Comparison of Prosthetic Feet Roll-Over Shapes Used in Developing Nations

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Introduction: Development of appropriate prosthetic devices for developing nations is a continual challenge. The main objective is to restore limb functionality to the highest degree of amputee comfort and mobility (Klute, et. al., 2001). One of the greatest obstacles to overcome is understanding proper limb function. Even in industrialized nations such understanding is limited as prosthetists rely on experience rather than a deliberate correlation of patient need to component performance (Lit-Review). In developing nations this understanding is even more limited, given the lack of detailed biomechanical studies at the component and system level.

In 2004, the authors initiated a program to develop improved lower-limb prosthetics for amputees throughout the developing world. A key component of this program was a desire to assess new prostheses with the same criteria applied to prosthetic devices in the industrialized world. In so doing, understanding the relationship between componentry and function would increase.

The program is currently investigating the development of improved transfemoral prosthetics with an emphasis on knee and ankle-foot components. This paper compares the function of six prosthetic feet often used in developing nations with a biological foot. The study specifically examines the roll-over shapes of prosthetic feet in comparison to a biological foot.

Background: Understanding the function of a biological foot is essential to simulate its performance in a prosthetic foot (Pitkin, 1995). A biological foot is an intricate musculo-skeletal system (Hansen, 2004a) and to quantify its performance Hansen has developed the shape and roll method. This method produces a roll-over shape that represents the center of pressure (COP) of a foot with respect to a reference axis defined between the knee and ankle in the saggital plane. The roll-over shape records the geometry of the walking phase (Hansen, et. al., 2004b) and enables comparison of biological and prosthetic feet because COP can be measured on deformable and non-deformable systems (Hansen, et. al., 2004a).

Roll-over shape of a biological foot changes when a person is walking uphill and in regard to a person's height, but it does not change with alterations in heel height, walking speed, or trunk weight (Hansen, et. al., 2004a, 2004b, 2004c, 2005). Studies indicate that when a prosthetist dynamically aligns an amputee's prosthetic foot that they match its roll-over shape with the roll-over shape of a biological foot (Hansen's, et. al., 2003).

Because a biological roll-over shape determines performance in multiple situations the authors believe the shape and roll method is a valid approach to quantify the functionality of prosthetic feet.

Methods: Quantitative roll-over shapes were measured from a biological (BIO) foot and the following six prosthetic feet: Northwestern University's Shape & Roll Prosthetic (S&R) foot (patent pending), Jaipur foot, Solid Ankle Cushion Heal (SACH) foot, Niagara foot™, International Committee of the Red Cross (ICRC) SACH foot, and LeTourneau University's first generation (G1) foot.

Figure 1 – Tested feet

Each distinctive roll-over shape was compared to the roll-over shape of a biological foot. To the extent of the authors' knowledge no other investigation has been done comparing such a comprehensive set of feet commonly used in developing nations.

Methods used to find the roll-over shape were the quasi-static and dynamic methods described by Hansen, et al. (2000). Data from both tests are compared because it seems that no significant variation exists between the test (Hansen, et. al., 2000).

Prosthetic feet were aligned on the Quasi Static Fatigue Tester (QSFT) such that the pylon was perpendicular to the bottom surface of the attachment plate and to the top surface of the prosthetic foot.

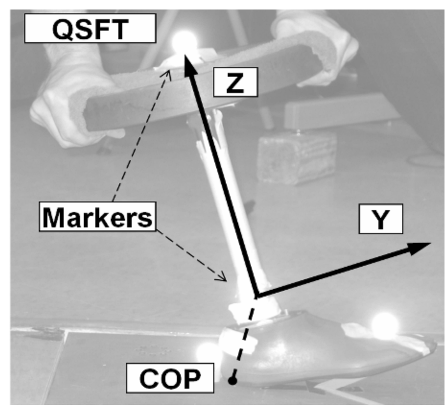

Figure 2 – Quasi Static Fatigue Tester and ref. YZ axis

The foot was loaded with an uniform vertical force (tolerance 100N) from heel strike to toe-off as the Bertec forceplate measured upward force. Motion Analysis infrared cameras captured position data in the YZ saggital plane from reflective markers placed on the simulated knee and ankle. For comparison, a test subject walked across the Bertec forceplate with reflective markers placed on their knee and ankle. Force in the upward direction and marker positions were measured. A minimum of four trials from each foot were averaged together and all data was filtered and then processed using an algorithm that determined the roll-over shape with Microsoft Excel and an algorithm to find the foot radii using MATLAB.

