The Ankle Joint(s)

Anatomy, Evolution and Function
Outline

• Anatomy
  – The ankle: 3 joints in 1

• Evolution
  – Mammalian evolution
  – The ape-like condition

• Function
  – Comparing apes and humans
  – Fossil inferences
Inferior Tibiofibular Joint

• Involves only the bottom ends of the tibia and fibula.
• Tibia and fibula are unfused at their top and bottom articulations.
• A ligamentous syndesmosis allows some flexibility at the bottom articulation.

AITFL and PITFL, anterior and posterior inferior tibiofibular ligaments; IM, interosseous membrane; TrTFL, transverse tibiofibular ligament. (Tsao, 2010)
Talocrural Joint

• The ankle ‘proper’ allows for plantarflexion and dorsiflexion only (raising and lowering of the foot).
• It is the main interaction of the leg with the tarsal bones of the foot.
• The only weight-bearing interaction is between the tibial plafond and the trochlea of the talus.

Soft Tissues
- Ligaments

• A complex of 4 ligaments attaches the tibia to the tarsals.

• These are known collectively as the deltoid ligament.

• The lateral ligaments attaching the fibula to the tarsals are more distinct from one another.

Soft Tissues
- Muscles

- The tibialis anterior (left) is the prime dorsiflexor (raises foot) at the talocrural joint.
- The gastrocnemius and the soleus inserting into the Achilles tendon (bottom right) are the prime plantarflexors (go on tiptoes).
Sub-talar (talocalcaneal) joint

- Consists of 3 largely distinct articular surfaces.
- The anterior & middle, and posterior articular surfaces act as counter-rotating screws.

Soft Tissues - Muscles

- Inversion (sole toward the body’s midline) and eversion (sole outwards) occurs around the subtalar axis (right).
- Tibialis anterior is the main invertor.
- The fibularis/peroneal muscles (below) act as the principal evertors.

Above: Lewis, 1980b.
Right: Barraclough, 2014.
Evolution of the Ankle Joints

• Pre-mammalian (therapsid) condition.
  – Talus lay next to, as opposed to on top of, the calcaneus.
  – There was a major weight-bearing joint between fibula and calcaneus.
  – More similar to a modern primate wrist with cartilage menisci (m) between bones (right).

Top: Calcaneofibular articulation in an alligator (Online Biology Library).
Evolution of the Ankle Joints

• Mammalian condition
  – Talus shifts superiorly to rest on top of the calcaneus.
  – Portions of the menisci are replaced by tibiocalcaneal and posterior tibiotalar ligaments in the tree shrew.
  – The talus assumes a trochlear morphology
  – Medial trochlear surface becomes distinct from the superior trochlear surface.
Evolution of the Ankle Joints

• Ape condition
  – Fibula and calcaneus no longer articulate.
  – Modified medial and lateral talar articular surfaces for the malleoli.
Comparative Functional Anatomy - Talocrural joint

- Lateral trochlear border is far longer front-to-back than the medial border in apes (right).
- In humans, the medial border is relatively higher, meaning the trochlea has a more horizontal surface. It is steeply angled in apes.

Right tali of male gorilla (top) (Lewis, 1980) and modern human (bottom) (Latimer et al., 1987).
Comparative Functional Anatomy - Talocrural joint

• The orientation of the distal tibial articular surface (talar angle; right) affects bipedal efficiency.

• Trochlear morphology (previous slide) further contributes to an exaggerated outwards-arcing path of the tibia in bipedal locomotion (right).

Talar angle (top) and path in bipedal locomotion (bottom in chimp (left) and human (right) (DeSilva, 2009; Aiello & Dean, 1990).
Comparative Functional Anatomy
- Talocrural joint

- The medial malleolar facet of the talus is cupped anteriorly (top right, far side).
- The lateral malleolar facet of the talus flares inferiorly and laterally (top right, near side).
- Medial malleolus is more robust in apes than in humans.

Left talus of a gibbon showing specialised morphology of malleolar facets (Latimer et al., 1987).

Orientation of the lateral malleolar facet in a common chimpanzee (left) and a modern human (right) (Aiello & Dean, 1990).
Comparative Functional Anatomy - Talocrural joint

- Fibular talar facet is inferiorly orientated in apes (arrows, right).
- Trochlear surface is highly convex front-to-back.
- Increased front-to-back wedging (bottom right, near side) in the chimp exaggerates the screwing motion of talus on calcaneus.

