Abstract

The aim of this study is to develop for the first time a foot raising device orthosis for hemiplegics (RFO). Our original idea is to take into account human mechanics as a whole, and not considering the pathological area, only. In fact the characteristic of the hemiplegics is muscles stiffness during walking inducing an incapacity to move fluently. For example, kinetics of the pathological legs shows for some subject’s stiffness of the Rectus Femoris during toe-off and swing phases prohibiting knee flexion. The results obtained for this first prototype confirm the capability of the system to improve knee and ankle movement during different walking phases. The perspective is to develop and to test this prototype with several subjects.

Keywords: Lower limbs, biomechanics, gait analysis, pathological walking, new orthosis, CAD

1. Introduction

Since 1970s orthoses are prescribed in a large number of cases. Such an equipment aims to correct a defective function, to compensate incapacity or to increase the physiological output of a member. Several orthosis types exist oriented to a specific function. Rehabilitation orthoses are the most studied ones. They are integrated into a therapeutic protocol and are recommended after serious sprains treated orthopedically or after a surgical repair. Their objective is to protect the ligament while limiting amplitudes. According to Colville (1986), an orthosis increases resistance to displacements as well as the stability impression of the subjects. Corde and al. (1990) showed that wearing orthosis in the rehabilitation phase allowed a return to work faster and less expensive than using a plaster. On the other hand, Martinek (1999) did not find a scientific argument justifying the wear of orthosis. Cawley (1990) showed an embarrassment side effect on the venous system.

By definition orthoses are devices intended to restore or to assist human movements. Drop foot is the inability of an individual to lift his foot because of reduced or no muscle activity around the ankle. The major causes of drop foot are nerve severing, stroke, cerebral palsy and multiple sclerosis. There are two common complications as a result of drop foot. First, the individual cannot control foot falling after heel strike, so foot slaps the ground on every step. This is referred to as slap foot. The second complication is the inability to clear his toe during swing. This causes the person to drag his toe on the ground throughout the swing phase.
Different orthoses are used to enhance the ankle-foot position and mobility. The most popular types are hingeless and hinge orthoses. Springs hinge orthoses assist ankle flexion/extension during gait, i.e. they are pseudo-active orthotic devices. The standard ankle foot orthosis (AFO) is a rigid polypropylene structure that prevents any ankle motion.

The main function of a RFO (raising foot orthosis) is to maintain the foot in good anatomical position and to avoid cross of patient’s foot during the execution of a dynamical task. This effect allows patients to keep certain autonomy in their daily life. Most studies have been focussed on patient’s walking analysis - Lehmann et al (1987), Ofir and Sell (1980) and patient’s rising movement - Sienko et al (2001).

In standing position, studies prove a better distribution of the weight with RFO - Chen et al (1999), Wang et al (2005). An orthosis can not treat spasticity, controlling it during loading and swing phases, which results in increase of loading time of the hemiplegic member and decrease of time of a double foot contact.

Plantar flexions blocked by the orthosis induce a heel attack on movement. This encourages hip dynamic extension and other effects, Guillebastre and Rougier (2007).

The aim of this study is to develop for the first time a special device, i.e. a foot raising orthosis, for hemiplegics (RFO), taking into account the mechanics of the lower limbs as a whole.

2. Methods and Results

The design of the considered device became actual after one year experience with hemiplegics. In order to choose a realistic solution depending on the actual techniques and available means, we plotted as a first step several sketches. As a second step, we used the CAD software CATIA and SolidWorks. These two programs gave us an idea for the design of the final product and allowed us to assess theoretically whether the device was realistic. We conceived each part and after having completed the design, we took into account various stresses applied on the device. The last objective was to manufacture the device easily and cheaper. The different steps of our work are as follows.

2.1. Drawing device and 2D conception

The 2D system is based on a thigh movement for user's foot raising. Each thigh movement implies foot reaction. This device reproduces well foot movement in walking, even if we are to review the adopted design principle of using two bars fixed between the knee and the ankle (Fig.1). In fact, the stem mounted in the rear (fig 1 (a) needs to be more elastic than the front one, since when the knee angle fluctuates the bar system lifts the foot faster. After this step, it seems that a 3D transition is needed in order to perform better visualization of the mechanisms.