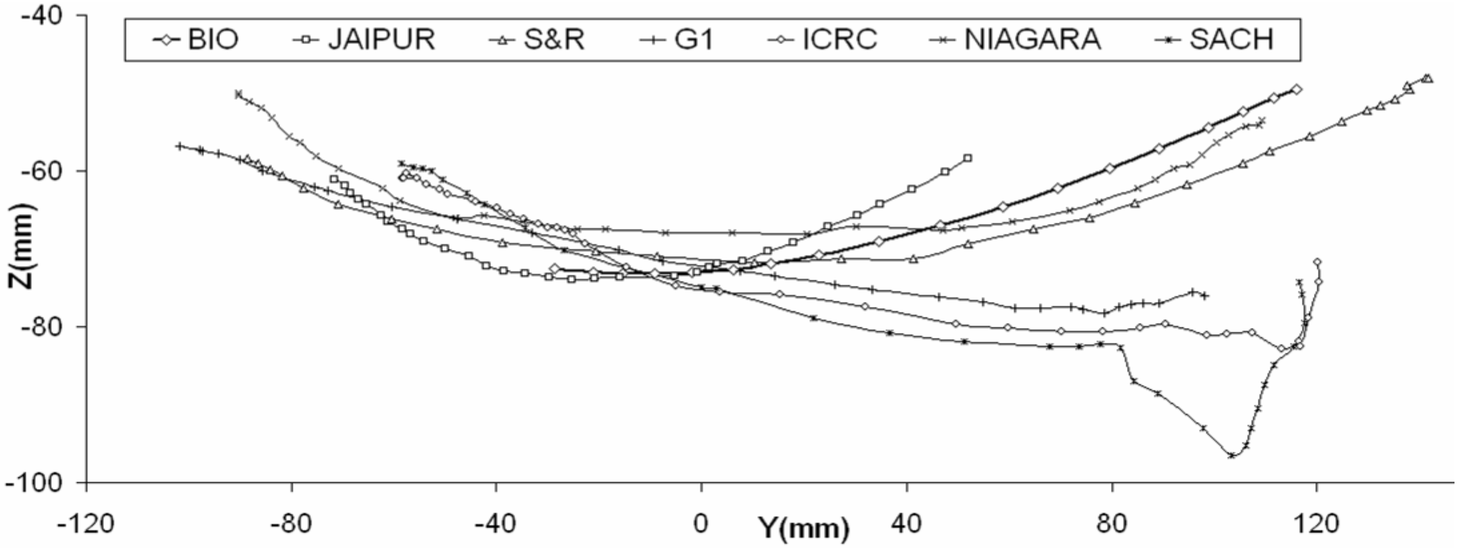

Figure 3 – Roll-over shapes of tested feet.

Results: The roll-over shapes of the seven tested feet are shown in Fig. 3. The Z-axis of the graph represents the fixed axis that travels from the ankle to the knee and the Y-axis represents the fixed axis that extends from the heel to the toe. Each point on the graph represents an average of the COP measured relative to the fixed axis.

Foot	Ave. Arc Length	Radii
BIO	156 mm	420 mm
Jaipur	129 mm	151 mm
Niagara	204 mm	300 mm
SACH	181 mm	350 mm
S&R	224 mm	360 mm
ICRC	178 mm	420 mm
G1	200 mm	740 mm

Table 1 – Average arc length and radius of curvature

Discussion: Large variations between the roll-over shapes are due to the differing arc lengths and radii of each foot. Anecdotal evidence suggests that increased length possibly leads to a greater amount of stability through the stance phase.

The two different types of SACH feet tested exhibited "drop-offs" in performance at the end of their keel where their toes were still in contact with the ground. This can be seen by the dips found 20mm–40mm before the end of their roll-over shapes. This can possibly contribute to a lack of stability and shorter stride length. (Meier, et. al., 2004)

It can be observed that the trend line of the roll-over shapes in Fig. 3 have diverse slopes. The direction of the slopes of these feet will be changed appreciably when aligned by a prosthetist. Hansen's, et. al., (2003) studies suggest proper alignment occurs when a prosthetic foot's roll-over shape is matched with the roll-over shape of a biological foot. Therefore when prosthetic feet are aligned the roll-over shape will be rotated so that it aligns best with a biological roll-over shape.

After initial testing, sources of error could be contributed to tolerance of force in the Z-direction, variance in prosthetic attachment, and data averaging, however the authors do not believe these are appreciable sources of errors and they plan to confirm that in a follow up test.

Conclusions: Hansen's shape and roll method provides a quantitative test that compares functionality of feet. Results show variable levels of imitation between the biological and the prosthetic roll-over shapes. The authors believe the variation of the prosthetic feet from the ideal biological foot is often a result of misalignment, and/or poor design. As a result of these tests, we believe we can use roll-over shape testing to develop a prosthetic foot capable of meeting the needs of developing nations by simulating the performance of a biological foot. This will increase the comfort and mobility of transfemoral amputees in developing nations.

References:

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