

Design and Fabrication of Improved Below-Knee Prosthesis to Better Mimic Natural Limb



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Abstract

Prosthesis is an artificial substitute or replacement of a part of the body such as tooth, eye, a facial bone, a hip, a knee or another joint, the leg, an arm. Lower limb prosthesis is device made to replace all or part of the leg or foot. Below-knee prosthesis specifically refers to a lower limb prosthesis that replaces part of the leg that is below the knee joint. Most amputees tend to live a dependent and sedentary life, especially when they cannot function effectively and efficiently with their prostheses. They tend to depend on their children and wards for some of their daily activities because of inability to design and fabricate a device (prosthesis) that will rehabilitate and reintegrate such a person into the society. This sometimes leads to a dormant life style, depression or psychological problems. Following this, there is need to design a prosthesis that will accommodate most functions of a lower limb, hence fully rehabilitate and reintegrate such amputees into the society. Secondly, effective and efficient ambulation is the major challenge faced by amputees. This poses a great challenge to them and the rehabilitation team as well. The focus of this research work is to design and fabricate an improved below-knee prosthesis that will better mimic natural limb in form/shape and function by inclusion of a devised ankle joint in the prosthesis. The main conclusion is that the inclusion of the devised ankle joint enhanced the functionality of the prosthesis, hence a better rehabilitation of the amputee than the conventional prosthesis which has direct pylon-to-foot assemblage without any provision for ankle joint.

Keywords: Below-knee prosthesis; Ankle joint; Rehabilitation; Functionality

Introduction

Prosthetic restoration and rehabilitation of amputees proceeded in a hit-miss fashion until after World War II. At that time, the large number of amputees returning from the armed forces stimulated the US Army and Veterans' Administration to take a hard look at the state of the art. Funds for research became available and for the first time, surgeons and engineers became deeply involved in the study of the problems of amputees. The result of these research included new and detailed information regarding the mechanism of gait, energy expenditure, prosthetic alignment principles, recognition of the causes of gait defects, hand functions and the development of better prosthetic components and techniques. In earlier times, the prosthesis available was made of wood with leather socket that was attached to a leather thigh lacer [1,2].

However, the first people that commercialized design and fabrication of prostheses in New York are the Mark Brothers (D.B and A.A Mark) in 1854 [2]. They secured patent to market prostheses for all levels of lower limb amputation. The philosophy of the design is based on the thorough understanding

of the biomechanics of the amputee's gait and uses the ground reaction forces generated to stabilize the knee and ankle joint during swing phase.

The decision to carry out this research work was informed by the fact that most available and locally designed below knee prostheses in our health system do not incorporate most of the functions of ankle joint in both design and function. The inclusion of a functional ankle joint in below knee prostheses has been a great challenge to prosthetists and biomedical engineers. With respect to feet and ankles, clinicians must perform a fine balancing act to provide prosthesis that will accommodate various terrains while providing the dynamics necessary to maintain an efficient gait. Currently, there is no technology in use that replicates the body's natural ability to adapt to variances in terrain while negotiating environmental obstacles [3]. The ankle joint is a hinge joint formed by the distal end of the tibia (condyles) and medial malleolus, the distal end of the fibula (lateral malleolus) and the talus. It is the joint between the foot and the leg [4]. On rocky surfaces, the natural ankle will initiate ground contact with reduced dorsiflexion to provide a relatively

flatter foot. Patients wearing prosthesis attempt to replicate this strategy but are unable to mimic the ankle angle to match the terrain, presumably due to the reduced range of motion available from the ankle and foot. As a result, a prosthetic foot and ankle mechanism with expanded ranges of ankle motion presents an opportunity to restore vital functions among amputees using lower limb prosthesis [5-11].

Materials

The fabricated below-knee prosthesis consists of a socket, metal pylon and ankle joint component, padding/suspension materials, screws, bolts and nuts. The materials used for designing these components and the below-knee prosthesis as a whole included: Plaster of Paris (POP) bandage and powder, Plastic polymer laminate (epoxy resin), Reinforcement textile (stockinet), Pelite, foam, Metals, Cosmetic finishing materials, Adhesives [12].

