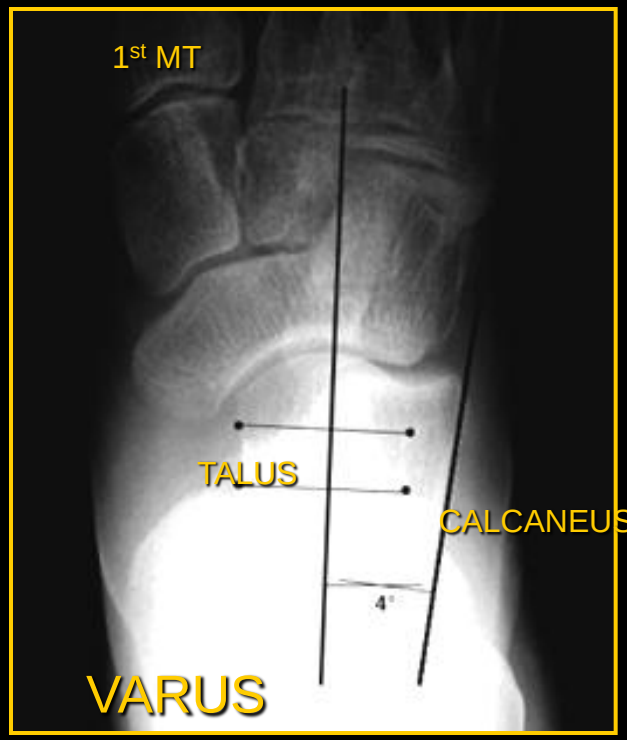
Hindfoot varus is less commonly seen in adults than in children.

When it does occur, it may be seen with pes cavus.

Lateral view:

The lateral talocalcaneal angle is decreased (< 25°) in this child with hindfoot varus.

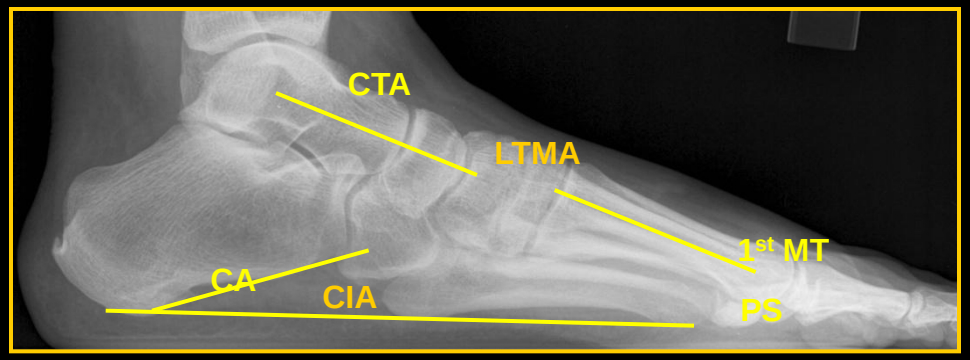
Hindfoot Malalignment: Varus



- The talocalcaneal angle is decreased.
- The long axis of the talus is lateral to the 1st metatarsal and overlaps more with the calcaneus.

Hunter J. Evaluation of Adult Foot Alignment. Website http://uwmsk.org

Midfoot: Normal Alignment
Longitudinal Arch



Use the lateral view to evaluate the longitudinal arch.

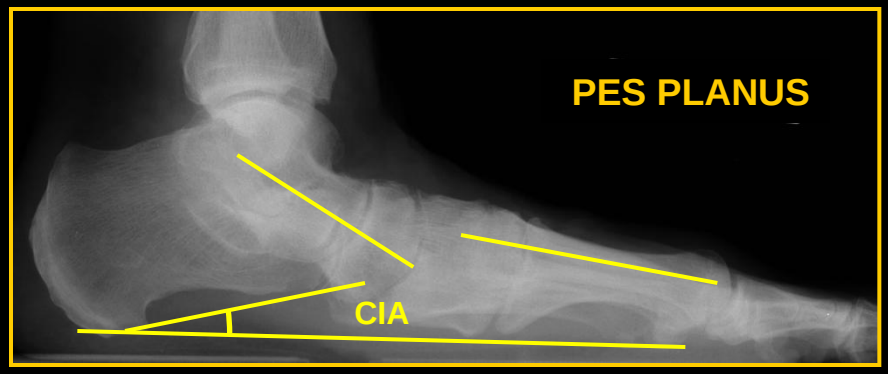
CHECKLIST:

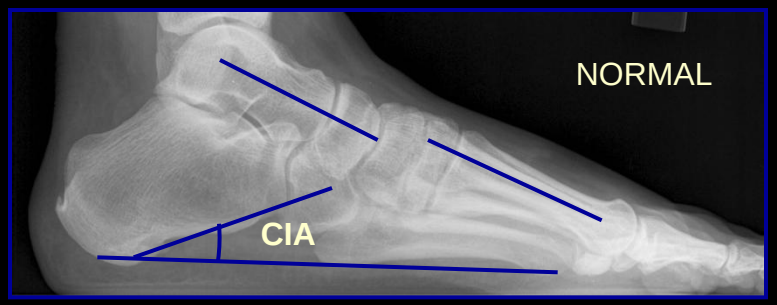
1. **Collum tali axis (CTA) should parallel 1st metatarsal axis**
   - Lateral talar-first metatarsal angle (LTMA) is measured between these two axes.
   - Normal is 0˚± 4˚

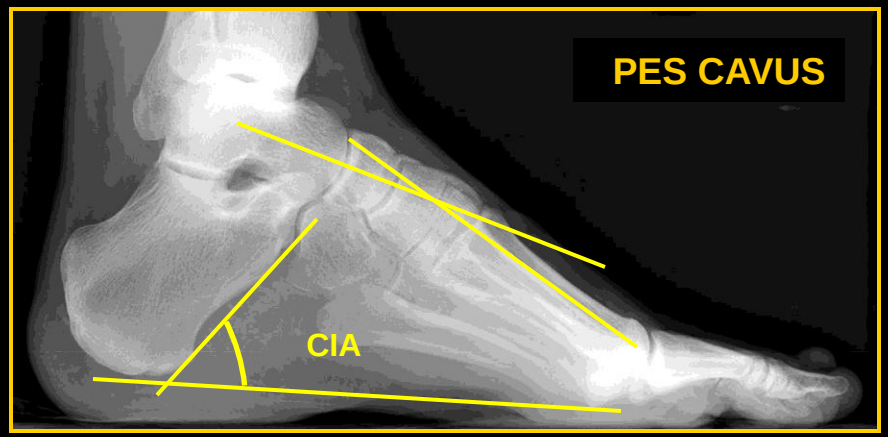
2. **Calcaneal pitch or inclination angle (CIA)**
   - Between the calcaneal inclination (CA) axis and plane of support (PS)
   - Normal average is 18-20˚ (range 17-32˚)

Longitudinal Arch Deformities

- Collapse of Arch:
  Pes Planus
  - Talus points down in relation to 1st metatarsal
  - Calcaneal inclination angle (CIA) is decreased, measuring < 18˚
- Abnormal High Arch:
  Pes Cavus
  - Talus is dorsiflexed in relation to 1st metatarsal
  - Calcaneal inclination angle is increased measuring > 30˚





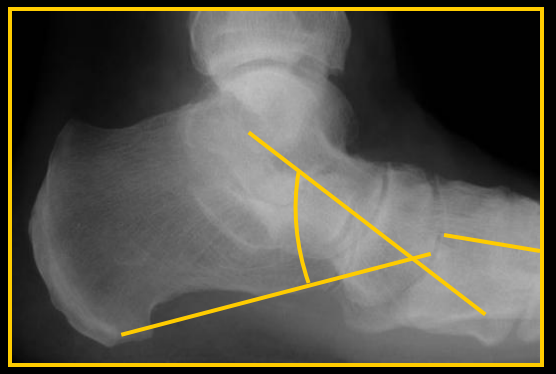


Longitudinal Arch Deformities
Pes Planus

1. Hindfoot:

Subtalar Joint

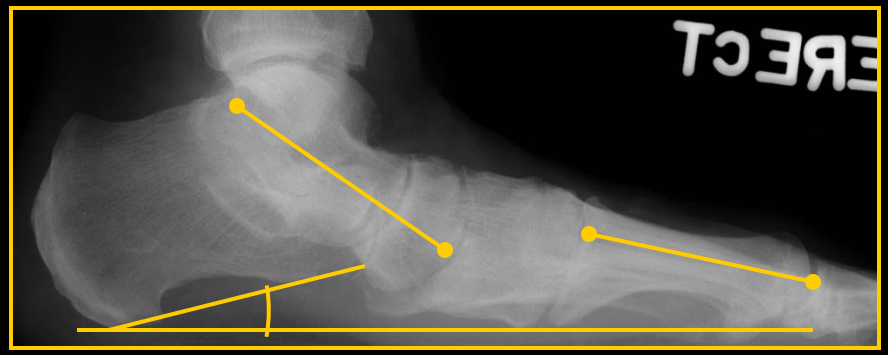
- Increased talocalcaneal (Kite's) angle on AP view > 30^0
- Increased lateral talocalcaneal angle > 45°
- Valgus



2. Midfoot:

Midtarsal Joint

- Talus points plantarward from 1st MT >4^0
- Decreased calcaneal inclination angle < 18°
- Longitudinal Arch Collapse



