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Hip Orthosis Powered by Pneumatic Artificial Muscle: Voluntary Activation in Absence of Myoelectrical Signal

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Abstract: Powered orthosis is a special class of gait assist device that employs a mechanical or electromechanical actuator to enhance movement of hip, knee, or ankle articulations. Pneumatic artificial muscle (PAM) has been suggested as a pneumatic actuator because its performance is similar to biological muscle. The electromyography (EMG) signal interpretation is the most popular and simplest method to establish the patient voluntary control of the orthosis. However, this technique is not suitable for patients presenting neurological lesions causing absence or very low quality of EMG signal. For those cases, an alternative control strategy should be provided. The aim of the present study is to develop a gait assistance orthosis for lower limb powered by PAMs controlled by a voluntary activation method based on the angular behavior of hip joint. In the present study, an orthosis that has been molded in a patient was employed and, by taking her anthropometric parameters and movement constraints, the adaptation of the existing orthosis to the powered orthosis was planned. A control system was devised allowing voluntary control of a powered orthosis suitable for patients presenting neurological lesions causing absence or very low quality of EMG signal. A pilot clinical study was reported where a patient, victim of poliovirus, successfully tested a hip orthosis especially modified for the gait test evaluation in the parallel bar system. The hip orthosis design and the control circuitry parameters were able to be set to provide satisfactory and comfortable use of the orthosis during the gait cycle. **Key Words:** Gait improvement—Electronic control—Pneumatic artificial muscle—Powered hip orthosis.

Neurological disorders and orthopedic affections of the lower limbs are the main causes of pathological gait pattern. Usually, in order to obtain the improvement of the patient walking capability, the use of an orthosis is indicated. A lower limb orthosis is an external device applied or attached to a lower body segment to improve function by controlling motion, providing support through stabilizing gait, reducing pain by transferring load to another area, correcting flexible deformities, and preventing progression of fixed deformities. The purpose of using an orthosis is to enhance normal movement and to decrease abnormal posture and tone. Lower extremity orthosis can be used to correct abnormal gait patterns and to increase the efficiency of walking. An orthosis is classified as a static or dynamic device. A static orthosis is rigid and is used to support the weakened or paralyzed body parts in a particular position. A dynamic orthosis is used to facilitate body motion to allow optimal function. There are a large number of static and dynamic orthosis types, varying from a simple crutch to myoelectrical controlled or employing functional electrical stimulation (1,2). Different types of ankle–foot, knee, or hip orthosis (or a combination of them) are described in the literature and are commercially available (3–7). Powered orthosis is a special class of gait assist device that employs a mechanical or electromechanical actuator to enhance movement of hip, knee, or ankle articulations. Pneumatic artificial muscle (PAM) is one of the most studied actuators to power lower limbs orthosis

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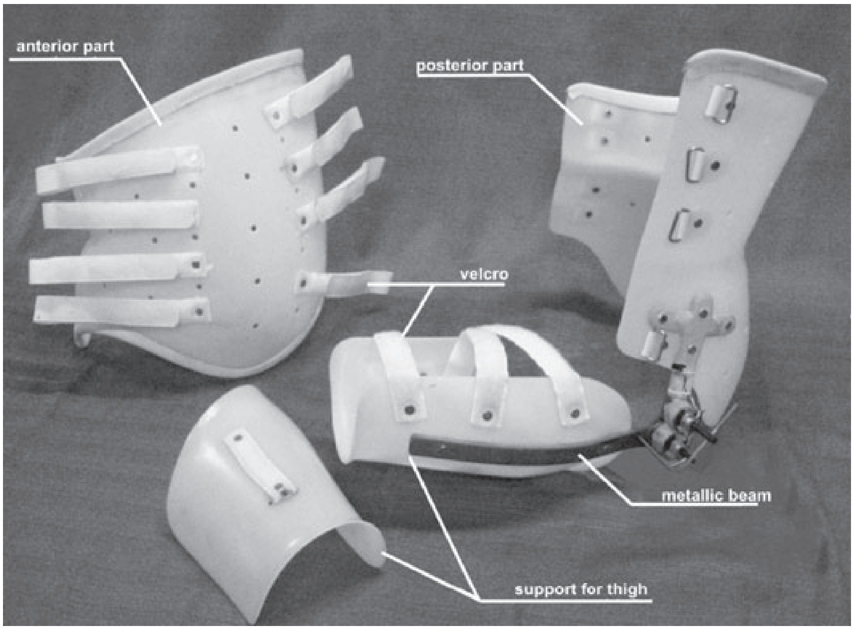