Methodology

This study seeks to make modifications in the ankle joint component of a below knee prosthesis (Inclusion of a devised ankle joint). A natural ankle joint which consist of the tibial condyles, medial and lateral malleolus and talus have some

Table 1: Result of ambulation achieved by the amputee with the improved prosthesis.

| Comfort | Energy Expenditure | Pain | Max. No of Strides Per Min. | Max. No of Strides Per Min. | Total Steps | Total Strides |
|--------------|--------------------|------|-----------------------------|-----------------------------|-------------|---------------|
| Satisfactory | Minimal | No | 51 | 17 | 153 | 51 |

Table 2: Result of ambulation achieved by the amputee with the conventional prosthesis.

| Comfort | Energy Expenditure | Pain | Max. No of Strides Per Min. | Max. No of Strides Per Min. | Total Steps | Total Strides |
|------------------|--------------------|--------|-----------------------------|-----------------------------|-------------|---------------|
| Not satisfactory | Moderate | little | 36 | 12 | 108 | 36 |

Discussion

Designing and fabricating a functional prosthesis that can take over the functions of an amputated body part without any limitation has been a challenge to Prosthetists and Biomedical engineers. This work looked at incorporating the shock absorption function of the ankle joint in the design and fabrication of a below knee prosthesis by means of a devised ankle joint. The ankle joint was made of sheets of metal plates and springs, which is then connected to the socket through a metal pylon and also to the foot component through metal bolts and nuts. The socket was laminated with layers of stockinet impregnated with resin. The socket is then attached to a metal pylon through metal bolts and nuts. The padding material/liners inside the socket are made with eva-foam. A trans-tibial amputee was fitted with both the improved below knee prosthesis and conventional below knee prosthesis which he used at different times and was allowed to walk with each of them through a distance of 100m and observations/evaluations the gait achieved with each of the prostheses were made by noting the different gait parameters at different instances. In the gait achieved with the research/improved prosthesis, two major gait divisions; stance and swing phases were present and achieved with easy. The amputee attested to; no pain, minimal energy expenditure and moderate

space in-between them which permits the ankle joint to perform its functions [13-26]. The conventional below knee prosthesis has a socket or pylon-to-foot design, which doesn't provide the arrangement (space) seen in a natural ankle joint, hence limits the functions of the user. This study focuses on incorporation of a devised ankle joint in the design and fabrication of below-knee prosthesis so that it will closely mimic natural limb in form and function. The fabrication processes included: assessment [27,28], impression/measurement taking [29], modification [30], lamination of test/check socket, lamination of new positive cast/model, formation of liners/inserts [30], lamination of definitive socket [31], attachment of socket to pylon and ankle joint/alignment [32,33], prosthesis finishing [34,35], amputee's training and follow-up [36].

Result

During ambulation, the amputee achieved a maximum of 51 steps and 17 strides per minute, unlike when ambulating with the conventional prosthesis where he achieves a maximum of 36 steps/min and 12 strides/min. Comfort level was satisfactory with no pain and minimal energy expenditure. The amputee also finds it easier and makes it faster to step down from a height (Table 1 & 2).

comfort and was able to walk without a walking aid as against that witnessed in the conventional prosthesis where he used with a walking aid. A number of 51 steps were taken per minute, 17 strides per minute and a total of 153 steps and 51 strides were taken through the distance which lasted for 3mins with the research/improved below knee prosthesis [37-61].

Conclusion

Although there have been much researches dedicated to advance the functions of below-knee prosthesis to improve amputee's comfort and rehabilitation. The result suggested that the inclusion of the devised ankle joint enhanced the functionality of the prosthesis, hence a better rehabilitation of the amputee than the conventional prosthesis which has direct pylon-foot assemblage without any provision for ankle joint.

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