Asian Journal of Convergence in Technology **Volume IV Issue I**
ISSN NO: 2350-1146 I.F-5.11

Review on the Anatomy and Biomechanics of the Foot-Ankle Complex

Das, A., Baruah J., *Student*, and Bhuyan, D. *Assistant Professor, Department of Mechanical Engineering, Girijananda Chowdhury Institute of Management and Technology,Guwahati – 781017, India*
anakshiguwahati@gmail.com

***Abstract—Abstract*—In this article; we aim to review the literature available on the anatomy and biomechanics of the foot-ankle complex where the main aim is to fill the gap present in the existing research literature that can lead to further development in the prosthesis design. This paper discusses the different joints and various ligaments and tendons which has a significant influence on the stability and biomechanical performance of the foot-ankle complex. It also has an insight on the ankle jointcomplexmotion including the degrees of freedom and linked movements.**

Keywords—Ankle Biomechanics, Degree of Freedom, Gait Cycle

I. INTRODUCTION

The ankle joint complex is a synovial joint which allows the interaction of the lower limb with the ground. The talus of the foot and tibia and fibula of the leg are involved in the ankle joint which along with a number of articulations allows the movement of the foot.[9] The key movements of the ankle joint complex are plantarflexion and dorsiflexion, that ocuurs in the sagittal plane, abduction and adduction that occurrs in the frontal plane. [2]

Pronation and supination are the other two important movements. Plantarflexion, inversion and adduction are combined to form what is known as supination making the sole face medially. Dorsiflexion, eversion and abduction are combined to form pronation causing thesole to face laterally. According to Brockett and Chapman, in dorsiflexion, the prefoot is raised and in plantarflexion the forefoot is depressed. Gait cycle is very important while studying the movements which are divided into two phases-stance phase and swing phase. [2] 60-62% of the gait cycle is constituted by stance phase while 40% of the gait cycle is constituted by swing phase. It has been discovered from the research that the ankle joint experiences 5 times and 13 times body weight during walking and running respectively.

II. ANATOMY

According to Drake, Vogl and Mitchell, the foot and ankle is made up of total thirty three jointstogether with the long bones of the lower limb, although there are twenty-six individual bones of the foot. Although commonly referred to as the “ankle joint”, there are a number of articulations which allow the motion of the foot. [1]

The talus of the foot and the tibia and fibula of the leg are involved in the ankle joint. It mainly allows hinge-like movements of the foot viz. dorsiflexion and plantarflexion. Strong ligaments firmly anchors the distal end of the fibula to the larger distal end of the tibiacreating a deep bracket-shaped socket. The articular part of the talus is shaped like a short half-cylinder tipped onto its flat side with one facing lateral and the other end facing medial. A synovial membrane encloses the articular cavity by attaching around the margins of the articular surfaces. A fibrous membrane again covers the synovial membrane which also attaches it to the adjacent bones. The medial ligament and lateral ligaments stabilizes the ankle joint. [1] [2].

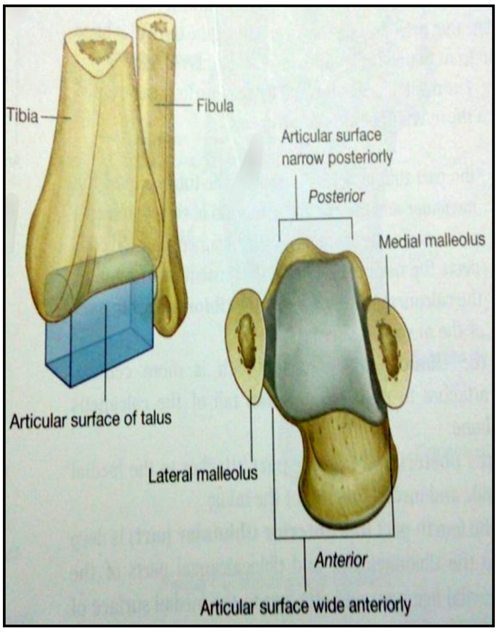

Fig. 1. Schematic joint and shape of articulat surface [1]

A. *Medial ligament*

According to Leardini, O'Connor and Giannini have reported that the medial ligament is large and strong. It is triangular in shape. Its apex is attached above to the medial malleolus. Also its broad base is attached below to a line that extends from the tuberosity of the navicular bone in front to the medial tubercle of the talus behind. It is further divided into 4 parts, viz.