FIG. 1. The hip orthosis composed of the pelvic brace and support for thigh.

(1,8– 12). PAM has been suggested as a pneumatic actuator because its performance is similar to that of biological muscle. The mechanical properties of PAM have been described in the literature (9,10).

Once the mechanism to perform the joint movement has been established, a new challenge arises: how will the patient control the orthosis operation? Different strategies may be used to execute this task. The electromyographic (EMG) signal and the electroencephalographic (EEG) signal are the most commonly used (1,10–12). EMG signal interpretation is the most popular and simplest method to establish the patient voluntary control of the orthosis. The advantages of EMG signals are that they form an intuitive interface and they can be used for every patient who has the sign pattern preserved (13–17). However, this technique is not suitable for patients presenting neurological lesions causing absence or very low quality of EMG signal. For those cases, an alternative control strategy should be provided.

The aim of the present study is to develop a gait assistance orthosis for lower limb powered by PAMs controlled by a voluntary activation method based on the angular behavior of hip joint.

METHODS

Hip orthosis—orthosis structure

The hip orthosis (Fig. 1) is composed of the pelvic brace and support for thigh, both made of thermoplastic (polyethylene). The pelvic brace, with bulkhead on the iliac crest, involves the hip to provide stability and must be made in two parts. The anterior part covers the region from the xiphoid process until the upper pubic region while the posterior part covers the region from the thoracic back end until the gluteus maximum. All parts must be molded on the patient to reassemble his/her shape. These parts are joined together laterally by Velcro ribbons.

The pelvic brace and the support for the thigh are connected by a vertical articulated beam. This beam must have a constraint to prevent the hip hyperextension. It must be fixed on two points in both extremities, to provide the system rigidity and to prevent rotation in the attachment point. It is manufactured using an aluminum alloy to reduce its weight.

The assembly of the orthosis with the PAM (Fig. 2) provides the movement of the hip joint and it is helpful during the balance phase of the gait.

PAM

The PAM mounted in the orthosis was developed in the Bioengineering Laboratory (18) and consists of an internal latex bladder surrounded by a braided nylon shell that is attached at each end to fittings. When the internal bladder is pressurized, the high-pressure gas pushes against its inner surface and against the external shell. By doing so, it tends to increase the internal bladder volume. Due to the braided nylon shell elastic properties, the muscle shortens accordingly to its volume increase. The PAM shortening process will make available a contraction force while the system is kept pressurized. The magnitude of the contraction force depends on the

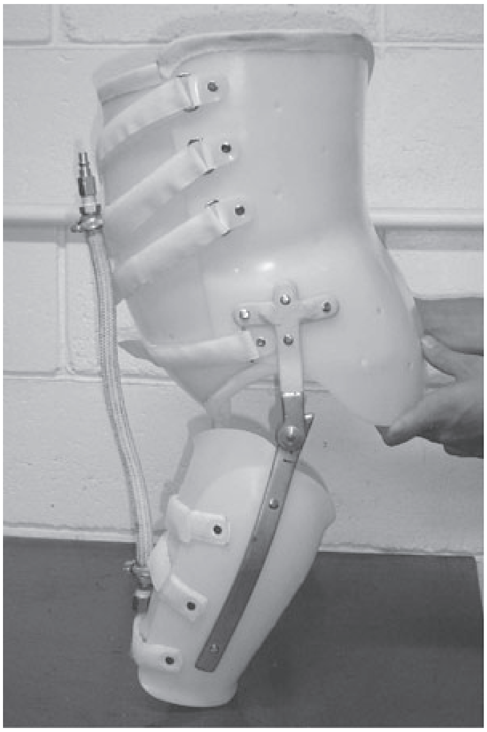

FIG. 2. The orthosis with the PAM.