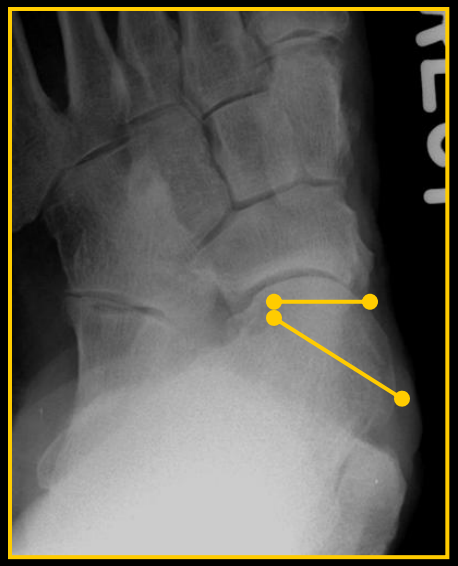
Longitudinal Arch Deformities
Pes Planus

Talonavicular coverage angle is measured between lines connecting the articular surfaces of the navicular and talus. Normal ≤ 7˚

Longitudinal Arch Deformities
Pes Planus

3. Mid/Forefoot:

- Talus points medial to 1st MT on AP view
- The navicular laterally subluxes on the talus increasing the talonavicular coverage angle > 7˚
- Metatarso-phalangeal and inter-phalangeal joints are aligned
- Abduction



Laterally subluxed navicular

Longitudinal Arch Deformities
Pes Planus

3. Mid/Forefoot:

Talus points medial to 1st MT on AP view

The navicular laterally subluxes on the talus increasing the talonavicular coverage angle > 7˚

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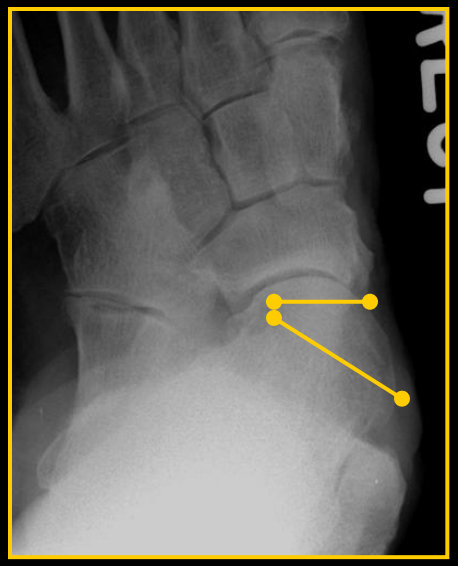
Abduction



Laterally subluxed navicular

Multiple causes include:

posterior tibialis tendon dysfunction
Charcot foot
posttraumatic
rheumatoid arthritis
neuromuscular disorder
tarsal coalition

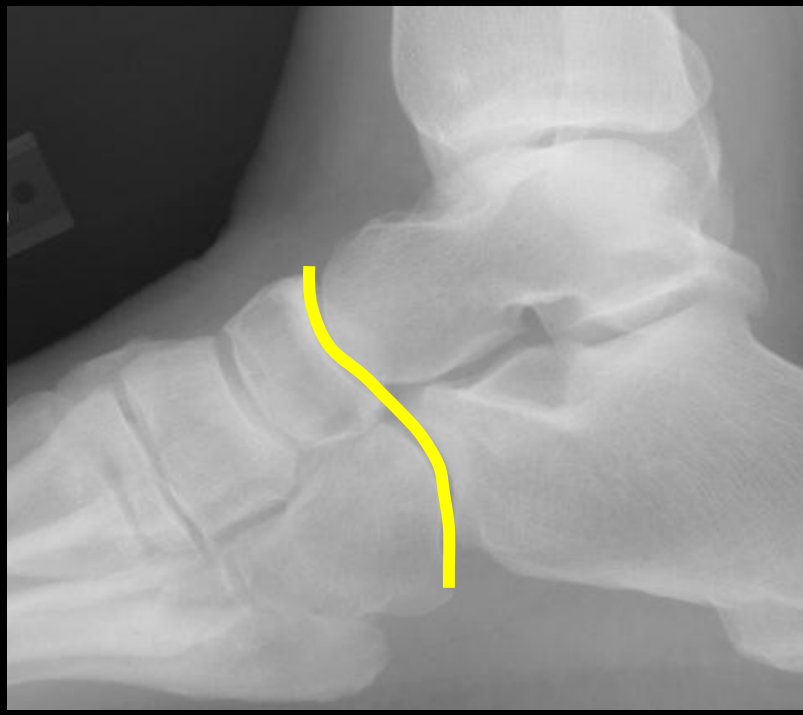
Abnormal loading on the medial column leads to collapse of longitudinal arch and eventual impingement on lateral column

Longitudinal Arch Deformities
Pes Planus

- Hindfoot valgus
  - Lateral: Talocalcaneal angle ↑
  - AP: Talocalcaneal angle ↑
- Collapse of longitudinal arch
  - Lateral: 1st metatarsal calcaneal angle >4^{0}
  - Lateral: Calcaneal pitch < 17^{0}
- Midfoot / Forefoot abduction
  - Talus points medial to 1st metatarsal
  - Talonavicular coverage > 7^{0}

Longitudinal Arch Deformities
Pes Planus





Cyma line

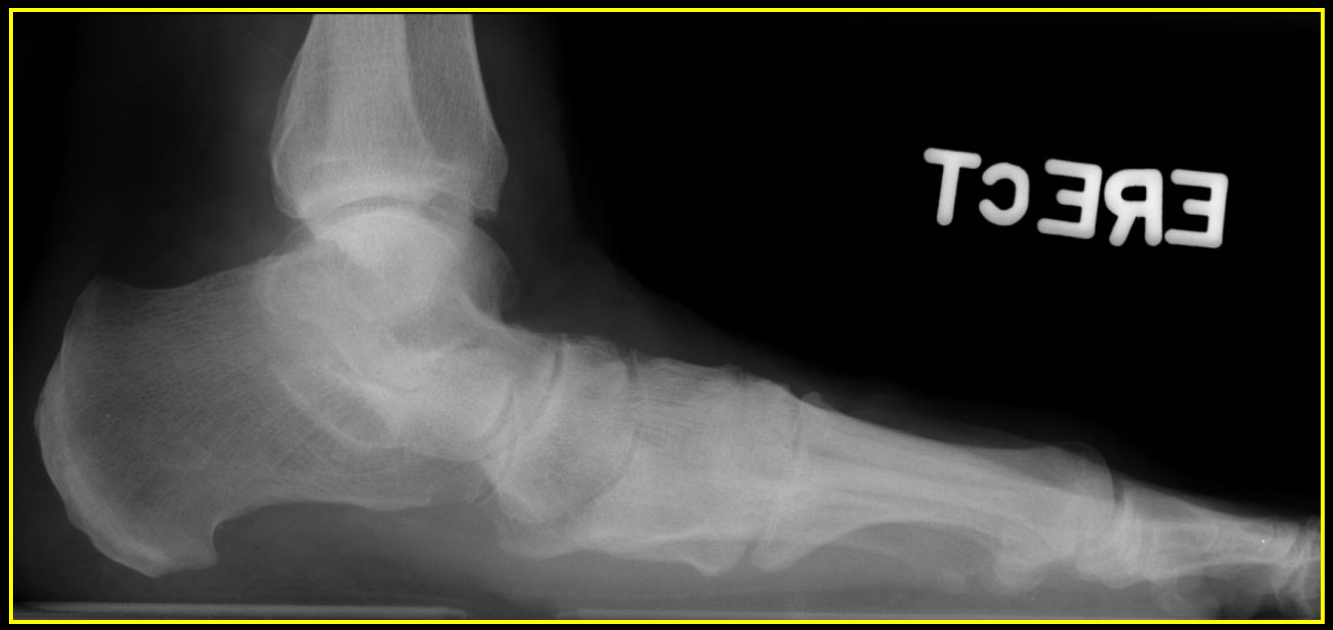
A cyma line is an architectural term designating the union of two curve lines resembling an S.

The normal talonavicular and calcaneocuboid joints should create a smooth cyma on both the AP and lateral views.

If the cyma line is broken it suggests “shortening” of the calcaneus relative to the talus.

This is often just a radiographic shortening possibly due to rotation of the talus on calcaneus

Longitudinal Arch Deformities
Pes Planus



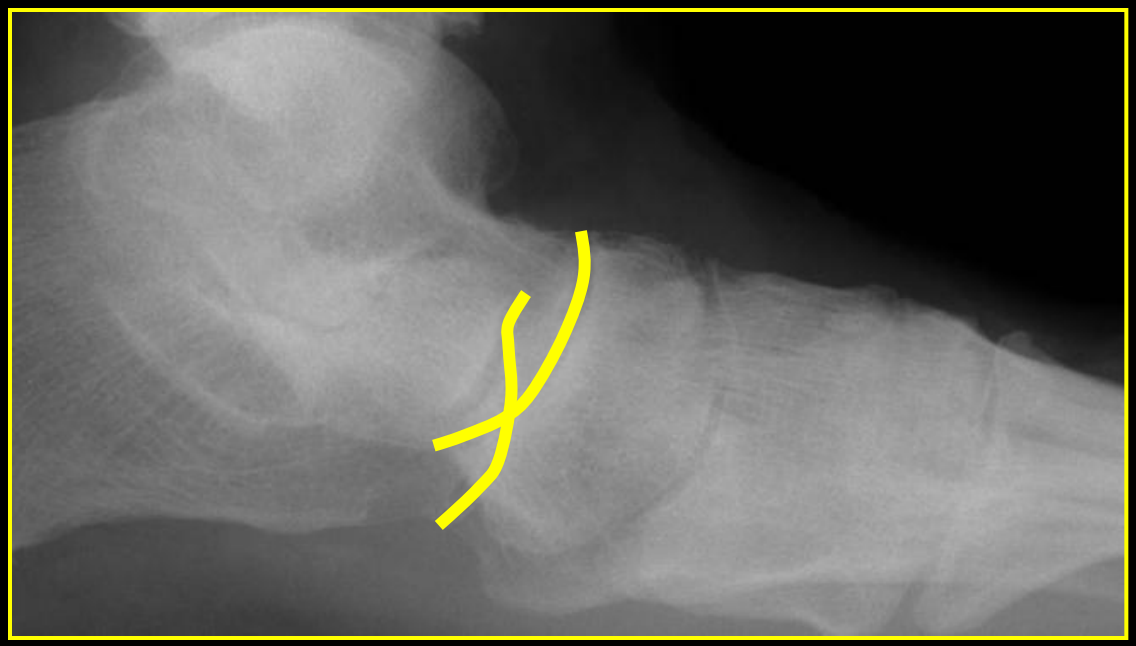
Cyma line

It may, however, be due to actual shortening of the calcaneus

Some surgeons would lengthen the lateral column

in addition to a medial column stabilization.

