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Lower Limb Prosthesis A Simplified Ankle Joint

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ABSTRACT

Lower Limb amputation is one of the major disability in India It restricts one of the basic motions of the human body. To overcome this a lot of alternatives are available, but not all of those are effective and economical at the same time. The objective of this paper is to (a) understand the mechanisms of the lower limb and its motions and (b) to propose a simpler and economical prosthetic design which can accomplish two motions

KEYWORDS

Introduction

India, a developing country has a total population of 1.252 billion people contributing to the nation's well being. Out of the 1.252 billion people, according to census 2001 has revealed that over 21 million people in India as suffering from one or the other kind of disability. This is equivalent to 2.1% of the population a staggering number really.

Among the five types of disabilities on which data has been collected, disability In seeing at 48.5% emerges as the top category. Others in sequence are: In movement (27.9%), Mental (10.3%), In speech (7.5%), and In hearing (5.8%).

	Population	Percentage (%)
Total population	1,028,610,328	100.0
Total disabled population	21,906,769	2.1
Disability rate (per lakh population)	2,130	--
Type of Disability		
(a) in seeing	10,834,881	1.0
(b) in speech	1,640,868	0.2
(c) In hearing	1,261,722	0.1
(d) in movement	6,105,477	0.6
(e) Mental	2,263,821	0.2

Source : Census of India 2001.

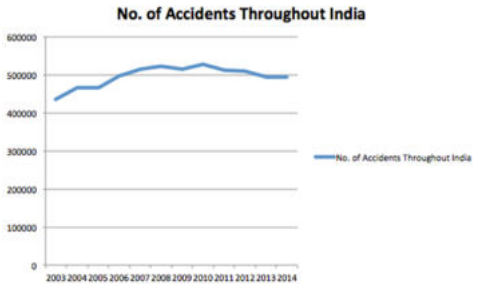
From the five types of disabilities, we reckon movement related disabilities can be overcome.

Movement related disabilities, are of two types mainly: disability from birth or disability caused due to some accident.

With each passing day, because of the heavy traffic influx in India and sadly because of less civic sense, the number of accidents are increasing.

Given below is a graph depicting the rate of accidents in India from 2003 to 2014.

Now as shown in the statistics above, 1.26 million pople are disabled with movement related injuries and if we take 50% of that value, we get 0.63 million people and we can assume that these 6,30,000 people have lower limb related injuries and thus disabilities which in this article we will be working on.

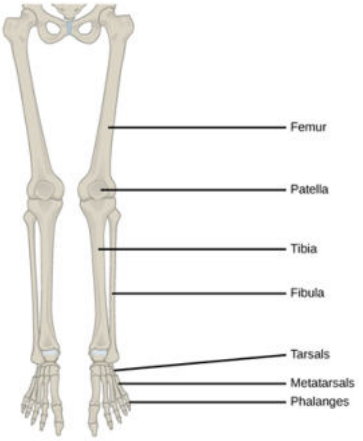


As shown in the graph, the number of accidents in 2014 were493474. Now with accidents come injuries or death and with injuries come disabilities and we can assume that the disabilities here are majorly movement related.

The Lower Limb

The lower limb basically is the part of the body below the waist i.e. the legs. Our legs can be considered to be amongst the most essential parts of our human body because it is with our legs only that we move. A leg related disability is a severe impediment because it restrict the human body from one of it's most essential qualities – movement. So here, lets understand how our leg works.

Given below is the skeletal structure of the leg



as shown, the leg is made up of 6 bones :

The femur (the thigh bone),
The Patella (the knee cap),
The tibia (the shin bone),
The fibula (the calf bone),
Tarsals or tarsus and
Metal Tarsals and Phalanges (these make up the toes of the foot).

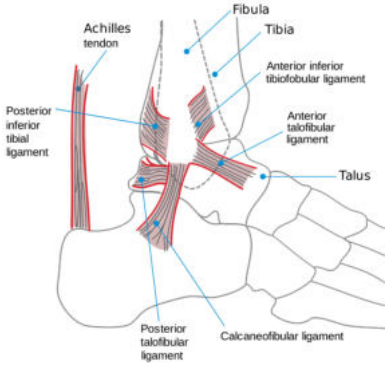
Here, the lower part of the Femur, the Patella and the upper part of the Tibia make up the Knee Joint and the lower part of the Tibia and Fibula and the Tarsals make up the Ankle joint.

This rudimentary knowledge is quintessential in understanding how our model will work.

There are various injuries that can cause a le movement impediment, but the one we will concentrate upon is the ankle joint related injury.

The ankle joint is an essential in all kinds of movements of the foot. Any injury in the ankle joint can cause severe pain and can lead to long term or permanent damage to a persons leg.

The Ankle Joint and it's movements



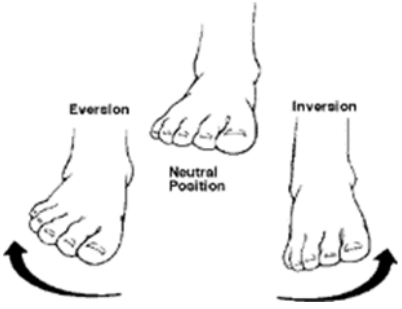
The Tarsals are a cluster of seven bones between the lower end of the Tibia and Fibula and the Metatarsals. So basically a combination of all these bones, the ligaments and tendons makes up the ankle joint and helps in its motions.