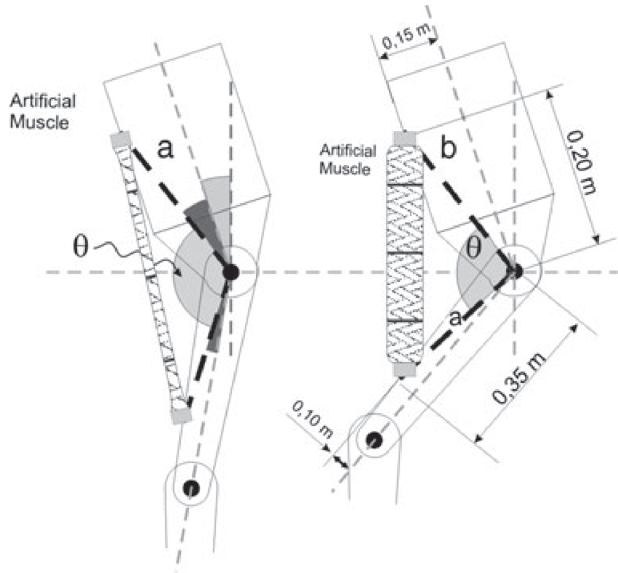

FIG. 4. Geometric parameters to determine the constants **a** and **b**.

pressure in the PAM and the reduction of the muscle length depends on the load imposed to the muscle. The performance parameters of the PAM (operation pressure and the length reduction) under different loads are shown in Fig. 3.

Orthosis assembly and the control strategy

In order to test the system features in real application, an orthosis that had been molded in a patient was employed and, by taking her anthropometric parameters and movement constraints (obtained from previous clinical evaluation), the adaptation of the existing orthosis to the powered orthosis was planned. The primary goal in designing the orthosis is to enhance the hip joint movement with the maximum comfort to the patient. The muscle total length, the position of the muscle insertion in the orthosis, the load in the muscle, and the trigger angles for muscle pressurization and for returning to the neutral position (pressure relieve) during the gait are the most important design requirements. The center of rotation of the orthosis articulation was made coincident with the hip joint rotation center (19).

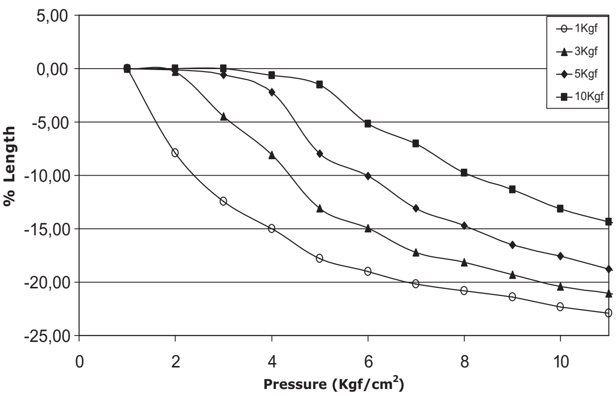

FIG. 3. Performance curves of the artificial muscle installed in the orthosis.

The muscle length in the neutral position and in the pressurized condition was obtained by using the cosine law considering the parameters showed in Fig. 4, where θ is the hip joint angle, **a** is the distance between the hip joint and the muscle insertion in the leg support, and **b** is the distance between the hip joint and the muscle insertion in the trunk support. The position of the insertion points was chosen to maximize the action of the PAM for the hip joint movement considering its initial and its final angle during the gait cycle. These angles were monitored by a potentiometer installed in the orthosis articulation. Potentiometer is an electromechanical transducer that converts rotary motion from the hip joint into a change of electrical resistance. This variation was calibrated to register the hip angle.