Longitudinal Arch Deformities
Pes Planus



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Longitudinal Arch Deformities
Pes Planus

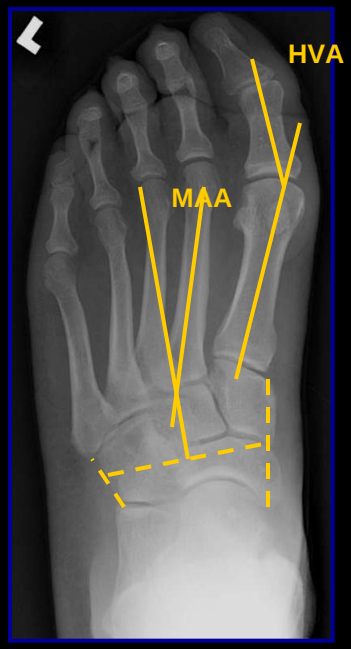
Marfans foot collapse 46M

Longitudinal Arch Deformities

Pes Cavus

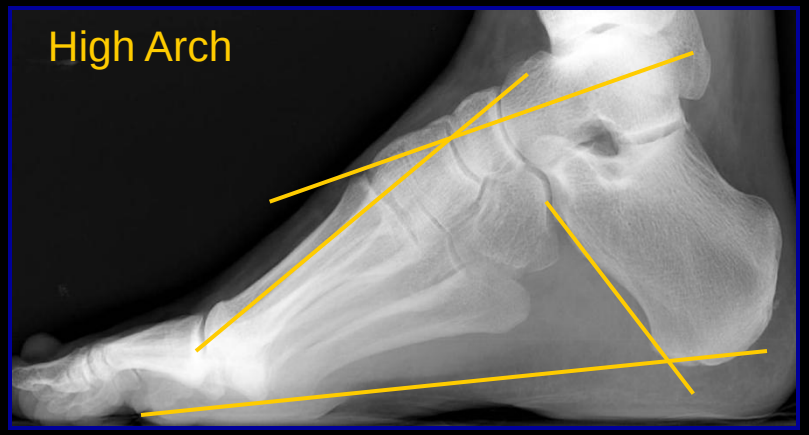
Longitudinal Arch Deformities
Pes Cavus

1. Hindfoot: Subtalar Joint
   - Talus points lateral to 1st MT
   - Lateral talocalcaneal angle is decreased.
   - Varus



2. Midfoot: Midtarsal Joint
   - Increased calcaneal inclination angle > 32°
   - Talus is dorsiflexed vs. 1st MT
   - High longitudinal arch

3. Forefoot:
   - Mild metatarsus adductus (MAA) > 15˚
   - Mild hallux valgus (HVA) > 15˚



Longitudinal Arch Deformities
Pes Cavus

Abnormal High longitudinal arch with persistent state of supination

Causes include neurologic disorders: Charcot-Marie Tooth, myelodysplasia, poliomyelitis

Muscular imbalance from neurologic disorder leads to foot malalignment.

- Forefoot plantarflexion
- Hindfoot dorsiflexion and varus
- High longitudinal arch

"Sinus Tarsi See-Through" Sign:

Hindfoot varus and forefoot adduction allow sinus tarsi to be in same plane as x-ray beam

Longitudinal Arch Deformities
Pes Cavus

“Double talar dome sign”:

Both medial and lateral aspects of the talar dome are visualized, due to exteranl rotation at time of positioning.

Causes include neurologic disorders: Charcot-Marie Tooth, myelodysplasia, poliomyelitis

22 yo male with Charcot Marie Tooth Syndrome

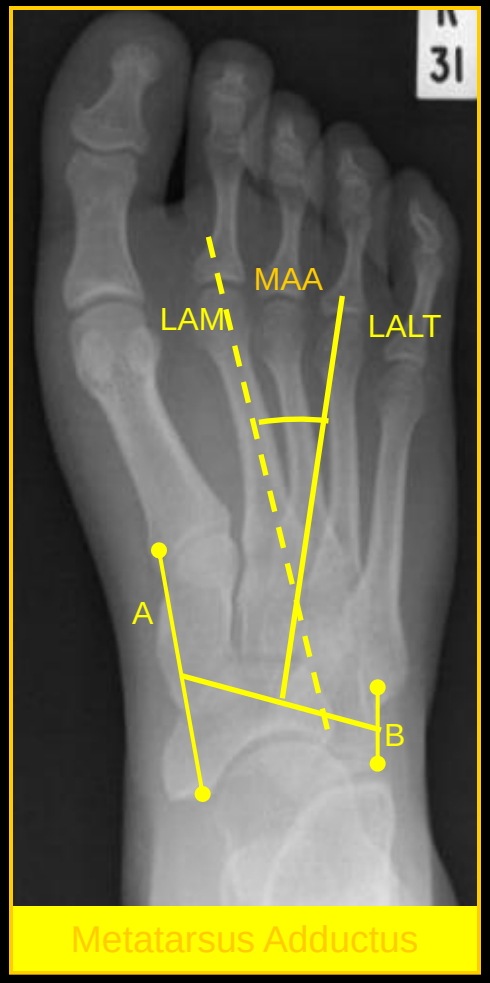
“Sinus Tarsi See-Through” Sign:

Hindfoot varus and forefoot adduction allow sinus tarsi to be in same plane as x-ray beam

Forefoot: Normal Alignment

Tarsometatarsal Joints

NORMAL



Metatarsus Adductus

Metatarsus adductus angle (MAA):

- Between the axes of the lesser tarsus and the 2nd metatarsal
- Longitudinal axis of the lesser tarsus (LALT):
  - A is line from medial talonavicular joint to medial 1st TMT joint.
  - B is line from lateral calcaneocuboid joint to lateral 5th TMT joint.
  - Line perpendicular to line AB that transects the lesser tarsus.
- Longitudinal axis of the metatarsus (LAM):
  - Line bisecting base and neck of 2nd metatarsal
- Normal ≤ 15°
- Metatarsus adductus is present if > 15°

Forefoot: Metatarsus Adductus

Tarsometatarsal Joints

1. Hindfoot: Subtalar Jt

Mild Valgus

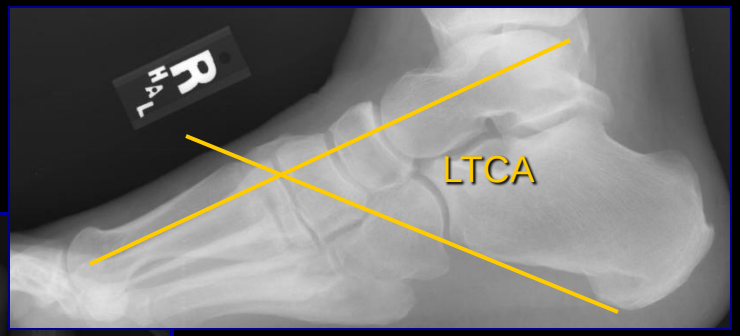
- Best seen on lateral view
- Slightly increased lateral talocalcaneal angle (LTCA) > 45˚

