**Foot and Ankle Biomechanics**

**Anatomy**

**Tibiofibular Joint**
- Very stable joint structure
- Only true motion occurs in full DF due to anatomy of talus moving in mortise
- Maximum gapping is approximately 14mm
- Fibula moves in accordance to ankle

**Talocrural Joint**
- Normal available motion:
  - DF=10-20°, PF=30-50°
  - Required during walking - 20° PF and 10° DF
- Axis of inclination 20-30° posterior to frontal plane and 10° inferior
- Not cardinal plane

**Subtalar Joint**
- Normal available motion:
  - inversion=30° eversion=10-20°
- Average axis of inclination: 42° superior from frontal plane and 16° medial from sagittal plane
- Triplanar motion

**Midtarsal Joints**
- Comprised of two separate joints: longitudinal midtarsal joint and oblique midtarsal joint
- Separate axes: longitudinal - talonavicular joint, oblique – calcaneocuboid joint
Midtarsal Joints

Longitudinal Midtarsal Joint
- Axis = 15° from transverse plane, 75° from frontal and 9° from sagittal planes
- Primary motion – inversion and eversion

Oblique Midtarsal Joint
- Axis = 52° from the transverse plane, 57° from the sagittal plane and 38° from the frontal plane
- Motion – DF and ABD, PF and ADD

First Ray
- Comprises the first metatarsal, medial cuneiform, navicular
- Axis of motion: posterior/dorsal/medial to anterior/plantar/lateral. 45° from the sagittal and frontal planes
- Motion occurs in 2 planes simultaneously:
  - Dorsiflexion and inversion
  - Plantarflexion and eversion

Plantar Fascia
- Attaches primarily from the medial calcaneal tuberosity to the base of the proximal phalanges
- Acts as a truss and beam system – windlass effect

Other Support Structures
- 4 layers of intrinsic muscles
- 19 extrinsic muscles (long tendons)
- Approximately 107 ligaments

Biomechanics and Alignment
**Normal Alignment**

- Open chain: calcaneal bisection comparison to lower 1/3 of leg is 0-2° inverted
- Closed chain: both plantar condyles and metatarsal heads are in the same plane and positioned on support surface

**Rearfoot Varus**

- Calcaneus is inverted with respect to the lower leg
- Considered by some to be the most common osseus foot deformity
- 3 types: compensated, partially compensated and uncompensated

**Tibial Varum**

- Curvature or bowing of the tibia in the frontal plane places the hindfoot in an inverted position in relation to the supporting surface
- Up to 4° is considered normal. 4-7° is notable. 8° or more is pathological.

**Rearfoot Valgus**

- Hindfoot is everted when held in subtalar joint neutral
- Extremely rare – probably wrong – measure it again
- Assess for contributing pathology

**Forefoot Varus**

- Medial aspect of the forefoot is inverted in relation to the lateral aspect of the forefoot.
- Also inverted in relation to the rearfoot (at level of midtarsal joint)
- Some consider forefoot varus to be most common deformity of the foot.
Forefoot Varus

- Medial aspect of the forefoot is everted in relation to the lateral aspect of the forefoot

- Forefoot is everted in relation to plantar condyles of the calcaneus

Forefoot Valgus

- Flexible forefoot valgus – the midtarsal joint has sufficient flexibility to allow the lateral column of the foot to reach the floor

- Calcaneus is vertical in weightbearing

- Rigid forefoot valgus – rigid midtarsal joint does not allow the lateral column to reach the ground subsequently the subtalar joint supinates to compensate.

Plantarflexed First Ray

- First Ray = first metatarsal + first cuneiform + Navicular

- Plantar aspect of the first ray is inferior to the plane of 2nd – 5th metatarsals

- Similar appearance to forefoot valgus if rigid

- If flexible, functions similar to forefoot varus, looks like a neutral foot.

Forefoot Supinatus

- Soft tissue deformity of forefoot

- Same appearance as forefoot varus

- Consequence of long term over-pronation

Ankle Equinus

- Maximum dorsiflexion is less than 10°

- Produces requirements of over-pronation

- Motion is required of oblique midtarsal joint

- Creates early heel off

- Increased energy expenditure during ambulation
Forefoot Equinus
- Forefoot is in plantigrade with respect to the rearfoot

Hallux Limitus
- Great toe extension at the MTP joint is less than 70° in open chain and less than 30° in closed chain
  - May be structural or functional limitation

Hallux Rigidus
- Great toe extension at first MTP joint is less than 30° in open chain or less than 10° in closed chain
  - Typically a structural limitation