Electronic circuitry was devised for monitoring the hip joint angle and processing this information to activate the control valves to pressurize the PAM or to return it to the neutral status. The quality of the

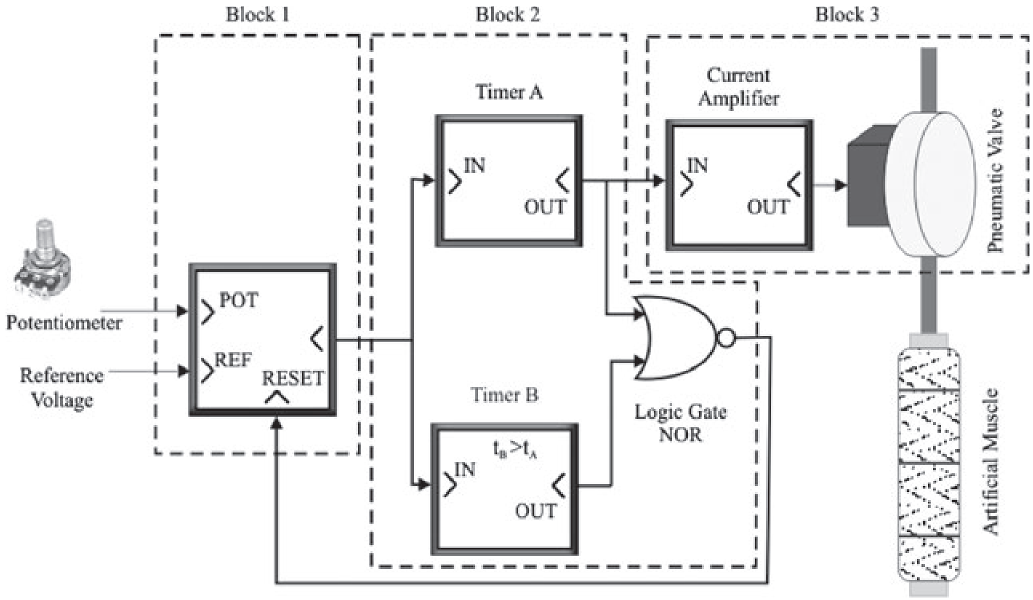

FIG. 5. Block diagram describing the electronic system for activation of artificial muscle.

information about the angular position of the hip joint was improved by installing an additional potentiometer in the orthosis. The role played by the additional potentiometer was to serve as a reference resistance which was compared to the resistance of the original potentiometer to precisely define the hip joint angle.

The control activation system of PAM may be represented by three blocks (Fig. 5). The first block is the voltage comparator, which constantly checks the value of hip angle and compares with the reference value. When the angle of the hip is bigger than the reference, it activates the second block, the timer block. This block is composed of two timers, A and B, and a NOR gate. The A timer sets the time for the muscle contraction while the B timer sets the minimal time for a new muscle contraction. These values can be adjusted because there is a specific value for timers A and B for each gait pattern. The third block is composed of a current amplifier and a pneumatic valve, which controls the air flow rate to the muscle contraction.

RESULTS

Pilot clinical study

The patient signed the informed consent agreement for her participation in the study. The pilot clinical study was conducted in the Gait Analysis Laboratory of the Physiotherapy Department of UFMG (University of Minas Gerais) under professional supervision and consisted in acquiring the hip joint angle information during the gait cycle of the patient wearing the powered orthosis in the parallel bar system. The orthosis control system was regulated to activate the PAM for hip joint angle of 37° flexion. Due to the clinical condition of the patient, the trunk presented an initial inclination of 35°. After a few minutes for equipment familiarization, the patient performed the test schedule.

Figure 6 shows the different parameters in the control circuitry: output voltage to the pneumatic control valve, the input signal from potentiometer resistance, and the angle variation from the PAM neutral position during the gait cycle.