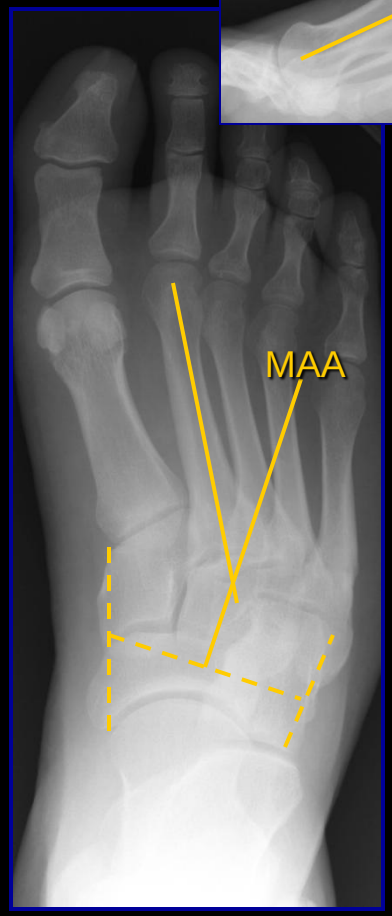
2. Midfoot: Midtarsal Jt

- Normal longitudinal arch

3. Forefoot:

- Metatarsus adductus (MAA) > 15˚





Stress changes at lateral proximal 5th metatarsal

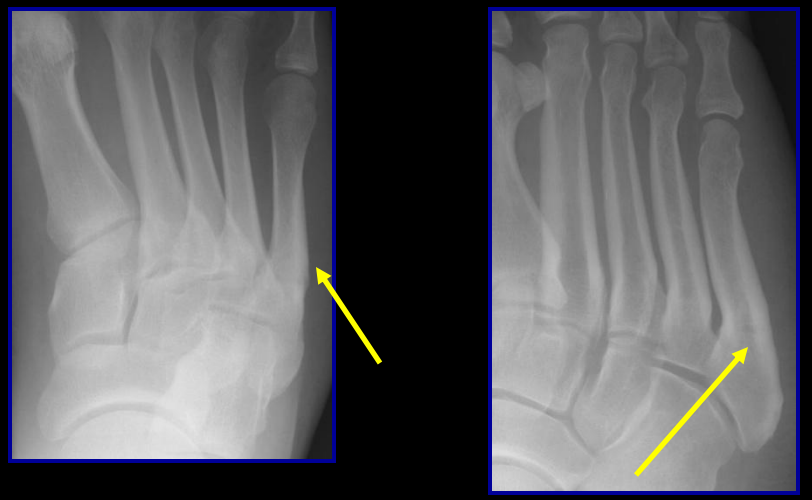
Forefoot: Metatarsus Adductus

Tarsometatarsal Joints

Abnormal Adduction of metatarsals relative to midfoot

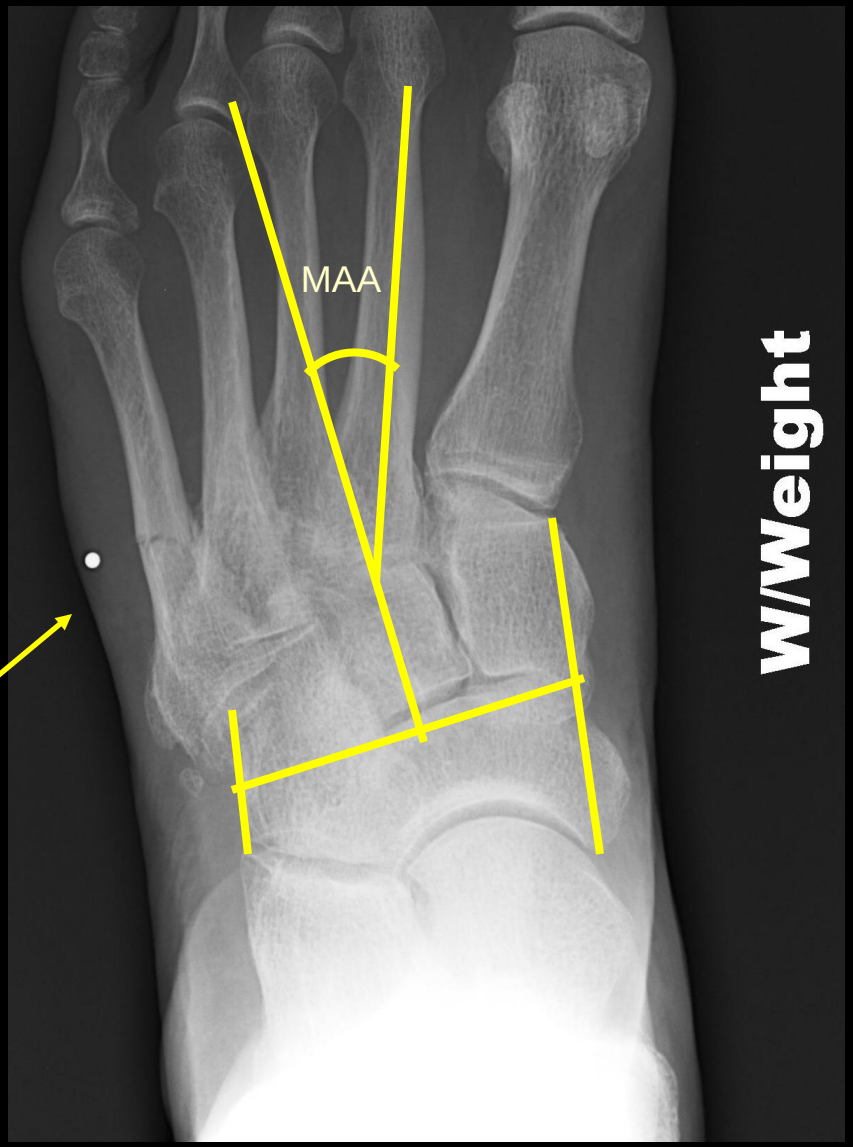
- Childhood foot deformity that may persist to adulthood
- 1:1000 live births
- 50% bilateral
- May occur with mild hindfoot valgus
- May develop hallux valgus

Adduction and inversion of the metatarsals lead to abnormal load on the lateral (4^{th}, 5^{th}) metatarsals and predispose them to develop stress fractures.



Forefoot: Metatarsus Adductus

Tarsometatarsal Joints



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Forefoot: Metatarsus Adductus

Tarsometatarsal Joints

Forefoot: Metatarsus Adductus

Tarsometatarsal Joints

Metatarsus adductus 16M

Charcot Marie Tooth Syndrome

- Pes Cavus
- Hindfoot varus
- Metatarsus adductus
  - Stress changes at lateral aspects of 4th and 5th MTs
- Claw toes

Weight Bearing Views

22 yo male with Charcot Marie Tooth Syndrome

Charcot Marie Tooth Syndrome

- Pes Cavus
- Hindfoot varus
- Metatarsus adductus
  - Stress changes at lateral aspects of 4th and 5th MTs
- Claw toes

22 yo male with Charcot Marie Tooth Syndrome

Charcot Marie Tooth Syndrome
Hindfoot Malalignment: Varus

- The long axis of the talus is lateral to the 1st metatarsal and overlaps more with the calcaneus.
- The talocalcaneal angle is decreased.

22 yo male with Charcot Marie Tooth Syndrome

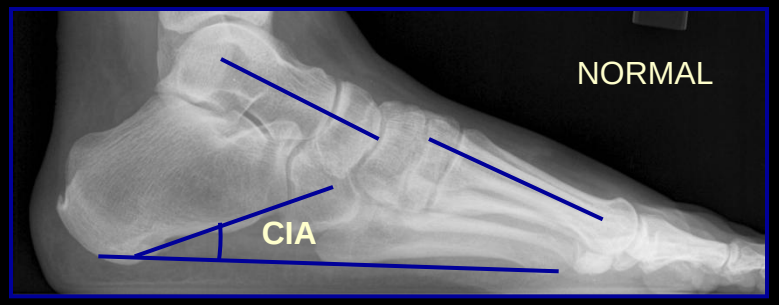
Charcot Marie Tooth Syndrome
Longitudinal Arch Deformities

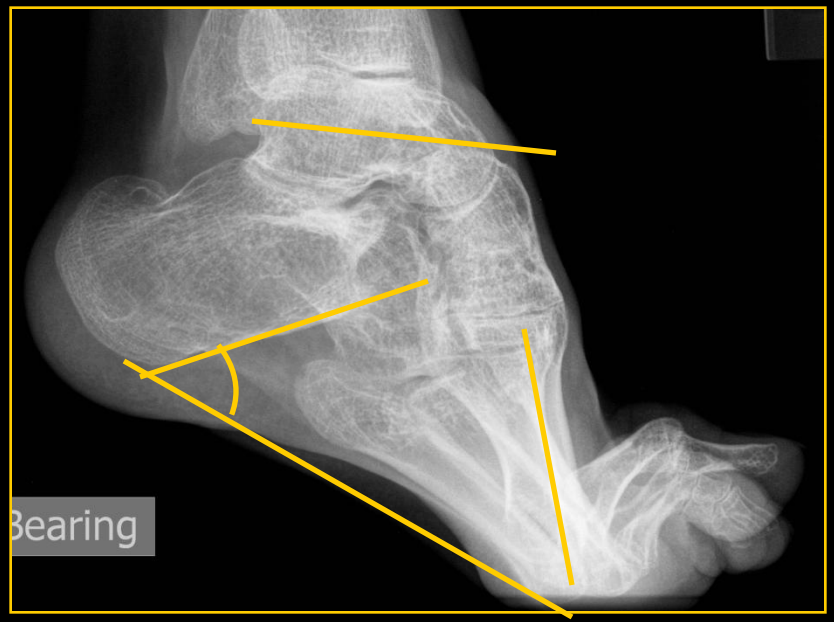
- Abnormal High Arch:

  Pes Cavus

  - LTMA points upward > 4˚ (Talus is dorsiflexed in relation to 1st metatarsal)

  - Calcaneal inclination angle is increased measuring > 30˚





22 yo male with Charcot Marie Tooth Syndrome

Charcot Marie Tooth Syndrome

- Inherited neuropathy
- CMT 1: Peripheral demyelination
- CMT 2: Axonal degeneration
- CMT 3: Dejerine-Sottas, infantile-onset
  - Severe demyelination
- Clinical Sx: distal extremity weakness and foot deformities, spinal deformity (scoliosis), rarely phrenic nerve weakness
- Radiographic Findings: Pes cavus, hindfoot varus, scoliosis, enlarged peripheral nerves

Charcot Marie Tooth Syndrome Foot Deformity

- Weakness of peroneus brevis and anterior tibialis muscles
- Stronger posterior tibialis muscle causes metatarsus adductus
- Stronger peroneus longus muscle causes plantar flexion of the first MT
  - Hindfoot varus occurs to allow lateral MTs to be on the ground
- Stronger flexor muscles lead to claw-toe deformity

Pes Planovalgus

- Rigid (Peroneal Spastic) flat foot
  - If rigid look for hindfoot coalition

- Flexible flat foot
  - May go if stand on tip toes
  - May go away if dorsiflex
  - May go away with Hubscher maneuver
    - Windlass effect

