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Development and Evaluation of Pneumatic Artificial Muscle (Pam) for Patients with Drop Foot

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Abstract

This study aimed to develop a Pneumatic Artificial Muscle (PAM) model to improve foot function and walking in podiatric patients with foot drop caused by neurological diseases. Determine the PAM for patients who know as compared to AFO and which is more effective. The PAM model was utilized to assist four-foot drop patients with foot drop for 12 weeks, with data collected through documentation and questionnaires for statistical analysis. PAM improves performance in foot drop patients, reduces pain, disability, and foot resistance, and increases overall comfort and function. PAM systems enhance user safety, mobility, and flexibility, necessitating ongoing research and development to enhance design, management, usability, and reliability for clinical use.

Keywords: Drop Foot, Pneumatic Artificial Muscle, Ankle Foot Orthosis, Gait Improvement, Randomized Controlled Trial, Assistive Technology.

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Development and Evaluation of Pneumatic Artificial Muscle (Pam) for Patients with Drop Foot

Abstract

This study aimed to develop a Pneumatic Artificial Muscle (PAM) model to improve foot function and walking in podiatric patients with foot drop caused by neurological diseases. Determine the PAM for patients who know as compared to AFO and which is more effective. The PAM model was utilized to assist four-foot drop patients with foot drop for 12 weeks, with data collected through documentation and questionnaires for statistical analysis. PAM improves performance in foot drop patients, reduces pain, disability, and foot resistance, and increases overall comfort and function. PAM systems enhance user safety, mobility, and flexibility, necessitating ongoing research and development to enhance design, management, usability, and reliability for clinical use.

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Contents

Introduction

Throughout their histories, the disciplines of orthotics, prosthetics, and physical therapy shared responsibility for the care and treatment of injuries and disabilities. Orthotics will play an important role for a patient suffering from neuromuscular and musculoskeletal injuries to overcome functional limitations and disabilities through the design, fabrication, and installation of orthotics or supports. The orthodontist's job is not just aesthetic work; rather, the job includes assessing the needs and aesthetics of the patient, designing orthotics, selecting appropriate materials, and designing, assembling, and cadencing products. In addition, orthotics participate in educating patients and caregivers on how to correctly use and care for their braces, advising on performance evaluation, and design of equipment. This is hand-made equipment that provides essential care to people suffering from partial or complete impairments of the limbs. It is designed to restore the ability to walk or take part in sporting activities, giving a sense of purpose and freedom. With rapid changes in technology and treatments, the roles of orthotics and prosthetics have changed tremendously. The technicians, who used to be mainly concerned with product development, now play crucial roles in the multidisciplinary medical teams. Their role has evolved from ensuring that the patients receive quality care through detailed examinations and evaluations and furthering their education to plan the treatments holistically. This is a reflection of the change towards being more patient-centered in their ways of treatment should not simply focus on healing the bodies but also ensure an increase in the quality of life and health Chui et al. (2019).