The patient reported that she was able to develop a better gait pattern and improvement of left step transposition, in the toe off phase, where the control circuitry has successfully identified the prescribed angle and activated correctly the control flow valve to pressurize the PAM and to allow it to return to the neutral position. Figure 7 shows the orthosis hip joint angle during the gait cycle. The PAM was pressurized when the hip joint angle reaches its minimum value. The pressure release occurs for the hip joint angle of 65°.

Preliminary in vitro test with the orthosis has identified the proper level of PAM operation pressure (6 kgf/cm^2) for the control valve optimal performance and for the acceptable level of acceleration exerted on the patient leg. For that reason, the orthosis was powered by two parallel PAMs to produce a force of 20 kgf, which was enough to perform the hip joint movement.

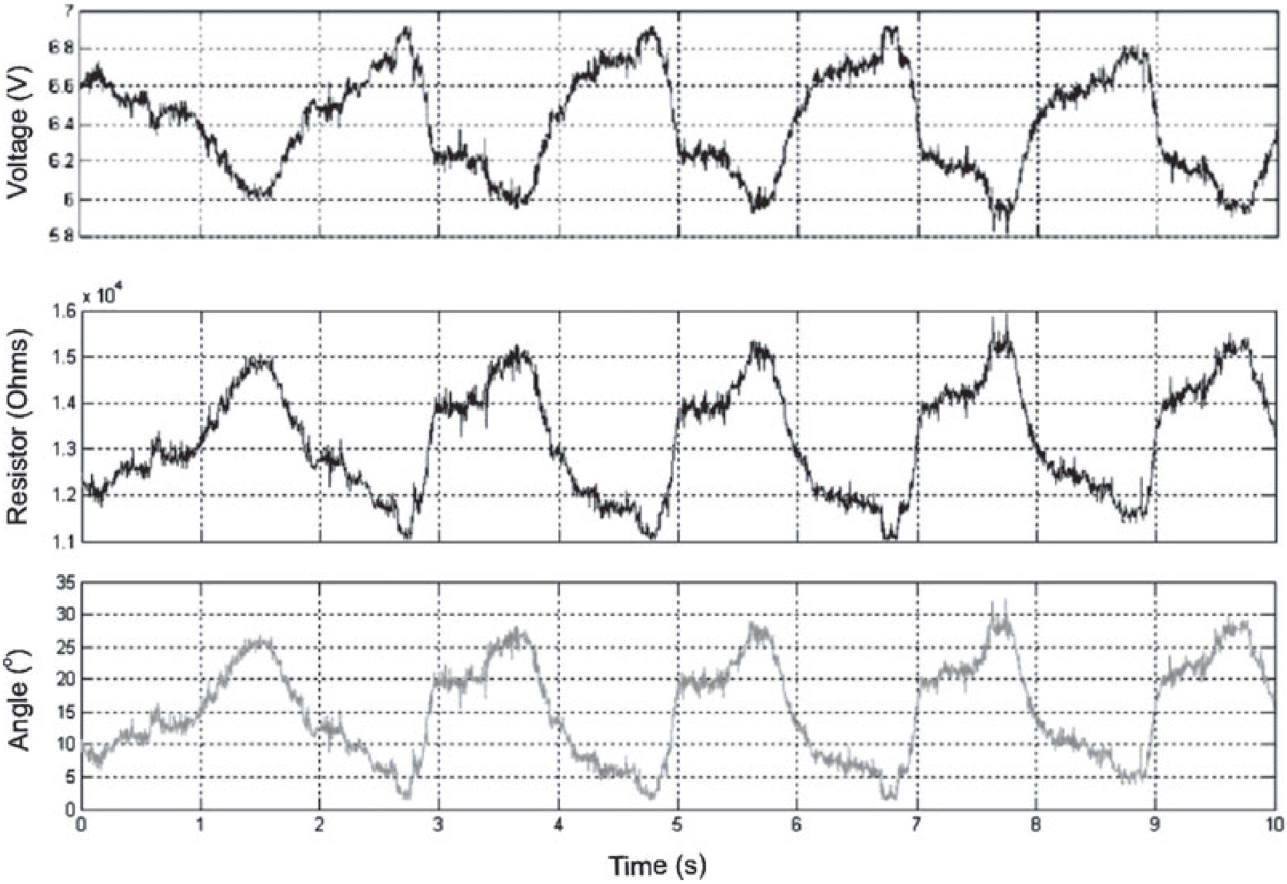

FIG. 6. Measured parameters in the control circuitry: output voltage to the pneumatic control valve, the input signal from potentiometer resistance, and the angle variation from the PAM neutral position during the gait cycle.

