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Monash Rehabilitation Technology Research Unit

# Investigation Of Prosthetic Ankle Design

**Work Experience Project**

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## **1. Introduction**

The object of the project was to investigate the movement of the human ankle joint during walking with the aim of developing a prosthetic foot/ankle joint which traces the movement of the human ankle more closely than prosthetic feet currently on the market.

During normal locomotion the ankle plantarflexes between heel off and toe off. Although most of the flexion may be due to gravity and inertia, it is also partly due to a contraction of the calf muscles, which creates a “push off” effect. None of the prosthetic feet commonly used today display this characteristic.

The investigation was aimed at assessing the push-off effect of the human ankle and trying to recreate it in a prosthetic foot. It would be an advantage to be able to store energy in the prosthetic foot in the period from heel strike to heel off and then to release it to give a “push off” effect after heel off.

Because of the complex nature of ankle movement the investigation was limited to motion in the sagittal plain during normal locomotion on a level surface

## 2. The Human Ankle

### Gait Cycle

A gait cycle is defined in terms of the interval of time from one heel strike to the next heel strike of the same foot. Conventionally, the cycle is measured in percent rather than seconds. The initial heel strike is designated as 0% and the following heel strike as 100%. This allows data from different subjects to be normalised. The cycle is divided into stance phase, which is the period of time when the foot is on the ground, and swing phase, when it is in the air. Stance phase starts at heel strike (0%) and ends at toe off (62%); swing phase starts at toe off and ends at the following heel strike (100%). The opposite limb repeats this cycle at 180° out of phase so that the initial opposite heel strike occurs at 50% of the gait cycle (Fig. 2.1.) (1).

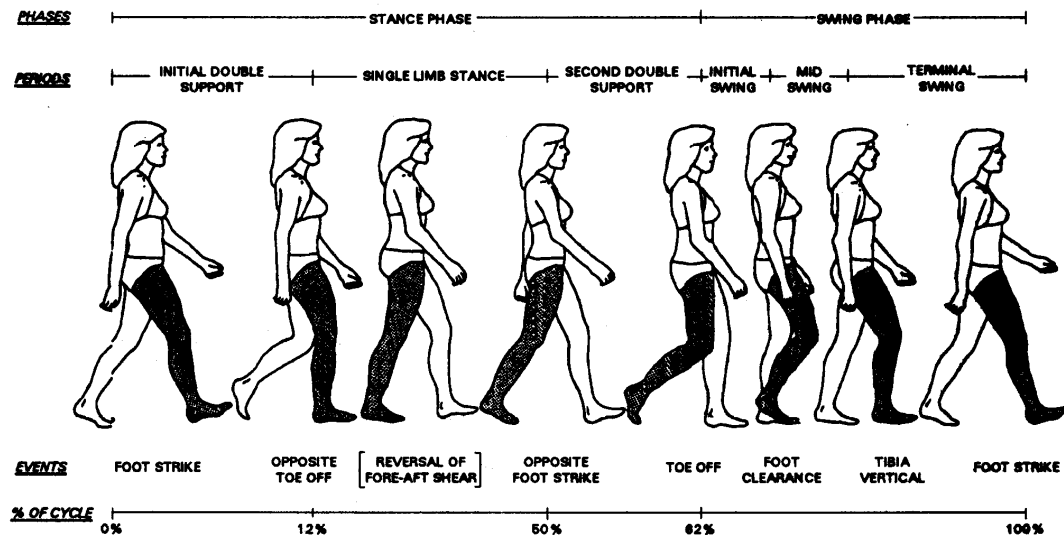


Figure 2.1 Normal walking cycle illustrating the events of gait (1).

## Motion of the Ankle during locomotion

The curve of ankle plantar/dorsiflexion can be broken down into four segments (Fig.2.2) (1).

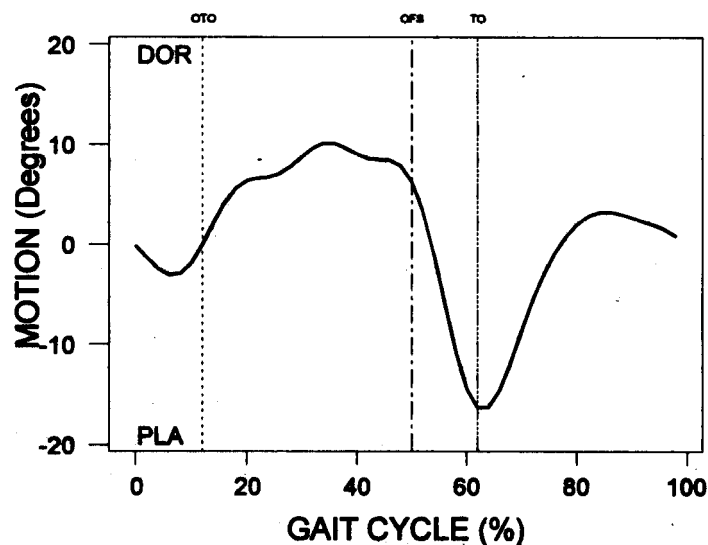


Figure 2.2 normal ankle plantar/dorsiflexion (1)

The first segment begins with heel strike and ends with foot flat at about 12%. The plantarflexion moment of the ground reaction force acting on the foot posterior to the ankle causes the foot to plantarflex from its neutral position before heel strike. Maximum plantarflexion at this time is about 6-8°.