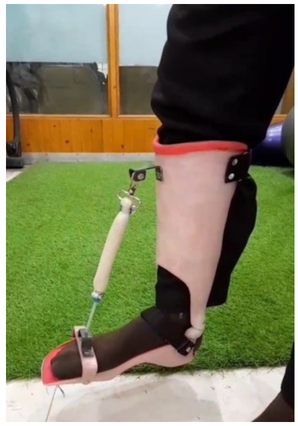
They are an important part of human mobility and weight bearing, basically supporting the ability to stand, walk, and run. The structure is so complicated, with lots of bones, muscles, and ligaments that make their strength hard to understand and measure. This difficulty, combined with possible injury, leads to difficulty in analyzing and comprehending foot biomechanics (Boehler, Hollander, Sugar, & Shin, 2008). And what do we mean when we talk about people having a bottom drop? We basically mean a condition where it becomes veritably delicate to lift the front of the bottom, which leads to dragging of the toes on the bottom when walking. Foot drop is a clinical sign, not a complaint opinion in itself. It's caused by problems related to the nervous system (whim-wham damage), muscle complaints, diseases of the brain and spinal cord, nonage problems, whim-whams contraction, or by an anatomical problem with the bottom, which makes it more delicate to move. Common causes include sciatic mononeuropathy following trauma or parturition, spinal cord problems, and supplemental neuropathy from conditions similar to diabetes, multiple sclerosis, stroke, or injury. The condition can be temporary, caused by a sprain or fracture to the bones that support the leg, but it also can be an endless issue. It'll affect a change in the weight-bearing on the bottom; frequently, the person will be unfit to lift the bottom duly, and the toes will scrape along the ground while walking. In addition to the physical pain, the reduction in movement will increase the threat of tripping over and falling. This problem can be combated by ensuring that the person wears a special brace, an ankle bottom orthosis(AFO), designed to support the leg while walking. similar orthotic bias stops the bottom from dragging along the bottom and improves gait and balance. Their addition in treatment also comes with activity to ameliorate the strength of muscles or movement. The operation of the bottom drop aims toward 'maximum attainable function' meaning that indeed those in pain can ameliorate their quality of life and independence (a book: Mayo Clinic Family Health Book, 5th edition (2023). However, before anything else, we do an electromyography (EMG) test, which is vital to the diagnosis and management of patients with drop feet. It helps to better understand the patient's neuromuscular function by providing information on the severity and course of the problem. If the EMG test is positive and shows aberrant electric activity in the muscle or nerve, the patient with a drop foot will not be eligible for either an AFO or PAM-AFO. This study focused on developing a pneumatically driven ankle-foot orthosis that aimed at improving gait in patients affected by drop foot. The innovation involved the use of Pneumatic Artificial Muscles, which are the main actuators for the device. Unlike the typical pneumatic actuators, like cylinders, PAMs possess a different structure and functionality, hence particularly suitable for an application where a more natural and responsive movement is desired.

A typical PAM consists of a rubber-like elastic bladder enclosed within a double-helically braided sleeve, with both ends of each attached airtight using mechanical fixtures. Actuation occurs when air pressure inflates the bladder and pulls the sleeve inward through contraction to create a pulling force. This form of unidirectional actuation mimics natural movement similar to muscles and therefore proves to be more fluid and controlled with regard to assisting with the dorsiflexion in patients with drop feet. With PAMs, use within the AFO can allow a far more dynamic and adaptive response to the gait of the patient, potentially leading to some great improvements in mobility and stability. This innovative approach marks the next advance in orthotics technology, offering a personalized solution to restore a more natural pattern of walking in restoring mobility in people affected by drop foot Doumit, M. D. and S. Pardoel (2017). PAMs are lightweight, either contractive or extensional actuators. They were originally developed as McKibben Artificial Muscles in the 1950s for use in artificial limbs. Their design effectively emulates the function of a natural muscle and hence is particularly useful where an application requires motion that is flexible and responsive. Applications in robotics and assistive devices, among others, have since been developed using this technology due in part to the advantages gained by its capability to contract and generate force in a manner similar to human muscles.

In order to stop plantar flexion of the foot, PAM is attached to the anterior side of the AFO. It serves as a plan for a control system. Additionally, this study's goal is to determine which is more lightweight, cost-effective, pleasant and requires less time to improve. As shown in Figure 1 PAM is attached with AFO.

Figure 1

PAM-based AFO control system scheme



It may cause blisters and calluses for excessive use, so we also analyze the wearing time limit. Gait generally is a complex sum of the movements of the foot, particularly plantar flexion, dorsiflexion, and eversion. The rationale for the movement dimensions under investigation is the complex structure of the foot and the challenge of accurately quantifying its movement in these three planes of motion. Plantar flexion is pointing the foot downwards, dorsiflexion is raising the foot upwards, and eversion is tilting the sole outwards. These are very important dimensions in the understanding of gait mechanics with regard to the clinical development of effective treatments or interventions for foot-related medical conditions (Boehler et al., 2008).

Methodology

Research design is a Randomized Control Trial (RCT) conducted in rehabilitation centers. The sample size is 4 because of the comparison between 2 devices which apply to 2 patients for PAM-AFO and the other 2 for dynamic AFO separately. The sampling technique was convenient sampling. Duration of study about 3 months. Inclusion criteria were diagnosis of drop foot, ability to wear AFO, functional impairment, no age limit, and no gender restrictions while Exclusion criteria were pregnancy, unstable health status, EMG test positive, and severe medical conditions. Ethical consideration was the lower limb is supported by an AFO, with or without pneumatic artificial muscle, to keep the foot from lowering during the swing part of the gait cycle. It lowers the chance of falling and regulates the foot's posture when walking. On the other hand, feeling heated, having trouble balancing, having swollen feet, skin irritation, and heel discomfort are typical adverse effects of this arch. After employing this device, there were around 20% improvements, and the average peak dorsiflexion angle during the swing phase was provided. Data collection procedure through examinations of existing records and questionnaires.