Considering the clinical history of the patient who had been a victim of poliovirus during childhood, like many polio survivors she complains of new musculoskeletal and neuromuscular symptoms, presumably related to her old poliomyelitis illness (20–22). The post-polio syndrome, a set of motor incapacities produced by polio, appears many years after the patient had contact with the poliovirus (22). The most frequent health complaints are fatigue and weakness, and the most frequent complaints concerning activities of daily living relate to difficulty with walking and stair climbing (23).

To improve the gait pattern of an individual affected by several different neurological and orthopedics injuries has been the main goal of developing new orthosis. The benefits of using the powered orthosis associated with physical exercises make it possible to offer to the patients a better quality of life and also endurance to prevent physical fatigue due to the muscular effort. In this context, the device reported in the present article may be helpful to patients exhibiting very low quality of EMG signal.

Additional study is necessary to address important issues like reducing the energy consumption, minimizing the weight, and designing different actuators to produce new types of orthosis.

CONCLUSIONS

A control system was devised allowing voluntary control of a powered orthosis suitable for patients presenting neurological lesions causing absence or very low quality of EMG signal. A pilot clinical study was reported where a patient, a victim of poliovirus, successfully tested a hip orthosis especially modified for the gait test evaluation in the parallel bar system. The hip orthosis design and the control circuitry parameters were able to be set to provide satisfactory and comfortable use of the orthosis during the gait cycle.

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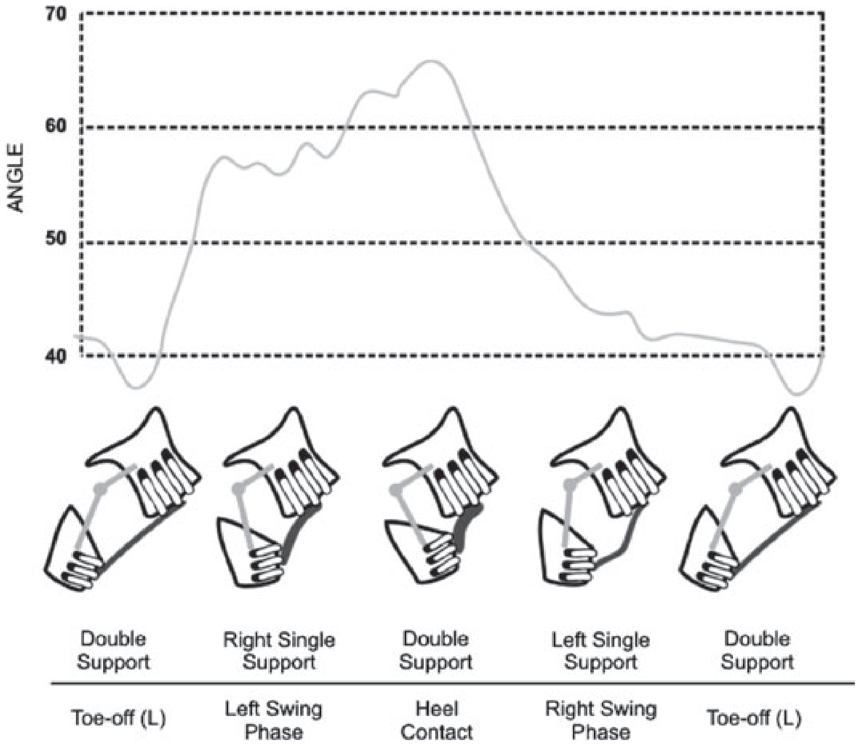

FIG. 7. Angular position of hip joint during the gait.

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