Clinical Presentation
Hubscher Maneuver

If a pes planovalgus deformity is present (which is seen with the typical peroneal spastic flatfoot), the *Hubscher maneuver* or the *toe test of Jack* can be performed

The Hubscher maneuver involves passive dorsiflexion of the hallux while the patient stands. When the hallux is dorsiflexed, the medial cord of the plantar aponeurosis and the flexor hallucis longus tendon are tightened

If the pes planovalgus deformity is flexible, as in the above photos, the medial longitudinal arch will increase in height and the hindfoot will supinate

Rigid (Peroneal Spastic) flat foot

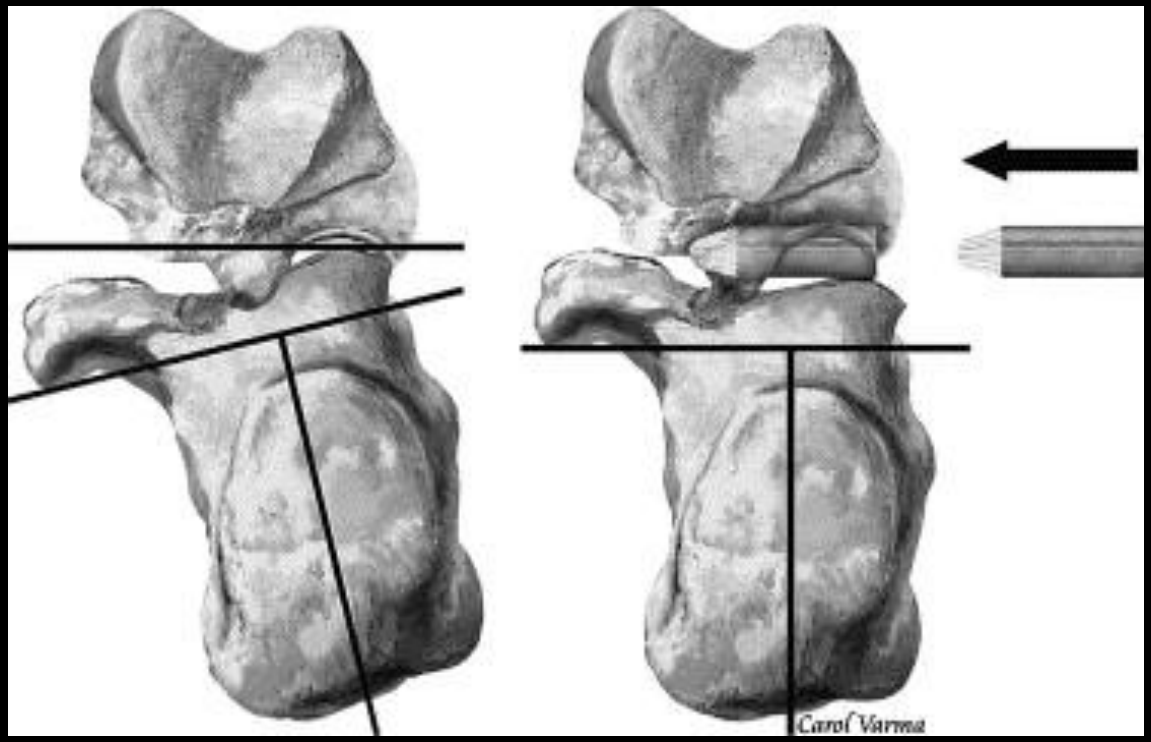
Pes Planovalgus
Flexible flat foot treatment - Arthroereisis

37F with hx of foot pain

Pes Planovalgus
Flexible flat foot treatment - Arthroereisis

40yo foot pain and unable to walk , PTT tear

Flatfoot and Arthroereisis



Pes Cavus

- Etiology identified 80% of time
  - Trauma
  - Neuromuscular disorders
  - Remaining 20% idiopathic, nonprogressive
- If unilateral and no h/o trauma, need to exclude spinal tumor
- Neuromuscular disorders
  - Charcot Marie Tooth
  - Cerebral Palsy
  - Muscular dystrophy
  - Spinal dysraphism
  - Syringomyelia
  - Polyneuritis
  - Poliomyelitis
  - Muscular imbalance leads to elevated longitudinal arch

Skewfoot / Z foot

Hindfoot valgus

But talus parallel with first metatarsal on AP

Longitudinal arch collapse

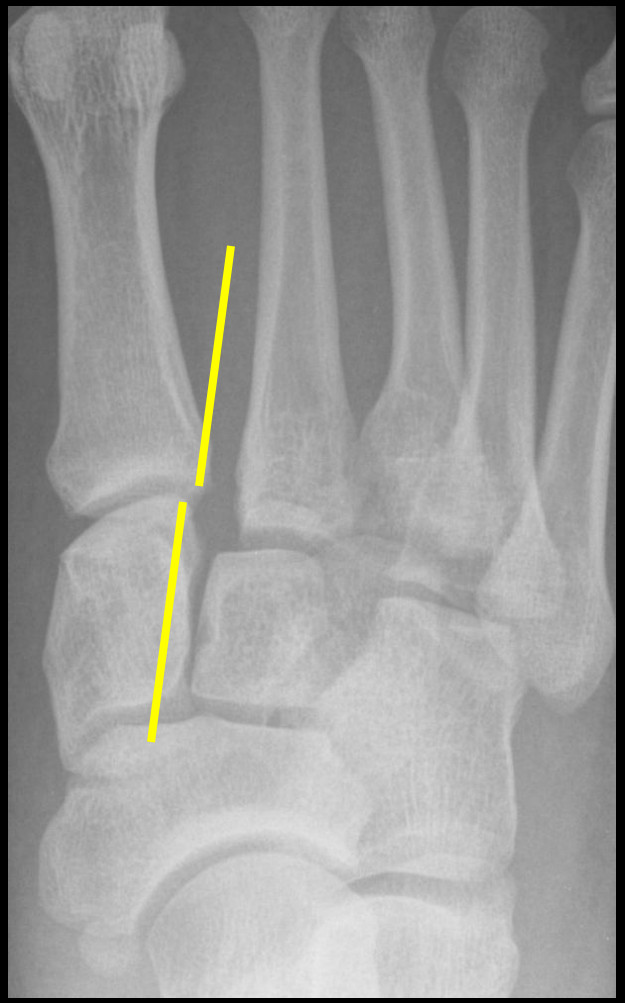
Talonavicular uncoverage / midfoot abduction

Metatarsus adductus

Z foot 78F

Lisfranc Fracture Alignment

- Often subtle
- Must be looked for
- Line up
  - Lateral margin of 1st on AP
  - Medial margin of 2nd on AP
  - Medial margin of 4th on Oblique
  - Medial margin of 5th on Oblique
  - Look for dorsal displacement on Lateral



Lisfranc 19M

Lisfranc Fracture Alignment

- Often subtle
- Must be looked for
- Line up
  - Lateral margin of 1st on AP
  - Medial margin of 2nd on AP
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- Line up
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  - Medial margin of 2nd on AP
  - Medial margin of 4th on Oblique
  - Medial margin of 5th on Oblique
  - Look for dorsal displacement on Lateral
  - Congruent intercunneiform joints

First ray separation Lisfranc 39F

Forefoot: Normal Alignment

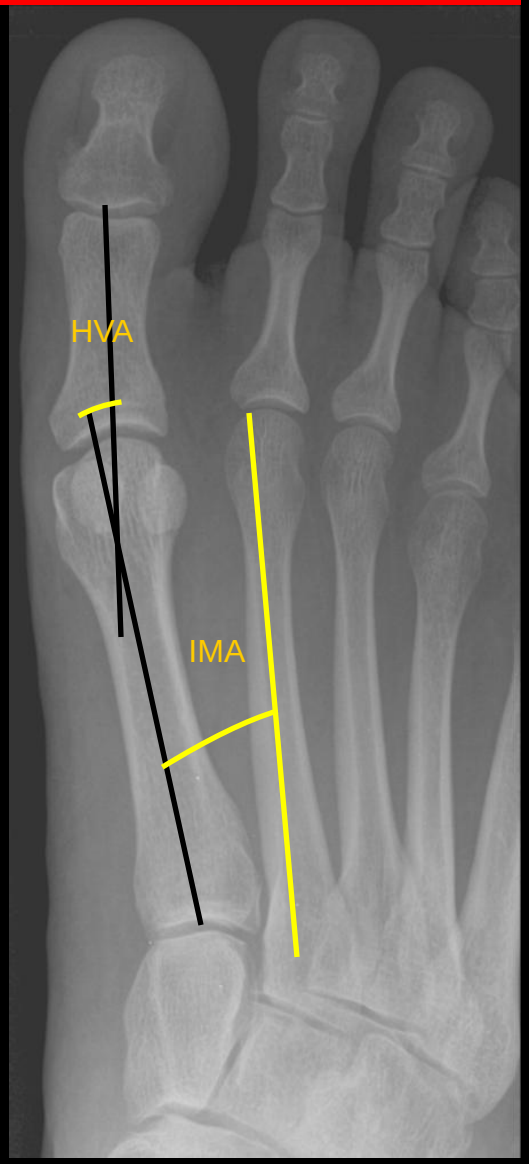
Metatarsophalangeal Joints

Hallux valgus angle (HVA):

- 1st metatarsophalangeal angle
- Between longitudinal axes of 1st metatarsal and 1st proximal phalanx
- Normal= 5-15°
- Hallux Valgus if > 15°

1st – 2nd intermetatarsal angle (IMA):

- Between longitudinal axes of the 1st and 2nd metatarsals
- Normal= < 10°
- Metatarsus primus varus if ≥ 10°