Results

- Improved dorsiflexion: PAMs can assist patients elevate their toes and lower their risk of stumbling by greatly enhancing dorsiflexion.
- Enhanced gait dynamics: PAM usage in AFOs frequently results in better gait patterns, which help patients walk more naturally and effectively. A more symmetrical and balanced gait may be one example of this.
- Increased muscle activation: PAMs may lessen muscular atrophy by assisting in the activation and strengthening of the muscles surrounding the foot and ankle.
- Energy efficiency: PAMs can lessen the energy required for walking, allowing patients to move around with less fatigue.
- Functional independence**:** Patients frequently experience more functional independence in their daily activities as a result of improved mobility and gait.

Discussion

The trial AFO design provides good support for the implant during walking. This improvement maintains stability throughout the gait cycle, making the user's gait more natural. Research shows the advantages features of PAM is a comparison with other types of actuators (Ferris D, Czerniecki J, 2005) (Ferris D, Gorden K, Sawicki G, 2006), related with its high power-to-weight ratio and variable compliance allowing a better adaptation and interaction with the human operator. PAMs modeled after natural muscle functionality, are actuators that contract when air pressure is applied, creating movement (Ferris, D.P., Gordon, 2006) Composed of an inner inflatable bladder and an outer mesh, PAMs convert radial expansion into linear contraction, allowing them to generate significant force while remaining lightweight flexible (Tucker, M. R., Olivier, 2015). Incorporating PAMs into AFOs involves using a control unit and an air compressor to manage inflation and deflation. Sensors detect the gait phase, activating PAMs to assist with dorsiflexion during the swing phase, resulting in a more natural and responsive movement (Lee, S. M., Kim, 2017). This mechanism contrasts with traditional AFOs, which often restrict movement and rely on rigid structures.

Studies have explored various designs and control strategies for PAM-integrated AFOs. EMG signals to control PAMs could effectively enhance ankle movements and improve gait symmetry in individuals with drop feet. This approach leverages the user's residual muscle activity, providing a personalized and adaptive assistance mechanism (Ferris, D.P., Sawicki, 2007). Other research has focused on optimizing the placement and configuration of PAMs. the experiment with different attachment points and orientations to maximize dorsiflexion torque while minimizing discomfort. Their findings suggest that strategic placement of PAMs can significantly enhance the biomechanical advantage, providing sufficient lift without compromising stability (Iqbal, H., Samiullah, 2015).

The flexibility of PAMs offers a more comfortable fit compared to rigid AFOs, potentially improving user compliance and satisfaction (Rehdar, R. J., Preuschoft, 2007). PAMs are lightweight and can be integrated into slim, low-profile orthosis, making them less conspicuous and more aesthetically pleasing (Tucker, M.R., Olivier, 2015). PAM systems can be tailored to individual needs with adjustable parameters for force, timing, and sensitivity, ensuring optimal assistance for each user's specific condition and preferences (Karavas, N., Artemiadis, 2010).

Now here we discuss some challenges and future directions.

Despite their potential, PAM-integrated AFOs face several challenges. The complexity of control systems and the need for a reliable power source can limit their practically everyday use. Additionally, ensuring the durability and reliability of PAMs under continuous use is crucial for long-term effectiveness (Lee, S.M., Kim, 2017). Future research should focus on miniaturizing and optimizing control units and air supply systems to enhance portability and user-friendliness. Advances in soft robotics and wearable sensors could provide more sophisticated and responsive control mechanisms. Moreover, large-scale clinical trials are needed to validate the long-term benefits and safety of PAM-integrated AFOs across diverse patient populations (Ferris, D. P., Sawicki, 2007).

Conclusion

The PAM system increases safety and mobility; therefore, it can offer solutions according to the needs of the users. It provides different supports according to the options and needs. However, the design, management, and usability of PAM-based AFOs still need more research and development. Regular updates of these devices make them safe, reliable, and effective enough for widespread use in the medical field. Developments in this technology and meeting the needs of the users will increase the performance of PAM-based supports and improve patient outcomes, enabling the use of this tool in therapy.

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