The most essential ligament, according to us, is the Achilles Tendon which is shown above too.

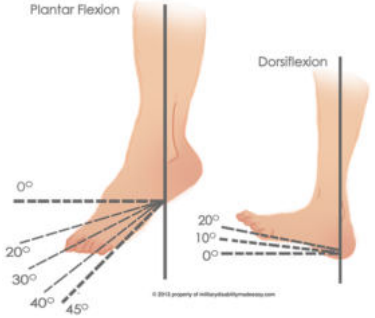
The basic role of a ligament is to join one bone to the other while the basic function of a tendon is to join a muscle to a bone.

The ankle joint only has four basic movements:
1) Inversion
2) Eversion
3) Plantar Flexion
4) Dorsi Flexion

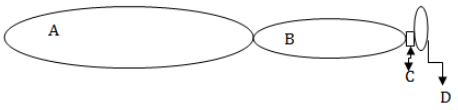
1)Inversion and 2) Eversion



3) Plantar Flexion and 4) Dorsi Flexion



How Muscle Simulations Work



(A) - Femur
(B) - Tibia and Fibula
(C) - cluster of Tarsals
(D) - base of the foot

so muscle stimulations pass from (A) to (B) to (C) which thus lead to the movement of (D).

These muscle stimulations are carried out between each and every muscle of the body and they work on impulses and with each impulse, a muscle moves and hence the desired movement is attained.

We can understand this better by thinking of the muscles as blocks

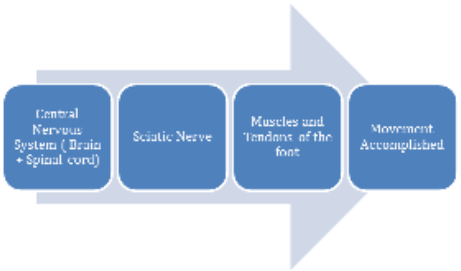
Here the movement occurs form block A to D, again A being the Femur and D being the base of our leg. Now a nerve impulse is sent by the brain and it travels like a wave from the spine all the way up to block A. From block A, it travels to B and C and eventually moves D and hence the muscle movement is executed.

The nerves of the leg and foot serve to propel the body through the actions of the legs, feet, and toes while maintaining balance, both while the body is moving and when it is at rest. Sensory nerves are of course present throughout the lower extremities; however, with the exception of the bottom of the foot, they play a lesser role here than in the upper extremities. Primarily, this section of the peripheral nervous system sends and receives signals regarding locomotion and balance of the body.

The motor regions of the brain and spinal cord control most of the nerve impulses that stimulate muscles in this region. However, many reflex pathways are also active in the legs and foot. The nerve signals in these reflexes come from stretch receptors located in the joints, ligaments, tendons, and even the muscles themselves. Reflexes help to maintain proper muscle tone, balance, and responsiveness of the legs and feet to stimuli such as stepping on a sharp object.

The nerves of the leg and foot arise from spinal nerves connected to the spinal cord in the lower back and pelvis. As these nerves descend toward the thighs, they form two networks of crossed nerves.

The sciatic nerve originates in the lower spine as nerve roots exit the spinal cord (through gaps in the bones at the back of the spine), and extends all the way down the back of the leg to the toes. The sciatic nerve supplies sensation and strength to the leg as well as the reflexes of the leg. It connects the spinal cord with the outside of the thigh, the hamstring muscles in the back of the thighs, and muscles in the lower leg and feet. As such, when the sciatic nerve is impaired, it can lead to muscle weakness and/or numbness or tingling in the leg, ankle, foot, and/or toes. This nerve then travels down the back of each leg, branching out to provide motor and sensory functions to specific regions of the leg and foot.



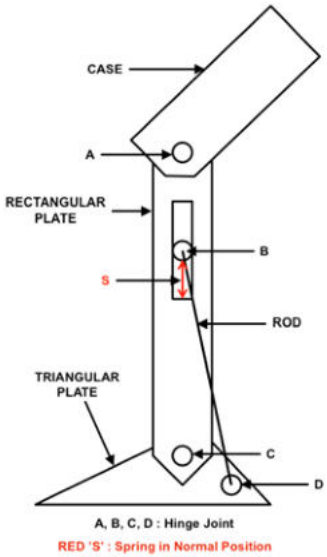
So the central nervous system sends the nerve impulse to the ankle joint via the sciatic nerve which moves the muscles and the tendons by passing on the impulse sent. The algorithm shown above explains how it is accomplished in an easy way. The arrow shows the flow of the nerve impulse. So basically, this is how an ankle joint works.

