International Encyclopedia of Rehabilitation

Center for International Rehabilitation Research Information and Exchange (CIRRIE)
515 Kimball Tower
University at Buffalo, The State University of New York
Buffalo, NY 14214
E-mail: ub-cirrie@buffalo.edu
Web: http://cirrie.buffalo.edu

This publication of the Center for International Rehabilitation Research Information and Exchange is supported by funds received from the National Institute on Disability and Rehabilitation Research of the U.S. Department of Education under grant number H133A050008. The opinions contained in this publication are those of the authors and do not necessarily reflect those of CIRRIE or the Department of Education.

Prosthetics: Foot and Ankle Prosthetics

Andrew H. Hansen, PhD
Research Health Scientist
Jesse Brown VA Medical Center
Research Associate Professor
Dept. of Physical Medicine and Rehabilitation Northwestern University
Feinberg School of Medicine Affiliated Faculty, Dept. of Biomedical
Engineering McCormick School of Engineering and Applied Science

The author would like to thank Tom Karolewski, CP, FAAOP, for reading this document and providing feedback on its accuracy.

Foot and ankle prosthetics are devices that are designed to replace one or more functions of the biologic human foot or ankle-foot system. Persons may experience amputation of their lower limb(s) due to disease or traumatic incidents. In many cases, the part of the lower limb that has been amputated is replaced by a mechanical device, commonly called an artificial limb or a prosthesis. The lower limb prosthesis must connect to the body through an interface, typically a socket that fits around the person’s remaining or residual limb. The prosthesis usually has a mechanism connected to its other end (i.e., the distal end) to improve function and/or cosmesis of its user. For lower-limb prostheses, the mechanisms at the end are typically referred to as foot and ankle prosthetics, prosthetic feet, or prosthetic ankle-foot systems. This article reviews different kinds of prosthetic feet that are used and the functions they are intended to replace. Science in this field is relatively young and many details necessary for making the most appropriate prescriptions of prosthetic feet for particular users are yet to be discovered.

Prosthetic ankle-foot systems are developed to replace the physiologic ankle-foot system. The physiologic ankle-foot system is amazingly complex and no mechanical device currently exists that can replicate all of its functions using the same volume of space and at the same weight. The physiologic system has bones, joints, and muscles that allow it to adapt its flexibility and its positioning for a variety of tasks, providing stability at times and laxity at other times to promote movement. Current ankle-foot prostheses are much less sophisticated than the physiologic systems they replace and offer limited functions for a variety of tasks.

Designing prosthetic ankle-foot systems is challenging because of numerous design goals that must be achieved. Among these is the goal for the prosthetic foot to be light in weight, because the prosthetic foot must be “carried” along with the prosthesis. A very heavy foot may compromise suspension of the prosthesis during the stepping movement, for example. Another design goal is that the foot should have high strength. The ankle joint in walking and running encounters enormous forces and torques and these high loads are repeatedly applied to prosthetic ankle-foot devices throughout their lifetime of use. International standards exist for testing the strength and durability of ankle-foot prosthetics, including loading schemes that mimic those seen in walking for two million cycles without failure. Volume and cosmesis are other important design considerations.

Ankle-foot systems must be made small enough to fit within the general volume of space of the physiologic ankle-foot system, allowing a cosmetic covering to be used (when desired) to make the prosthesis appear similar to the biologic ankle-foot system and allowing the entire system to fit into a shoe. In general, practical and simple designs tend to last long periods of time and require less maintenance. However, some of the more elaborate systems may allow improved function on uneven terrain or for tasks other than walking straight on level terrain.

Some of the earlier designs of prosthetic ankle-foot systems included the solid ankle cushioned heel (SACH), the single-axis, and the multi-axis foot. The SACH foot typically has a rigid inner keel structure surrounded by a compressible foam cosmesis. The typical plantarflexion movement of the ankle in early stance phase of able-bodied walking is simulated through deformation of a heel cushion in the SACH foot. The prosthesis user then “rolls” forward over the stiff SACH keel and then “tips” about the end of the keel (i.e., toe) in late stance. The single-axis foot also has a rigid keel structure, but includes an integrated, articulated ankle joint. The ankle joint of a single-axis foot typically has a different stiffness (usually “softer”) when driven into plantarflexion than when driven into dorsiflexion. This difference is usually accomplished through compression of two different rubber bumpers within the single-axis foot. The multi-axis foot is similar to the single-axis foot, although it allows movements about two axes of rotation (both plantar-dorsiflexion and in-eversion) instead of one (just plantar-dorisflexion).

The movement of the single-axis and multi-axis ankle joints in walking allows a closer representation of the able-bodied foot-ankle system assuming proper choice of stiffness levels. Additionally, these prosthetic ankle-foot systems are thought to allow better accommodation to different terrain than feet with rigid or even flexible keels. However, the single-axis foot and the multi-axis foot have moving parts that may require more maintenance than a non-articulated foot.

Many additional types of prosthetic feet have been developed in the last 30 years. Several of these feet use a flexible keel to simulate ankle-foot function in walking and other tasks. Some of these prosthetic feet use keels made of plastic, while others use carbon fiber composites to form their keels.

A number of ankle-foot systems also allow for simple manual changes in ankle alignment to accommodate shoes of different heel heights. Although nearly all systems could be adjusted to a variety of heel heights using tools, these newer systems allow for alignment adjustments without the need for tools, typically using a push-button on the ankle that allows the wearer to unlock the ankle, position it, and then lock it in the desired position.

A few new systems that are reaching the prosthetics marketplace are claimed to adapt to different terrain in walking and standing beyond the use of flexibility alone. For example, some systems change the alignment of the ankle into dorsiflexion for walking uphill and into plantarflexion for walking downhill. These systems could potentially enhance stability of prosthesis users on non-level terrain beyond that of flexible systems alone, but will likely require more maintenance due to more complex electrical-mechanical approaches.

For walking, prosthetic feet can be thought to provide some level of shock absorption in early stance phase, after the heel contacts the walking surface. Then, prosthetic feet provide a roll-over shape, or effective rocker, that the person can use to “roll” forward over the foot. Lastly, prosthetic feet provide energy return in late stance phase as they are being unloaded. The alignment of the foot, which is the positioning (and orientation) of the foot with respect to the person’s residual limb socket, largely contributes to overall function in walking and standing. In general, prosthetic feet with different mechanical properties are aligned differently, but likely to achieve a similar roll-over pattern in walking.

Further research is needed to gain a better understanding of mechanical function of prosthetic feet in walking, standing, and other tasks of daily living. Improved knowledge gained from research will hopefully lead to improved prescription of prosthetic feet to persons with lower limb amputation.

References

Kapp S, Cummings D. 1992. Chapter 18B: Transtibial Amputation: Prosthetic Management. In: Bowker JH and Michael JW, editors. Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles. 2nd Edition. St. Louis (MO): Mosby-Year Book, Inc. Missouri/ pp. 453-478.

Official Findings of the State-of-the-Science Conference on Prosthetic Foot/Ankle Mechanisms. Journal of Prosthetics and Orthotics 17(4S). http://www.oandp.org/jpo/library/index/2005_04S.asp

Seymour R. 2002. Prosthetics and Orthotics: Lower Limb and Spinal. Baltimore (MD): Lippincott Williams & Wilkins.