Orientation of the lateral malleolar facet in a common chimpanzee (left) and a modern human (right) (Aiello & Dean, 1990).

Illustrating left tali of common chimpanzee (left) and anatomically modern human (right) (DeSilva, 2009).
Comparative Functional Anatomy - Sub-talar joint

- The posterior and anterior sub-talar joints act as counter-rotating screws.
- The axis of the sub-talar joint runs at an oblique angle to the foot (arrow).
- Talus screws the calcaneus forward into the more distal tarsal bones.

Diagram of a saki monkey right foot in eversion (left) and inversion (right) (Lewis, 1980c).
Comparative Functional Anatomy - Sub-talar joint

• In non-human primates:
  – Relatively large-angled articular surfaces allow a great range of inversion/eversion (far right).
  – The foot is in a stable inverted configuration for grasping a vertical branch or other support.

Diagram of a saki monkey right foot in eversion (left) and inversion (right) (Lewis, 1980c).
Comparative Functional Anatomy
- Sub-talar joint

• Sustentaculum tali (bears the anterior and middle sub-talar joint facets; arrow) is more prominent in humans. (Sadly this picture is from the wrong side to see it properly).

• The calcaneal tuberosity is greatly enlarged in humans relative to apes (bracket; more later).

[Calcanei of a common chimpanzee (top) and a human (bottom) (Lewis, 1983).]
Comparative Functional Morphology - Sub-talar joint

- Sub-talar axis is more vertically orientated in humans than apes.
- Talus screws downwards, causing the calcaneus to rotate (far right).
- The foot is now in a stable configuration for weight-bearing.
- Smaller-angled articular surfaces limit the range of inversion/eversion.

Showing orientation of the sub-talar axis of a human foot in early (left) and middle (right) stance phase (Lewis, 1980c).
Comparative Functional Anatomy  
- Soft tissues

- Plantarflexor (gastrocnemius & soleus) muscle mass is relatively greater in humans than apes.
- The Achilles tendon is longer and more robust in humans than in apes (right).
- A well-developed enthesis organ is present in the human heel (bottom right).
  - The bursa protects the tendon from friction on the calcaneus.
  - The Sharpey’s fibres increase the strength of the tendon’s insertion.
    • (If the Achilles tendon comes away from the bone, it usually takes some bone with it!)
Comparative Functional Anatomy
- The Hominins

• 2-million-year-old fossils from East and South Africa (D & E) both show an ape-like talus and a human-like rest of foot.

• A key adaptation to bipedality is closer alignment of the sub-talar axis with the long axis of the foot (B is a modern human).

Orientation of the sub-talar axis in: A, Neanderthal; B, modern human; C, composite Dmanisi foot; D, OH8; E, Stw573. (Pontzer et al., 2010).
Comaparative Functional Anatomy
- The Hominins

• The angle of the distal tibial articular surface is a useful proxy for a bipedal gait.

• It is possible to infer this angle from an isolated talus using wedging angles discussed earlier.

• A whole range of hominins from between 4 and 1.5 million years ago show more similarity to modern humans than to African apes.

Comparing the talar angle between a modern human (left) and a generalised African ape (right) (Aiello & Dean, 1990).

Talocrural joints (posterior aspect) of: Left, Australopithecus afarensis; middle, common chimpanzee; right, gorilla (Latimer et al., 1987).
Comaparative Functional Anatomy
- The Hominins: Soft tissues

• 2-million-year-old hominin *A. sediba* appears to have had a bursa. Compare human and *sediba* (*, top right & bottom left).

• The Neanderthal calcaneal tuberosity (bottom right) is relatively longer than in modern humans.

• This would have biased the Achilles tendon lever action to producing powerful movements, rather than faster movements of the foot as in modern humans.

Lateral calcaneus of a common chimpanzee (top left); human (top right); *Australopithecus sediba* (bottom left); *A. afarensis* (bottom right) (Zipfel *et al*., 2011).
Summary

- Three separate joints help to produce a complex suite of movements.
- These include movements in the distal foot.
- Bony anatomy can be used to infer soft tissue anatomy and locomotor mode.