Our proposed ankle joint design

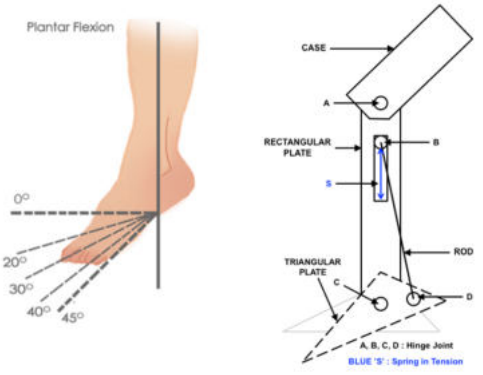
In this section, the researchers have given an idea as to how a proposed prosthetic ankle joint should be designed so that it can accomplish all the necessary movements needed for everyday walking while also making it easily available to the common mam.

As shown in the diagram, a simple ankle joint works as a hinge joint that provide a unidirectional motion (ie. up and down). You might have noticed that when you stretch your foot (plantar flexion) or contract it(dorsiflexion), it automatically comes back to the neutral position. This activity is done by the Achilles tendon, that acts as a spring that keeps the foot in the neutral position. The proposed design uses a combination of hinge joints, sliding joints and a spring to attain the unidirectional motion.

The upper part of the device is the case that is specifically designed to suit every individual. As shown in the figure below , it is then connected to a combination of rectangular plates by a ' Hinge Joint A '. The rectangular plates have a groove carved on them so as to fit a ' Sliding Joint B'. A 'Moveable Hinge Joint C' connects the bottom of that rectangular plate to a triangular plate. The triangular plate is also connected to the ' Joint B ' by using a ' Fixed Hinge Joint D ', with the help of a link. The joint B is connected to a specially designed spring ' S ' as shown in the figure. The rectangular plates act as the Fibula/Tibia, while the triangular plat acts as the base of the foot and the spring 'S' does the function of the Achilles tendon.

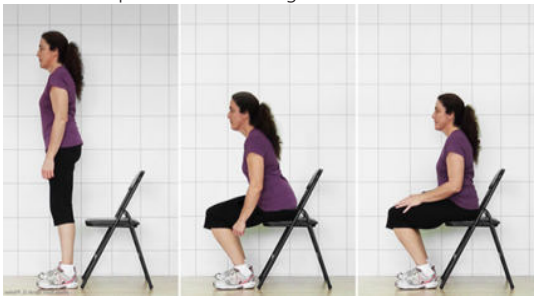


The neutral position is shown in the figure 1 . Now when the person starts to walk, the primary movement that needs to be achieved is the plantar flexion. It is achieved by the mechanism explained below. When the person starts to walk, a downward force acts on the foot, in this case it will act on the tip of the triangular plate. When this force is applied, because of the sliding joint mechanism and the spring, the front end of the triangular plate will move downwards while the back end which is connected to the joint B will move up as the joint D is fixed. This will inturn expand the spring S. Now, when the foot is in the air, no force will be acting on the triangular plate and because there is no force available to keep the spring expanded, it will contract and the joint B will move downwards. As B moves downwards, D will also move downwards which helps to triangular plate to return to its normal position. The movements from 0-40 degrees can be achieved in the mechanized plantar flexion. The figure below shows the Planter Flexion.



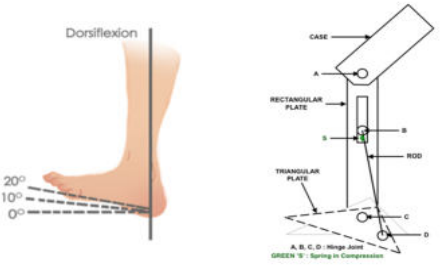
The above figure shows comparison of the actual foot movement with the proposed design.

The secondary movement is the Dorsiflexion as shown in the figure below. This movement is important when a person is sitting and needs to stand up as shown in the figure.



Dorsiflexion is needed for basic movements such as standing up, running and much more. Thus it is important to achieve such movement so that the person can perform basic functions. The proposed design will be able to perform the basic functions and the mechanism is explained as follows:

When a person starts to stand up, an upward force acts on the tip of the triangular plate the forces it to move upwards. Therefore, the joint B also moves downwards and the spring gets compressed as the joint D moves downwards w.r.t joint C. When the person is standing as shown in figure above then the joint will be in the normal position.



This is a simple design that allows a leg amputee to perform all everyday activities like walking, cycling, running etc. easily and without having to did deep into their pockets.

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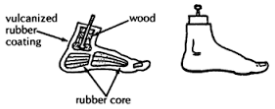
Comparison

THE JAIPUR FOOT



As seen above the Jaipur foot is used as a prosthetic foot for lower limb amputations does not have an ankle joint which can accomplish the movements which we have explained above. Our ankle joint if installed in this Jaipur foot will accomplish the movements and on applying the vulcanized rubber coating, in the same way it is done on conventional Jaipur foots we can have a more flexible and prosthetic with an ankle joint which can move just as a healthy human ankle joint does.

Conclusion

Finally, here the researchers have shown how crucial the ankle joint is, they have given a brief idea on the human leg, focused on the ankle joint and it's movements, explained the muscle stimulations and have proposed a completely, mechanical design that will be economical and will help handicaps with lower limb injuries thus trying to eliminate the handicap which is their ultimate aim.

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