Alignment of the Adult Foot: Axes and Angles

Dr. Tudor H. Hughes M.D., FRCR
Department of Radiology
University of California School of Medicine
San Diego, California
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

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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

Non Weight Bearing

Weight Bearing
Radiographs need to be Weight Bearing

Good radiographs are with full weight bearing
Radiographs need to be Weight Bearing

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Tibia not vertical indicates partial weight bearing
Radiographs need to be Weight Bearing

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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

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Hindfoot: Subtalar Joint
Normal Alignment on Lateral View

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°

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.
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

- 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.
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 1\textsuperscript{st} metatarsal axis**
   - Lateral talar-first metatarsal angle (LTMA) is measured between these two axes.
   - Normal is $0^\circ \pm 4^\circ$

2. **Calcaneal pitch or inclination angle (CIA)**
   - Between the calcaneal inclination (CA) axis and plane of support (PS)
   - Normal average is 18-20$^\circ$ (range 17-32$^\circ$)
Longitudinal Arch Deformities

- **Collapse of Arch:**
  **Pes Planus**
  - Talus points down in relation to 1\textsuperscript{st} metatarsal
  - Calcaneal inclination angle (CIA) is decreased, measuring < 18°

- **Abnormal High Arch:**
  **Pes Cavus**
  - Talus is dorsiflexed in relation to 1\textsuperscript{st} 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°
   
   • Increased lateral talocalcaneal angle > 45°
   
   • Valgus

2. **Midfoot:**
   
   **Midtarsal Joint**
   
   • Talus points plantarward from 1st MT >4°
   
   • Decreased calcaneal inclination angle < 18°
   
   • Longitudinal Arch Collapse
Talonavicular coverage angle is measured between lines connecting the articular surfaces of the navicular and talus. Normal ≤ 7°
### Longitudinal Arch Deformities

#### Pes Planus

<table>
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[Images of foot anatomy with labels indicating mid/forefoot deformities.]
### Longitudinal Arch Deformities

#### Pes Planus

3. Mid/Forefoot:

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Abduction

Abnormal loading on the medial column leads to:

- collapse of longitudinal arch
- eventual impingement on lateral column

Multiple causes include:

- posterior tibialis tendon dysfunction
- Charcot foot
- posttraumatic
- rheumatoid arthritis
- neuromuscular disorder
- tarsal coalition
Longitudinal Arch Deformities

**Pes Planus**

- Hindfoot valgus
  - Lateral: Talocalcaneal angle $\uparrow$
  - AP: Talocalcaneal angle $\uparrow$

- Collapse of longitudinal arch
  - Lateral: $1^{st}$ metatarsal calcaneal angle $> 40^\circ$
  - Lateral: Calcaneal pitch $< 17^\circ$

- Midfoot / Forefoot abduction
  - Talus points medial to $1^{st}$ metatarsal
  - Talonavicular coverage $> 7^\circ$
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.
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

Marfan's foot collapse 46M
Longitudinal Arch Deformities
Pes Cavus
Longitudinal Arch Deformities
Pes Cavus

1. **Hindfoot:** Subtalar Joint
   - Talus points lateral to 1\textsuperscript{st} MT
   - Lateral talocalcaneal angle is decreased.
   - **Varus**

2. **Midfoot:** Midtarsal Joint
   - Increased calcaneal inclination angle > 32°
   - Talus is dorsiflexed vs. 1\textsuperscript{st} 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

Muscular imbalance from neurologic disorder leads to foot malalignment.

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

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

“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 external rotation at time of positioning.

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

“Sinus Tarsi See-Through” Sign:
Hindfoot varus and forefoot adduction allow sinus tarsi to be in same plane as x-ray beam

22 yo male with Charcot Marie Tooth Syndrome
Forefoot: Normal Alignment
Tarsometatarsal Joints

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 $\leq 15^\circ$
  - Metatarsus adductus is present if $>15^\circ$
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 (4th, 5th) metatarsals and predispose them to develop stress fractures.
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Forefoot: Metatarsus Adductus
Tarsometatarsal Joints
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Tarsometatarsal Joints

WT Bearing

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

22 yo male with Charcot Marie Tooth Syndrome
Charcot Marie Tooth Syndrome

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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
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 1\textsuperscript{st} on AP
  - Medial margin of 2\textsuperscript{nd} on AP
  - Medial margin of 4\textsuperscript{th} on Oblique
  - Medial margin of 5\textsuperscript{th} on Oblique
  - Look for dorsal displacement on Lateral
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  - Look for dorsal displacement on Lateral
  - Congruent intercunneiform joints
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
1. Hindfoot: Subtalar Jt
   Normal

2. Midfoot: Midtarsal Joint
   Normal

3. Forefoot: Metatarso-phalangeal and Interphalangeal Joints
   - Hallux Valgus
     - Angle > 15°
   - Metatarsus Primus Varus
     - 1\textsuperscript{st} - 2\textsuperscript{nd} intermetatarsal angle ≥ 10°
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°
Hallux valgus measurements

Hallux interphalangeus angle
<8°

Hallux valgus angle
<15°

Metatarsus primus varus angle
<25°

First intermetatarsal angle
<10°
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
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 procedure 62F
Metatarsal length

SHORT
<2 mm.

EQUAL

LONG
>2 mm.

Morton / Roman / Greek / Egyptian
Lesser Toes

- Hammer toe
  - Ex-Fi-Ex

- Claw toe
  - Ex-Fi-Fi

- Mallet toe
  - N-N Fi
Tailor’s Bunion (Bunionette)

1. **4th- 5th Intermetatarsal Angle < 9°**
   - Between long axes of 4th and 5th metatarsals

2. **Lateral Deviation Angle ≤ 7°**
   - Between line through neck/head and line along medial proximal shaft of 5th metatarsal

3. **5th Metatarsophalangeal Angle ≤ 14°**
   - Between long axes of 5th 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
References

References

• Hunter J. Evaluation of Adult Foot Alignment. Website http://uwmsk.org
• Donovan a, Rosenberg ZS. Extraarticular lateral Hindfoot Impingement with Posterior Tibial Tendon Tear: MRI Correlation. AJR 2009; 193: 672-678.