DESIGN AND DEVELOPMENT OF A SOFT ROBOTIC BACK ORTHOSIS

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ABSTRACT

Chronic back pain is a disorder which affects a large portion of the American population at some time during their lifespan. There are many causes for lower back pain and usually can be an indicator of a serious medical condition. This problem plagues the nation and the world leading to an estimated annual cost for back pain treatment amounts to $50 billion. This problem isn’t isolated to just the United States either, the world at large suffers from back pain and unfortunately modern treatment methods are effective but the technology simply hasn’t progressed in decades. The main drawback appears to be the rigidity of the device, which limits flexibility and comfort. Soft pneumatic actuators of this newfound device have the potential to provide the appropriate applications chronic back pain suffers and postsurgery patients.

In this work, the design and development of a soft robotic back orthotic device that has the capability to relieve back pain by assisting patients to fully achieve the upright position and stabilize the lumbosacral spine, is presented. The soft pneumatic actuators of this device allow the support to be disabled when the patient is in a supported position. Unlike conventional robotic assistive devices, this pneumatically actuated back orthosis provides dynamic support while being lightweight, comfortable, and cost affordable. After testing the device in a laboratory environment, the data overall displays a trend decreasing in EMG activity of the Erector Spinae muscles. This reduced activity leads to a reduction in strain on the patient.

BACKGROUND

Lower back pain is a disorder which affects almost 80% of the American population sometime during their life [1, 3]. Approximately 90% of the episodes are resolved within six weeks to three months [3]. As low back pain is usually a symptom of a medical condition, many cases cannot be given a definite diagnosis which renders the condition difficult to treat [4]. The estimated annual cost for back pain treatment amounts to $50 billion, in the United States alone [6, 7].

Several devices have already been designed for low back pain assistance. The current technology involves a rigid material, usually a plastic or metal piece, surrounded by some padding or fabric to provide stability for the spine. A prime example of a device used today is the Aspen Evergreen LSO. This design uses stiff plating to limit motion of the spine by generating both a lifting and squeezing motion that compresses the body while supporting the spine. This support usually is enough to take the strain off the back and allows the user some relief [4]. The main drawback with these devices are their rigidity, which limits flexibility and comfort. Soft pneumatic actuators have the potential to provide the appropriate applications for low back pain prior- and post-surgery rehabilitation purposes.

In this paper, the design and development of a soft robotic back orthotic device (Fig. 1) that has the capability to relieve back pain by assisting patients to fully achieve the upright position and stabilize the lumbosacral spine, is presented. Unlike conventional robotic assistive devices, this pneumatically actuated back orthosis provides dynamic support while being light, comfortable and cost affordable.
After acquiring the needs of both doctors and patients alike, it was necessary to convert these qualitative terms into quantitative functional requirements. Chief of which was the ability to support the back in a comparable fashion to existing back braces. These braces work by creating a lifting and squeezing motion on the spine by applying force at the base of the spine and abdominal area.

In addition to this functional requirement, it is also important to create a device that produces ~13 Nm of torque. This is the amount of torque it takes the average male to straighten the thoracic portion of the spine assuming arms are forward and body weight of the upper body is the only force acting on the point of torsion. The proposed device would need to be able to resist this motion by generating a torque that is greater than 13 Nm. Generating this torque is important as it limits patients from leaning past a certain angle preventing further spinal injury.

As each patient is different, it is also necessary to permit customization of the orthotic device to suit individual patient needs. These parameters need to be programmable by a physician as they are the most knowledgeable on their patients' needs. Using a microcontroller, it is possible to create a simple user interface and allow fine tuning of the flexion angle permitted, the torque required to achieve this, as well as the required force of support necessary to stabilize the lumbosacral spine. Also, it is necessary for the device to have a don and doff time of roughly two minutes, as this would place the time in line with existing back orthotic devices.

Taking these above functional requirements, a set of concepts were created. After a few different concepts and literature research, a concept that utilizes encapsulated air bladders (see Fig. 1) was elected. These bladders are made of plastic sheets that are heat sealed together. These are then placed inside a sewed fabric pouch of slightly smaller dimensions than these of the bladder. The outer layer of fabric constrains the air bladders and takes the strain off of the heat sealed seams; allowing the bladders to be inflated to much higher pressures. Thus generating more straightening force. In Fig.2a, \( P \) represents the pressure that is exerting force outwards against the edge of the bladders, and \( F \) is the constraining force that the encapsulation sleeve exerts to prevent the bladder from bursting. Through preliminary torque testing, it was determined that one bladder was capable of 9 Nm of torque exertion. Using two bladders of this design in parallel, placed on either side of the spine, allows to exert the necessary forces to resist the back’s thoracic motion (Fig.2b). A fully rigid (pressurized) bladder (Fig. 2d) and a flattened bladder (unpressurized) is shown in Fig. 2c.