![Fig. 1. 2D device: (a) view of the mechanical system tested; (b) global view of the system with knee and ankle joints; (c) design conception of the system plus stem visualization.](image)
2.2. 3D Conception

We adopt a principle similar to the above one, but in 3D space. We have done a few changes especially at the level of the two bars fixed on the thigh. A more complete leg model needs a realistic pattern. Hence, leg view aided us to model a right thigh and a right calf (Fig 2 (a)) using SolidWorks and CATIA. After assembling them together with the foot, we added the foot-rising system (Fig 2 (b)). However, a specific problem exists, i.e. when a user is sitting down, the foot raises, too.

Fig. 2. 3D conception of the leg : the global leg and the device

2.3. Third realization and new system

Considering the problems outlined, we present some new ideas. A more viable system is under preparation (Fig 3). The advantage of this raising device is that it raises the sole by a pivot at a level, the same as that of user’s ankle.

Fig. 3. Foot 3D conception system. (a) system plot. (b) system view. (c) the same system incorporating 3D conception of shoe and global leg
The raising device of the foot has three springs located in two discs. The spring system is located at the ankle level. We can adjust it for each patient. With the elasticity of the springs, foot can easily reproduce the movement (Fig 4). Then, when patient sits, foot can rise. However, a problem with spring fixation arises again, because grooves where spring edges are fixed can't stay collinear during device rotation, inducing spring shear as a result. Hence, the system needs improvement.

2.4. Improvement of the old system

We consider again components of the foot raising device, improving the device or adding other components. The main component added is a central disc, located between the two discs. Using this newly added disc, with its two holes tapped and the disc linked to the sole (through six holes), we can regulate the slope of the raising device. This is done by means of two fixation screws maintaining the ankle natural slope in resting position.

As for springs, we reduce them to two pieces. They work in compression, and they are located in the central disc and in the discs surrounding the ankle. Fasteners are fixed to the axis both sides, and the disc is fixed to the sole. For more details see Fig.5.
For aesthetic reasons, the foot model has been revised. We used “Sketch Tracer” in CATIA (Fig 6) to reproduce the frames provided by a medical scanner.

Fig. 6. 3D conception of the foot in (a) and (b). In (c) global view of the leg incorporating new 3D foot conception

Having improved our system, we tested it mechanically on a prototype. We simulated different positions to show its good functionality. Fig. 7 presents movement divided into twelve stages.
2.5. Raising device of foot stem spring

A stem-spring is also mounted, inserted at the back of the sole and at the back of the ankle. As seen in Fig.8, the system is composed of sole and fixation at calf level, and both of them are linked by two stems sliding one into another.
Functionality: yellow stem in the pivot around the ankle is on a sliding link joined to the grey stem which is in the pivot and which is connected to the sole. These two stems are pushed apart by a compression spring, and the sole raises user’s foot (Fig.9).

4. Discussion

Three methods of designing 3D models of the ankle-foot orthoses using CAD technology and SolidWorks are presented. In the first method, the proposed system in 2D realization is based on the movement of the thigh to raise patient's foot. Each thigh movement exercises an impact on the foot. Regarding the second method, we realize new ideas of design. The advantage of the raising device is that it raises the sole by a pivot at a level, the same as that of patient’s ankle. Foot raising device has three springs located into two discs. The spring system is located at ankle level, and it is adjustable for any patient. Due to spring elasticity, the foot can reproduce easily the movement. However, a problem with the fixation of the springs arises, since grooves where spring edges are fixed can not stay collinear during device rotation, and spring shear is induced. Hence, the system needs improvement.

The third method of ankle guiding is based on a system “stem-spring” inserted at the back of the sole and ankle, performing assembly of foot and calf. The system consists of a sole and fixation at calf level. Both of them are linked by two stems sliding one into another.

The methods presented have not been yet applied to realize AFO, but they have been successfully used for 3D modeling, oriented to eventual design and manufacture.
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References