- Tibiocalcaneal part
- Tibionavicular part
- Anterior tibiotalar part
- Posterior tibiotalar part[10]

Fig. 2. Medial ligament[1]

B. *Lateral ligament*

According to Leardini,three separate ligaments compose the lateral ligament of the ankle. These are:

- Posterior talofibular ligament
- Calcaneofibular ligament
- Anterior talofibular ligament[8]

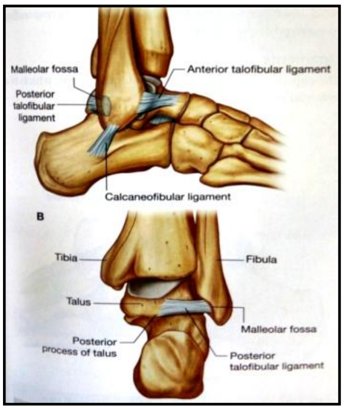

Fig. 3. Lateral ligament [1]

C. *Intertarsal Joints*

According to Siegler, Chen andSchnek, these are numerous synovial joints which are present in between the individual tarsal bones that mainly inert, evert, pronate and supinate the foot. Only a limited movement is allowed by the intertarsal joints present between the cuneiforms and between the navicular and the cuneiforms.[5]

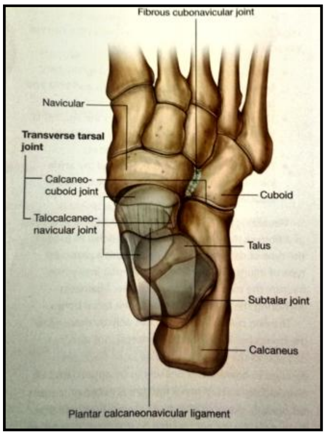

Fig. 4. Intertarsal Joint [1]

D. *Talocalcaneonavicular Joint*

The talocalcaneonavicular joint is a complex joint in which the head of the talus articulates with the planter calcaneonavicular ligament and the calcaneous. The talocalcaneonavicular joint allows rotation movements and gliding, which together with the similar movements of the subtalar joint are involved with eversion and inversion of the foot. It is also engaged with pronation and supination of the foot. The capsule of this joint is reinforced with:

- Interosseous talocalcaneal ligament posteriorly.
- Talonavicular ligament superiorly.
- Planter calcaneonavicular ligament inferiorly. [1]

Fig. 5. Talocalcaneonavicular Joint [1]

E. *Calcaneocuboid Joint*

According to Delan, Morris and Sung, calcaneocuboid joint is a synovial joint which is present between the facet on the anterior surface of the calcaneous and the corresponding facet on the posterior surface of the cuboid. This joint allows rotatingand sliding movements that causes inversion and eversion of the foot and is also involved in pronation and supination of the forefoot and the hind foot. [1] [9]

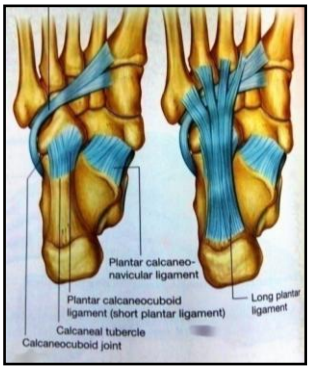

Fig. 6. Calcaneocuboid Joint [1]

F. *Tarsometatarsal Joint*

The tarsometatarsal joints between the metatarsal bones and adjacent tarsal bones are plane joints.They allow limited sliding movements. The tarsometatarsal joints along with the transverse tarsal joints are involved in pronation and supination of the foot. [1]

G. *Metatarsophalangeal Joints*

The metatarsophalangeal joints are ellipsoid synovial joints that are present between the sphere shaped heads of the metatarsals and the corresponding basis of the proximal phalanges of the digits. These joints allow limited adduction, abduction, circumductionand rotation and alsoextension and flexion. They are stabilized by:

- Plantar ligaments
- Collateral ligaments.[1]

H. *Interphalangeal Joints*

The Interphalangeal joints are hinge joints are reinforced by medial and lateral collateral ligaments and plantar ligaments. They mainly allow flexion and extension.[1]

Fig. 7. Tarsometatarsal, Metatarsophalangeal, Interphalangeal Joint [1]

III. BIOMECHANICS

The study carried out by Brockett and Chapman demonstrates a dorsiflexion moment on ankle movement from the analysis of gait cycle at the striking of the heel. This occurs when the dorsiflexors contract eccentrically to control rotary motion of the foot and thus prevent from slapping onto the ground.

The second phase is carried by eccentric contraction of dorsiflexors which allows forward progression of the shank over the foot describing a plantar flexion moment.

In the third phase the plantar flexion moment continues along with concentric contraction of plantarflexors towards toe-off. [2]

The ankle kinetics pattern always remains same irrespective of the walking speed. Only magnitude increases.

A. *Gait Cycle*

There are two phases of the human gait

- Stance phase
- Swing phase

The stance phase begins with the striking of the heel and progresses till toe off. It constitutes about 60-62% of the gait cycle. The stance is subdivided into three phases.