In addition to the two back bladders, a novel design was created for the waist bladders; it entailed manufacturing three different sized bladders each with smaller radius than the previous in a cascaded design. These bladders were placed into a single greater sleeve in an orientation that places the biggest diameter bladder at the bottom. This cascading design allows the device to form a wedge shape when constrained between a body and an outer brace. This in turn generates both the squeezing and lifting motion that is key to supporting and immobilizing the lumbosacral spine (Fig 2e & 2f).

To control the entire device in a manner that is safe for consumer use, the electronics and pneumatics were placed into two control boxes. A microcontroller, placed in one of the control boxes, is programmed with the physical parameters of each patient to ensure exertion of correct stabilization forces on the spine. It receives inputs from the IMU, which is integrated into the Shoulder Strap Harness (Fig 1). The microcontroller then uses the IMU inputs to determine the angle of back flexion and assumes the overall position of the spine. These inputs are processed by the microcontroller to determine how much torque

\[ \text{Figure 1: Soft robotic back orthosis design in a side and back view, showing the location of back and waist air bladders.} \]

\[ \text{Figure 2: (a) Pneumatic bladder design principle. (b) Back bladders in their unactuated and actuated states. (c) Single bladder unpressurized. (d) Pressurized stiff bladder. (e) Waist bladder actuators unpressurized. (f) Waist bladder actuators pressurized (the arrows indicate the generated output force).} \]
the bladders need to exert to ensure proper stabilization of the spine. This dynamically adjustable set of bladders give the device the ability to detect resting postures and lessen the air pressure appropriately to promote patient comfort. For example, if the user is detected to be in a supine position where the back is supported by a bed, the brace will deflate the back air bladders completed to allow the device to be more comfortable. this action utilizes the novelty of soft robotics to exert powerful forces without sacrificing user comfort with bulky and rigid pieces, such as those present in current technology.

RESULTS

A comparison between muscle activities in the lower back with and without the prototyped orthotic was made to evaluate the overall effectiveness of the device. Muscle activity of the erector spinae muscle group was focused on, using eight surface electromyography (sEMG) sensors. These were placed along the sides of the lower spine, four on each side, during the test (Fig. 3b). The test participant performed three different activities to simulate common muscle activities of the back: sitting, standing, bending to lift a weight. Each test was run as two types, a baseline test, without the orthosis, and an active test, with the pressurized orthosis. The baseline and active tests were run three times each to ensure accurate collection of muscle activity data.

The sitting test required the participant to sit on a chair with the upright posture, while avoiding resting on the back rest. The standing test required the participant to stand, while keeping the back as straight as possible. These tests were run in thirty second recording intervals with a two-minute rest periods. The bending test consisted of the participant starting in the standing position with a 5-kg weight placed at the knee level, bending the back to reach for the object, and returning to the upright position with the object in hand. To ensure correct posture, a motion tracking system was used with each test as a visual cue that the participant did not vary its posture.

The voltage output of each sEMG sensor was recorded during each test. The outputs for each sEMG sensor were then filtered using a Butterworth filter to eliminate any excess noise and averaged across trials. Indicative results of sEMG sensor 9 were graphed to illustrate the difference between the baseline and active test for the bending test (Fig. 3a). The overall trend of the data demonstrates smaller muscle activity when the device is worn and active.

INTERPRETATION

This paper presented the use of soft-robotics to create a robust orthotic device that provided two unique qualities: stabilized the lumbosacral spine and prevented poor posture. Furthermore, the developed prototype added variability to the support of the waist brace in real time, so that it could be soft and conforming to the body when not needed. It also added programmability, allowing customization on a patient by patient basis. Preliminary sEMG testing with one participant demonstrated promising indications that muscle activity can be decreased when assistance is provided by the orthotic device.

In future work, further EMG testing will validate the preliminary results. Beyond validating the test results, the orthotic brace could benefit from low-level development. This includes improving the ergonomics of the don and doff process, decreasing the weight and size of the electro-pneumatic system, and improving the overall aesthetic.

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REFERENCES