Design, Manufacture, and Selection of Ankle-Foot-Orthoses

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INTRODUCTION

Ankle-foot-orthoses (AFOs) are externally applied assistive devices that are prescribed to the patients with neuromuscular dysfunctions in order to improve abnormal lower limb motor functions. AFOs are mainly used to control the range of motion of the ankle joint, to compensate for the muscle weakness caused by different motor-neuron diseases, to improve the gait functions during post-operative stages and to optimize the efficiency of walking.

Different types of AFOs are used to treat different dysfunctions. Each type of AFOs has its characteristic function. However, AFOs with same function can have different designs that differ in material, geometry, additional mechanism and components which affect the comfort, cost of AFO and oxygen consumption of patients. Additionally, recent advances in different technology areas, such as additive manufacturing (AM), three dimensional (3D) scanning and CAD-CAM (computer aided design-computer aided manufacturing) have led to new designs and manufacturing methods for AFOs. The objective of this chapter is to provide a survey on design, manufacture and selection of AFOs.

BACKGROUND

First of all, it would be beneficial to describe orthosis and prosthesis concepts that are mostly confused with each other. Briefly, orthoses are braces to support dysfunction of a body part, while prostheses are artificial parts to replace a missing body part. Prostheses are devices for external and internal use. External prostheses, such as prosthetic legs or prosthetic breast form used after mastectomy (Lake, Ahmad, & Dobrashian, 2013), can be employed for cosmetic and also functional aims with the developments in prosthetic technology. On the other hand, internal prostheses, such as artificial knee joints (Guo, Hao, & Wan, 2016) and cataract lenses (Heys & Truscott, 2008) are devices which are surgically implanted within a body.

Orthoses are assistive devices that are used to align, protect and assist limbs or body parts besides supporting to treat deformities. Orthoses can be used for neurological conditions, injuries and congenital deformities. Orthoses are designed as standard or custom made forms from an individual mold in the shape of patient's foot. Orthoses can be divided into two classes, i.e. *i*) standard orthoses for general use and *ii*) custom made orthoses

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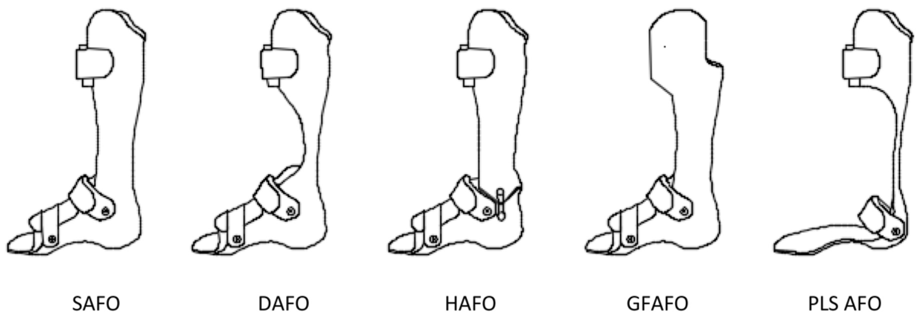
Figure 1. Typical examples of ankle foot orthoses



that are prescribed for more complex conditions. Orthoses are used for lower extremity (Moisan & Cantin, 2016), upper extremity (Belda-Lois et al., 2006), and spine (Hofmann et al., 2016). Lower extremity orthoses have a wide range of use that are designed for hip, knee and ankle joints' immobilizations. They reduce energy consumption and pain as assisting the gait and improving the posture. Development of lower extremity orthotic technologies and new materials lead to new designs and manufacturing methods, and also affect selection criteria of orthoses.

AFOs are braces encompassing the lower leg, ankle joint and foot of the patients. AFOs provide stability in the ankle joint and biomechanical control above and below of ankle. For example, a patient with crouch gait pathology (walking with flexed knees) can reduce knee flexion during stance phase by using an AFO. Because, AFO produces a moment around the ankle joint that prevents ankle dorsiflexion in stance phase which prevents excessive knee flexion by directing the ground reaction force in front of the knee joint center. They are manufactured using metal and plastic materials. However, plastic AFOs are more preferred than metal ones, because they are lighter and more cosmetic (Franceschini et al., 2001). Also it was reported that custom plastic AFOs decrease oxygen consumption in the patients. However, the patients, who want to use AFO, should have sufficient active hip flexion to propel their legs. And their quadriceps muscle strength should be greater than four or five grade according to manual muscle test (Hsu, Michael, & Fisk, 2008).

There are several different types of AFOs for different biomechanical aims (Figure 1). Solid ankle foot orthosis (SAFO) (Ridgewell, Rodda, Graham, & Sangeux, 2015) rigidly supports ankle and prevent any movement at the ankle. Dynamic ankle foot orthosis (DAFO) provides subtalar stabilization. Unlike solid AFO models, this device allows ankle to dorsiflex and partially limits the plantarflexion (Sherief, Gazya, & El Gafaar, 2015). Hinged ankle foot orthosis (HAFO) is also a type of dynamic AFO which let the dorsiflexion exists during gait. On the other hand, HAFO is commonly used to restrict three-dimensional ankle mobility and limit the motion of ankle joint within the sagittal plane (Leardini, Aquila, Caravaggi, Ferraresi, & Giannini, 2014). Ground reaction ankle foot orthosis (GRAFO) is used to reduce excessive knee flexion (Ries & Schwartz, 2015). This type of orthoses has a solid part below the knee (pre-tibial support) which doesn't allow the knee joint moving forward. Posterior leaf spring ankle foot orthosis (PLS AFO) is used to primarily for foot drop in order to control plantarflexion during heel strike and swing phases to improve the functional quality of locomotion (Leone, 1987). All these AFOs have different characteristics, since they are designed for specific goals. Different characteristics of AFOs meet specific needs which result from injuries and diseases, such as foot drop (Everaert et al., 2013), cerebral palsy (van Beeten, Hartman, & Houdijk, 2015), spina bifida (Duffy, 1997) and hemiplegia (Nolan, Savalia, Lequerica, & Elovic, 2009).