1. Controlled dorsiflexion (constituting about 38% of gait cycle beginning with foot flat to maximum dorsi flexion)
2. Controlled planter flexion (constituting about 12% of gait cycle starting from heel strike and ending with foot flat)
3. Powered plantar flexion (constituting about 10-12% of gait cycle starting from maximum dorsi flexion till toe-off).

Swing phase occurs when the foot is raised from the ground and it continues till the heel strike the ground of the same foot. It accounts for 40% of the gait cycle. [3][6]

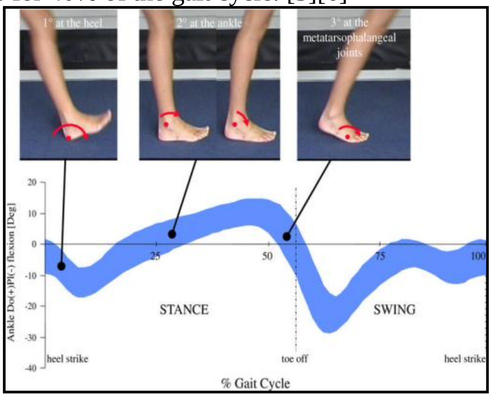

Fig. 8. Human Gait Cycle[4]

B. Function of Foot in the Gait

The ankle and the subtalar joints are the most important parts that contributes to movement in humans. As studied by Shiegler, Chen and Shneck, the internal/external movements of foot ankle complex is equally contributed by ankle and subtalar joints.[5] The foot ankle complex provides three different rotations in the sagittal plane about three different points.

i. It helps in descendindg the foot to the floor by rotation about the heel which remains in contact with the foot initially i.e. from terminal part of swing phase to foot lying parallel(flat)to the ground;
ii. Forward motion is continued by rotation of ankle joint during the period in which foot remains flat to ground and the shank advances;
iii. The power generation during push off phase happens through rotation about metatarsophalangeal joints.[4]

C. Degrees of freedom

Potentially there are 6 degrees of freedom in all joints:

3 plane rotation:

1. Abduction-adduction.
2. Internal-external.
3. Flexion-extension .

3 plane translation:

1. Medial-lateral.
2. Compression-distraction.
3. Anterior-posterior [4]

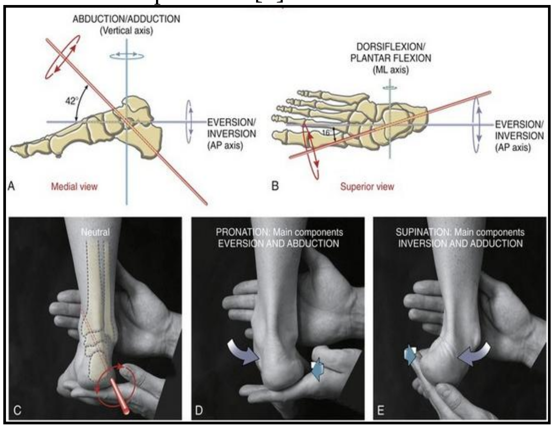

Fig. 9. Motions of Foot [3]

IV. CONCLUSION

The anatomy of the ankle joint ascertains the complexity of its biomechanics. It consists of not just a single hinge joint but a multi-axial motion taking place at the same time to aid the process of human gait.

REFERENCES

[1] Drake Richard L., Vogl A. Wayne, Mitchell Adam W. M., *Gray's Anatomy* 2nd edition; Churchill Livingstone Elsevier; 2010

[2] Brockett Claire L., Chapman Graham J. *Biomechanics of the ankle;* 2016

[3] Masum Habib, Bhaumik Subhasis, Ray Ranjit, *Conceptual Design of a Powered Ankle-Foot Prosthesis for Walking*; 2014

[4] Leardini Alberto, O'Connor John J, Giannini Sandro, *Biomechanics of the natural, arthritic and replaced human replaced human ankle joint*; 2014

[5] Siegler Sorin, Chen Jie, Schnek C. D, *The Three Dimensional Kinematics and Flexibility Characteristics of the Human Ankle and Subtalar Joints-Part I: Kinematics*; 1988; 364-373.

[6] Au Samuel k, Dilworth Peter, Herr Hugh, *An Ankle-Foot Emulation System for the Study of Human Walking Biomechanics;* 2006

[7] Oatis Carol A, *Biomechanics of the Foot and Ankle under Static Conditions*; 1988

[8] Leardini A, *Geometry and mechanics of the human ankle complex and ankle prosthesis design; 2001*

[9] Deland JT1, Morris GD, Sung IH, *Biomechanics of the ankle joint. A perspective on total ankle replacement;* 2000

[10] Leardini A, O'Connor JJ, Catani F, Giannini S., *Mobility of the human ankle and the design of total ankle replacement*; 2004