Forefoot: Hallux Valgus

63M Hallux valgus

Forefoot: Hallux Valgus

63M Hallux valgus

Forefoot: Hallux Valgus

1. Hindfoot: Subtalar Jt

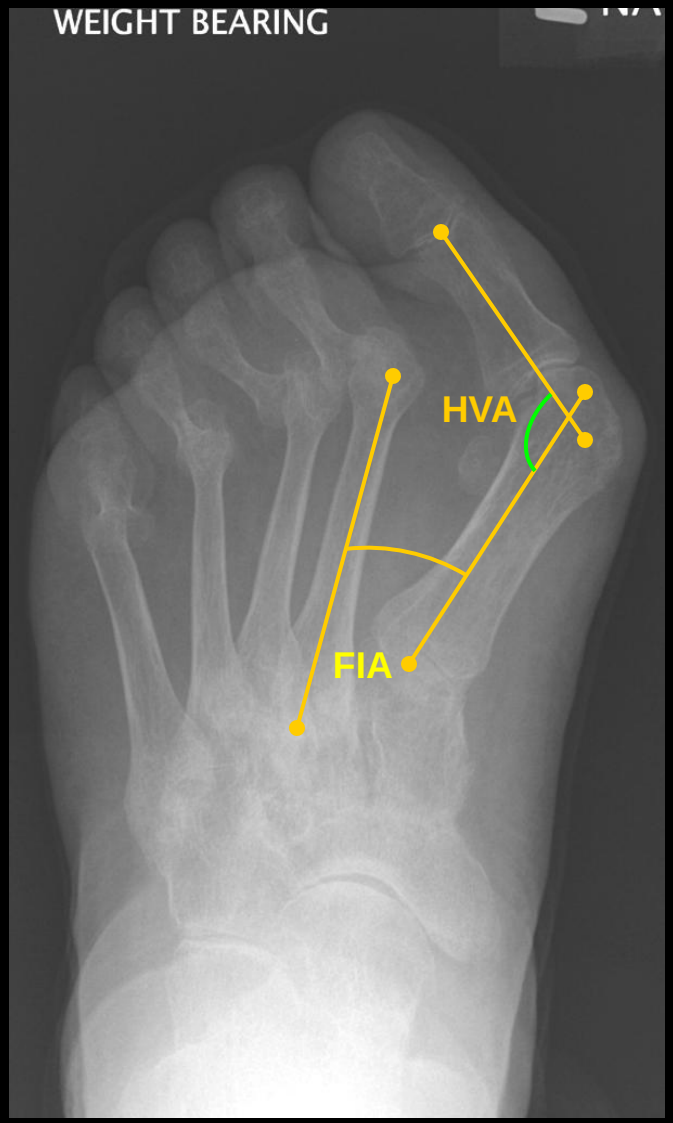
   Normal

2. Midfoot: Midtarsal Joint

   Normal

3. Forefoot: Metatarso-phalangeal and Inter-phalangeal Joints

- Hallux Valgus
  - Angle > 15˚
- Metatarsus Primus Varus
  - 1st – 2nd intermetatarsal angle ≥ 10˚



Met primus varus 34F

Forefoot: Hallux Valgus

1. Hindfoot: Subtalar Jt

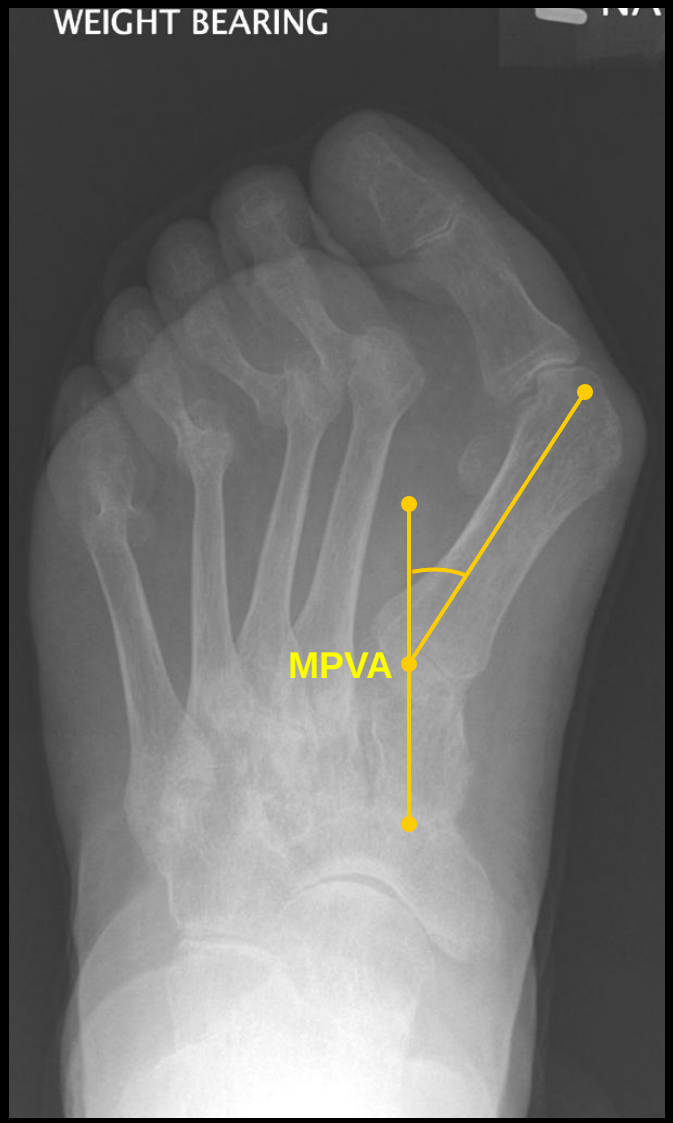
   Normal

2. Midfoot: Midtarsal Joint

   Normal

3. Forefoot: Metatarso-phalangeal and Inter-phalangeal Joints

- Hallux Valgus
  - Angle > 15˚
- Metatarsus Primus Varus Angle
  - 1st metatarsal – medial cuneiform angle ≥ 25˚