Hallux Primus Elevatus
- Dorsal first ray hypermobility
  - In weight bearing, first ray is forced dorsally secondary to instability and ground reaction forces

Hallux Abductovalgus
- Medial deviation of the great toe at the level of the MTP
  - Typically see widening of the space between the first and second metatarsal shafts
  - One part of a bunion formation

Metatarsus Adductus
- Medial deviation of all five metatarsal shafts
  - Produces the appearance of a curved shaped foot.
Biomechanical Evaluation Process

- Analyze gait, noting main abnormalities
- Gain an impression of lower extremity function as a whole through functional screening
- Measure/assess objective data
- Put the pieces of the puzzle together

Functional Evaluation
- Perform in order to maximize patient comfort
- Use information to formulate a functional hypothesis and compare to actual function
- Compare available motion vs motion utilized
- Carefully bisect the posterior calcaneus and distal limb first
- Don’t split hairs – if all does not correlate then NOTHING IS

Prone Evaluation
- Passive inversion available
- Passive eversion available
- STNJ position (rearfoot and forefoot)
  - Talar head congruency
  - Passive DF from inversion to eversion
- Dorsoflexion (gross ROM and in STJN with knee flexed and extended)
- Assess extrinsic and intrinsic muscle strength (gross strength and isolated strength)
- All performed in ‘Figure 4’ position or in hip neutral

Prone Evaluation – Lab Activities
- Bisect distal leg and posterior heel
- Measure available inversion
- Measure available eversion
- Find subtalar joint neutral
- In STJN, measure leg rearfoot relationship
- In STJN, measure rearfoot to forefoot relationship
- Measure DF/PF with knee flexion and

Supine Evaluation
- Utilized to determine leg length inequalities
- Measured from ASIS to medial malleolus and umbilicus to medial malleolus. Average over 3 trials. Recorded in cm.
- Must first clear the pelvis to assess leg length differences.
- Measure malleolar torsion
  - With femoral condyles in neutral, palpate malleoli, measure the plane of the axis
  - Norms: 18-23° of external rotation
Supine Evaluation

- Measure midtarsal joint integrity
  - LMTJA: with rearfoot in supination, assess the flexibility of medial midfoot invert and evert
  - OMTJA: with rearfoot in supination, assess flexibility of lateral midfoot to dorsiflex/abduct and plantarflex and adduct
- Measure great toe ROM into extension

Supine Evaluation – Lab Activities

- Leg length assessment
  - Visual inspection in supine and sitting
    - Measure ASIS to medial malleolus
    - Measure umbilicus to medial malleolus
- Malleolar Torsion
  - Femoral condyles neutral
  - Measure axis
  - Great toe ROM

Standing Evaluation

- Resting Calcaneal Stance Position – provides information on self selected foot postures
  - Patients frequent subtalar joint position
- Half Squat – provides information on maximum pronated position
  - Mimics loading response and early midstance positions during gait
  - Gives information on foots effect on kinetic chain

Pronation/Supination Test

- Quick screen utilized to determine the flexibility of the subtalar joint
- Gait cycle requires pronation from ground up and supination from the hip down
- Grossly measured as excessive, adequate, inadequate

Heel Rise Test

- Used to demonstrate posterior tibial function
- Rated as normal inversion, partial inversion, unable to perform/eversion. Rate height of elevation as well.
- Must compare to noninvolved side if applicable.

Tibial Angle

- Measured posteriorly from bisection of distal limb and a known angle
- Provides information on contributions of proximal structures on foot function
- Greater than $4^\circ$ is excessive, greater than $8^\circ$ is pathological
Axis of Inclination

- Used to predict suspected amount of subtalar motion that is normal for the individual
- Measures frontal plane motion of calcaneus to transverse plane motion of talus
- High axis = 2-4° of suspected eversion at maximum pronation, average axis = 4-6° of eversion, low axis = 6-8° of eversion

Navicular Drop Test

- Measures magnitude the navicular tuberosity drops from a non-weight bearing position to a weight bearing position
- Average for normal is 7-8°

Standing Evaluation Lab Activities

- Measure RCSP
  - Resting calcaneal stance position – leg to rearfoot
- Measure ½ squat position
  - Leg to rearfoot
- Measure tibial angle
  - Leg to floor
- Assess axis of inclination
  - High, normal, low
- Assess
  - Pronation/supination test
    - Excessive motion, normal motion, insufficient motion
  - Assess heel rise test
    - Full ROM?
  - Calcaneal inversion?
  - Navicular Drop test
    - Seated height
    - Standing height