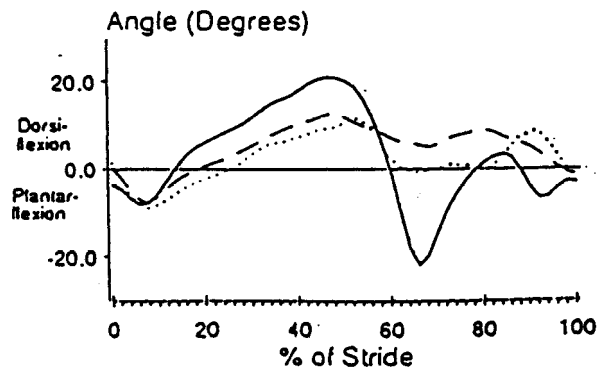
During the second segment (12% - 50%) the body passes over the fixed flat foot causing the ankle to dorsiflex to about 10° before the heel starts lifting of the ground at about 40% of the cycle and the dorsiflexion is reversed. This is due to contraction of the calf muscles which counteracts the dorsiflexion moment of the ground reaction force acting on the foot anterior to the ankle.

The third segment starts at 50% and ends with toe off at 62%. During this time rapid plantarflexion occurs, reaching a maximum of about 20°. To a great extent this plantarflexion is passive. It is most probably due to rapid weight transfer to the opposite limb after opposite foot strike at 50% of the cycle.

Swing phase makes up the fourth segment (62%-100%). Rapid dorsiflexion caused by the pretibial muscles brings the foot back to a neutral position as quickly as possible to achieve maximum foot clearance while the limb is swung forward before the next heel strike occurs.

### 3. Comparison of Prosthetic/ Human Foot Motion During Locomotion

In fig. 3.1 the angular displacement data of a Sach and ESCF foot are compared to the normal limb during a walking stride. All data was taken from a single subject (2). Other commonly used prosthetic feet would display similar characteristics as the two prosthetic feet used for that particular study.



Solid line - normal limb. Broken line - Sach Foot. Dotted line - ESCF Foot

**Figure 3.1** comparison of angular displacement data of a Sach, ESCF foot and a normal limb from one subject during walking (2)

A particular difference between the curves of the prosthetic feet and the normal limb can be seen between heel-off and toe-off. The strong plantarflexion of the normal limb cannot be observed in either of the prosthetic limbs. Both prostheses dorsiflex passively as the body moves over the foot and only return to their neutral position giving no “push off” effect.

So called energy storing prosthetic feet such as the ESCF foot usually consist of a leaf spring made of carbon fibre or similar materials that deflect when the joint plantar or dorsiflexes, storing energy, then returning the energy when released.

#### **4. Concept of Prosthetic Ankle with “push off” Effect**

By utilising both the plantar flexion of the ankle in the first segment and the dorsiflexion in the second it would be possible to store a greater amount of energy to be released after heel-off to give a push-off effect. This would be similar to the action of the calf muscles in a normal limb.

This can be achieved by either using a mechanical or a pneumatic system.

##### **Mechanical System**

In a mechanical system the energy could be stored in a spring which is loaded by the plantar and dorsiflexion of the ankle until heel-off, then released to spring back. (see sketches in Appendix)

To achieve this, several mechanisms would be necessary:

1. To be able to use both plantarflexion and dorsiflexion a switching mechanism would be necessary, which would switch when the ankle moves from plantar to dorsiflexion at 12% of the gait cycle. This would allow the spring to continue loading while the ankle rotates in opposite directions.
2. A mechanism would be necessary to release the spring in the direction of plantarflexion at heel-off and give a push-off effect.
3. A third mechanism would probably be necessary to reset the other mechanisms during swing phase, ready for the next cycle.

##### **Pneumatic/Hydraulic System**

The pneumatic or hydraulic system would principally work in the same way as the mechanical system. The plantar and the dorsiflexion action of the ankle before heel-off would build up pressure in a chamber, which would then be released to give plantarflexion. The system would be controlled by valves which open and shut, depending on the angle of the ankle joint. (see sketches in Appendix)

##### **Possible Problems**

Possible problems could be:

- control of functions

The control of the different mechanisms or valves which will be performing a sequence of different functions during the cycle could prove difficult.

- timing of loading and releasing the energy

Depending on how these functions are triggered, the timing could become a problem. To achieve the desired effect it will have to be very accurate.

- simplicity and durability of design

To be effective in every day use, the ankle joint will have to be durable and as simple as possible.

- adaptability to different walking speeds and styles

Because of the precise timing and triggering needed for the joint to function, it could be difficult to make it adaptable.

### Future Direction

Both the mechanical and the pneumatic options will have to be looked into in more detail. This would involve finding a switching, a releasing and a resetting mechanism for the mechanical system. It could also prove worthwhile, working with a pneumatic modelling kit to model a pneumatic system.

Modelling the ankle on a computer is also an option. The Mechanical Engineering Department at Monash University would be able to give advice on which software would be feasible. One programme that was suggested by them is “Working Model” by Knowledge Revolution. They would also have information on any other software, which could be of use.

Dr Bruce Field is available at the Mechanical Engineering Department at Monash University for any help and information concerning mechanisms and mechanics. He was most helpful throughout the course of this project.

## **References**

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- (2) Smith A.W. **A Biomedical Analysis of Amputee Athlete Gait**. International Journal of Sport Biomechanics