Met primus varus 34F

Hallux valgus measurements

Hallux interphalangeus angle

$<8^0$

Hallux valgus angle

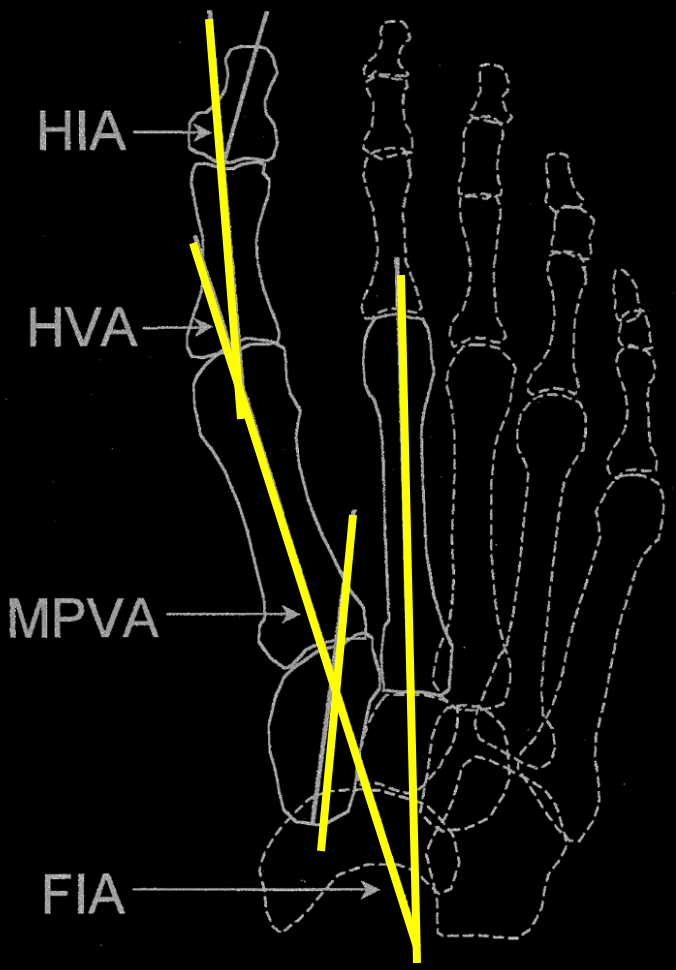
$<15^0$

Metatarsus primus varus angle

$<25^0$

First intermetatarsal angle

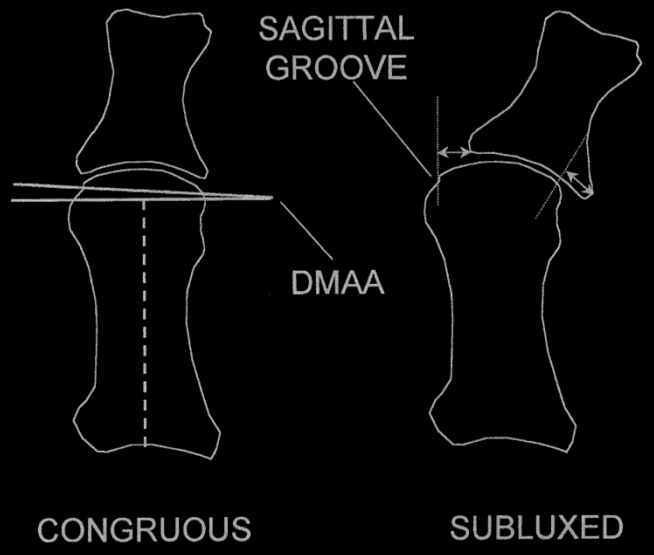
$<10^0$



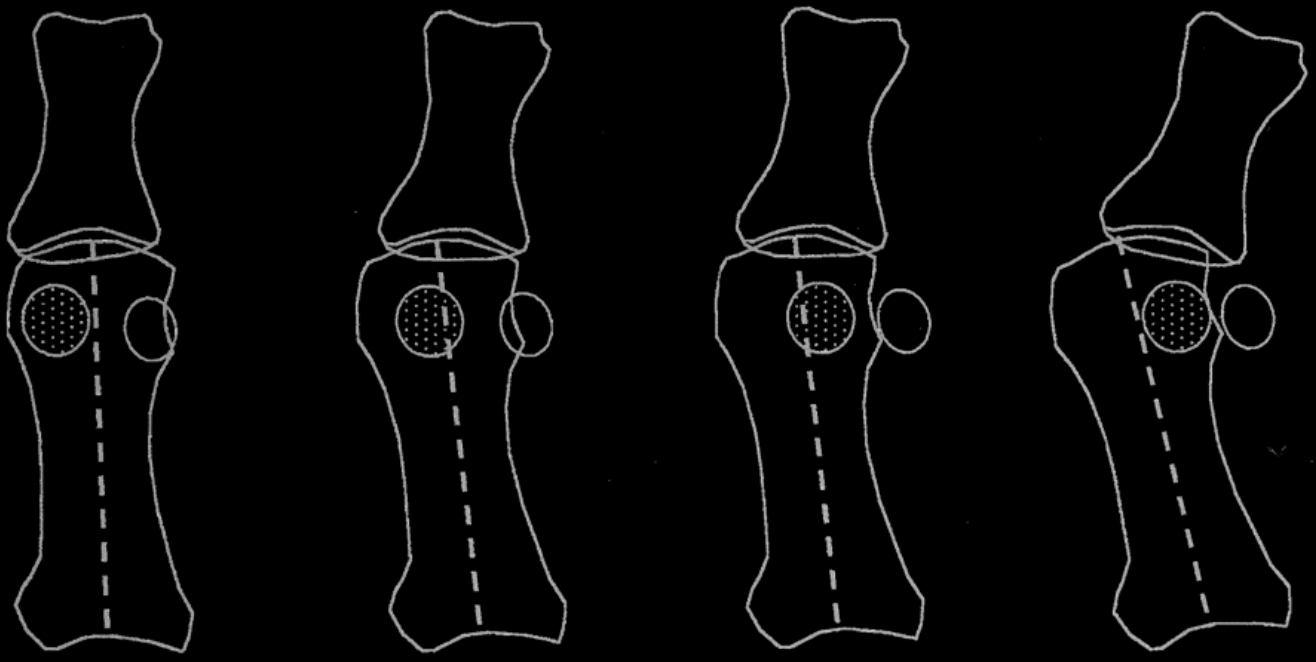
Hallux valgus measurements
Distal metatarsal articular angle

- Normally this is zero deg;
-

  - lateral deviation more than 10 deg is abnormal;
  - typically a moderately severe hallux valgus with a significantly increased DMAA will be associated with a congruent bunion



Hallux valgus measurements
Sesamoid subluxation



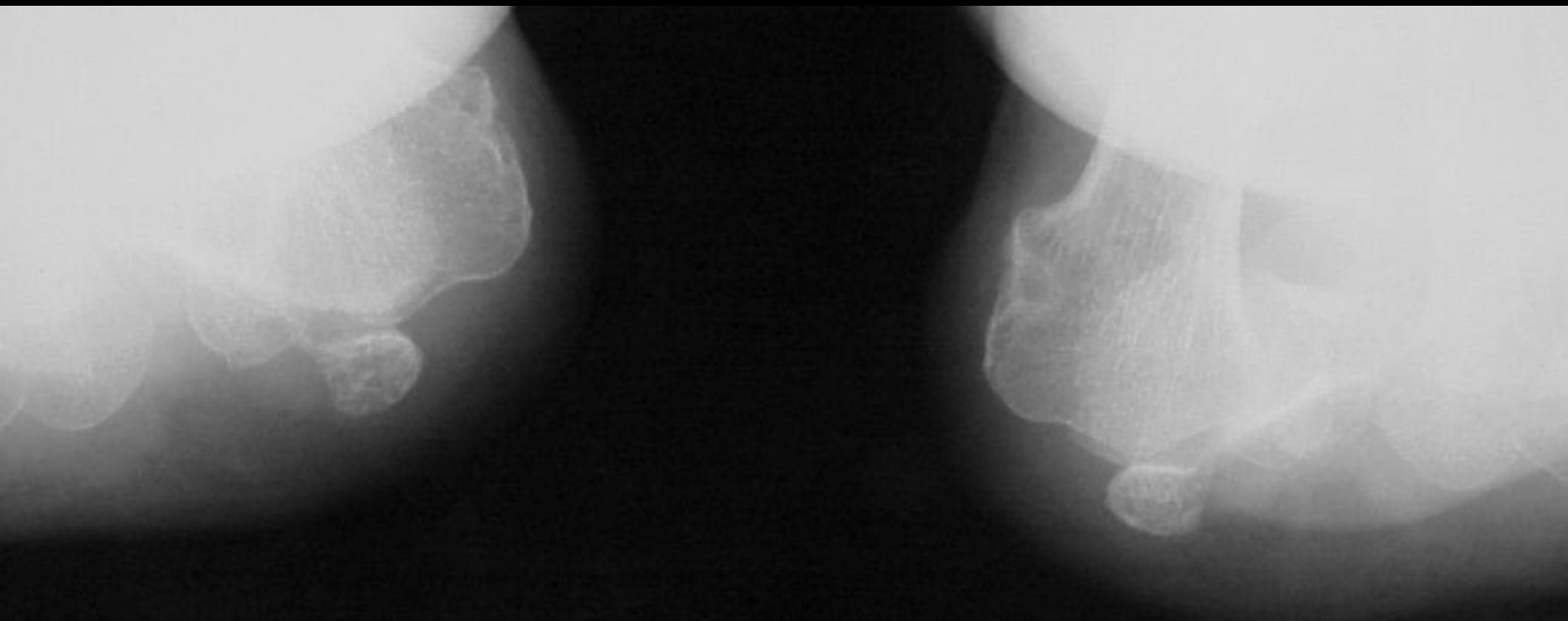
GRADE 0 GRADE 1 GRADE 2 GRADE 3

Hallux valgus measurements
Sesamoid subluxation

Grade 3 sesamoid subluxation

Met primus varus 34F

Hallux valgus measurements
Sesamoid subluxation



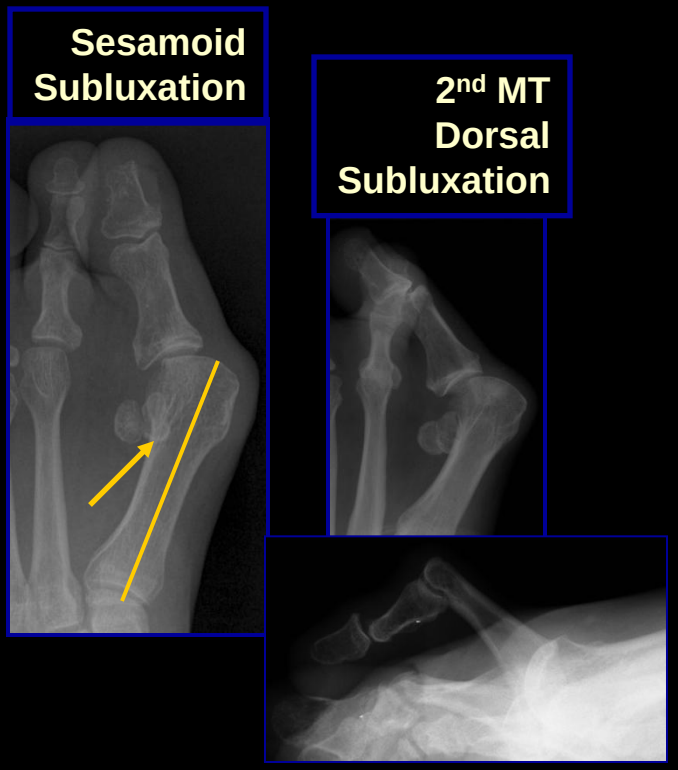
Forefoot: Hallux Valgus

Lateral deviation of the great toe with medial deviation of the 1st metatarsal

- Most common cause is wearing shoes, especially high heels with narrow toe-boxes.
- Female: Male = 4:1

Preoperative Evaluation

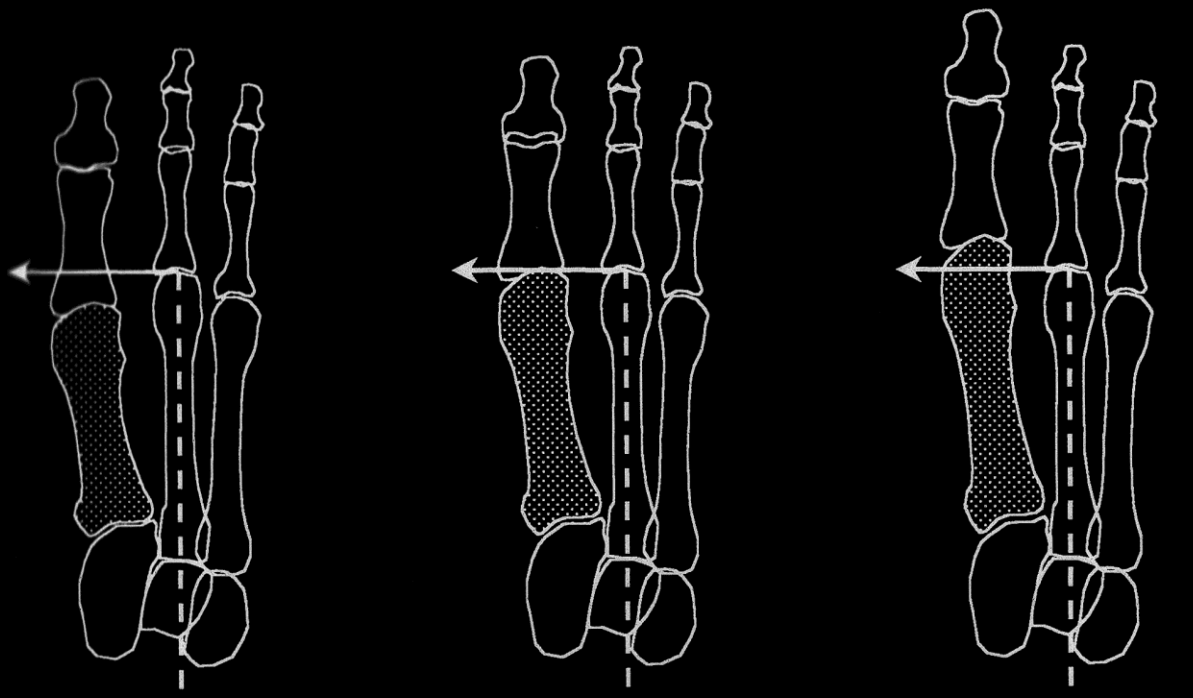
- Severity: Hallux valgus angle (HVA)
  - Mild: HVA 16-25°
  - Moderate: HVA 26-35°
  - Severe: HVA >35°
- Presence of metatarsus primus varus:
  - 1st intermetatarsal angle ≥ 10°
- Presence of tibial sesamoid lateral subluxation:
  - Apparent lateral subluxation to mid-longitudinal axis of 1st metatarsal
- Subluxation of lesser toes: (most commonly 2nd MT)
- Osteoarthrosis of 1st MTP joint



Forefoot: Hallux Valgus Surgery

Hallux fixation closing medial wedge osteotomy Akin proceedure 62F

Metatarsal length



SHORT
<2 mm.

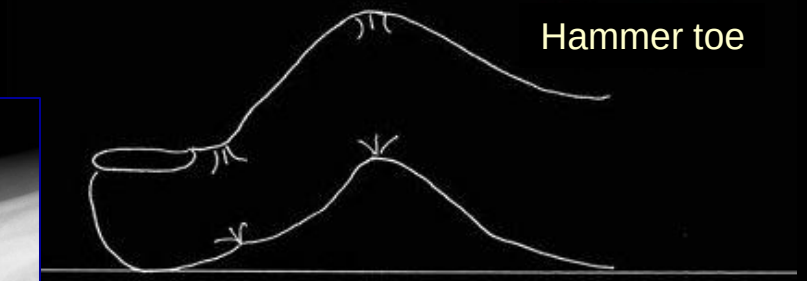
EQUAL

LONG
>2 mm.

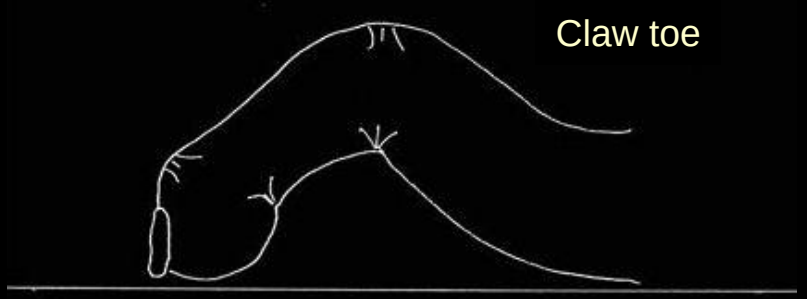
Morton / Roman / Greek / Egyptian

Lesser Toes

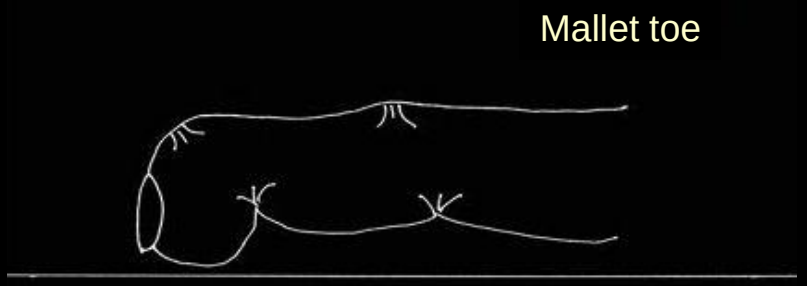
- Hammer toe
- Ex-Fl-Ex



- Claw toe
  - Ex-Fl-Fl



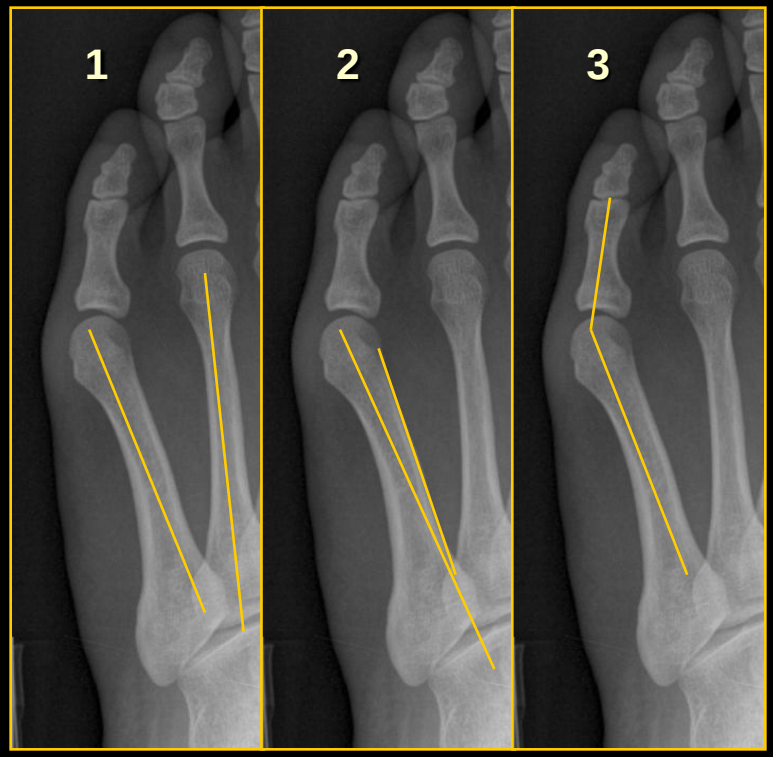
- Mallet toe
  - N-N Fl



Forefoot: Other Reference Measurements

Tailor's Bunion (Bunionette)

1. **4^{th}- 5^{th} Intermetatarsal Angle** < 9˚
   - Between long axes of 4^{th} and 5^{th} metatarsals
2. **Lateral Deviation Angle** ≤ 7˚
   - Between line through neck/head and line along medial proximal shaft of 5^{th} metatarsal
3. **5^{th} Metatarsophalangeal Angle ≤ 14˚**
   - Between long axes of 5^{th} metatarsal and proximal phalanx

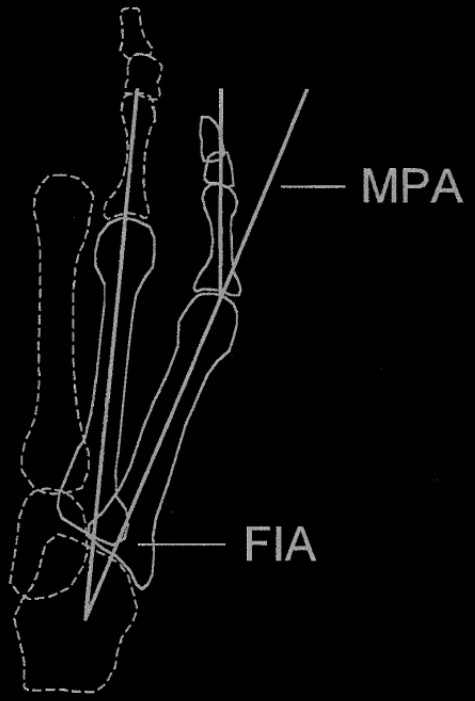


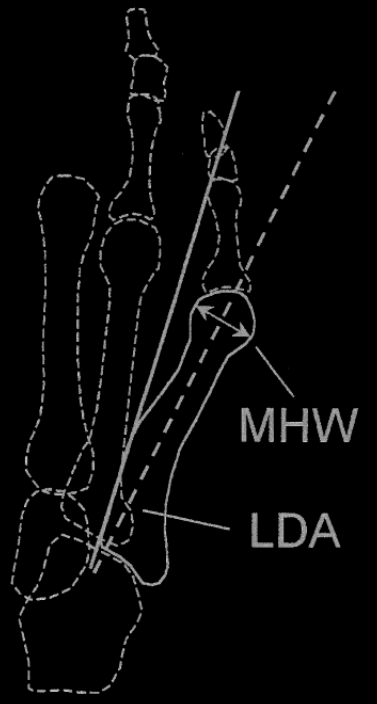
Bunionette measurements
Metatarsophalangeal angle >10

- Type 1 27%
- Metatarsal head width >13

- Type 2 23%
- Lateral deviation angle (medial base to long axis) >3

- Type 3 50%
- 5th intermetatarsal angle >8





Splayfoot = 1st IA >10 and 5th IA >8

Thanks to Michelle Nguyen

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